Resilience and agency in mature sustainability transitions. Theoretical conceptualisation and empirical analysis of actor- & system-level dynamics in sociotechnical energy systems

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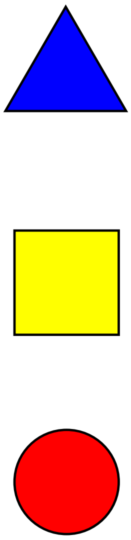

to Romano

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Abstract

Problem statement In Switzerland, Germany and Austria, as in many European countries, the transition of the energy sector towards more sustainability is a long-term transition process, unfolding since decades. It however only reached the regime level in recent years and the established technologies and governance structures of the energy systems. This fundamental transition process causes complex, interrelated and non-linear dynamics and changes on multiple scales – in the technological and social sphere of the energy systems. The energy transition, thus, became a mature sustainability transition, which is a new challenge for research and decision-making in practice.

Research aim This dissertation contributes to an improved conceptual and empirical understanding of actor- and system-level structures and dynamics in mature sustainability transitions.

Methodology To tackle this research aim, the dissertation employed an iterative theory building process, which develops theoretical considerations based on pre-existing theories and frameworks as well as empirical evidence. The empirical analyses were conducted using a mixed methods approach, which allowed for rich empirical evidence and triangulation. The research was implemented in four modules, whereby each module tackled one research question. Main data sources were scholarly literature, regional structural data and documents as well as transcripts from several rounds of semi-structured expert interviews and expert workshops. The empirical data stemmed from three cases: energy regions in Austria and Germany, a network of change agents in Germany and urban utility companies in Germany and Switzerland. The main analytical methods, employed in this dissertation were qualitative literature analysis, document analysis and structuring qualitative content analysis.

Results For the analysis of system structure for functionality and transition dynamics, this dissertation presents an indicator set to analyse and measure resilience of socio-technical energy systems in transition, based on the key system characteristics of diversity and connectivity. The empirical application provided rich insights on the socio-technical system structure and its changes over time and discusses appropriate methods for the empirical analysis. For the analysis of transition dynamics, this dissertation provides a re-conceptualised framework for the systematic analysis of actor- and system-level determinants of agency as well as the feedback of agency on the system. Especially focussing on the role of incumbents in mature sustainability transitions, the dissertation moreover provides findings from the empirical exploration of urban utility companies and derived analytical categories for public incumbent actors in network industries in transition. The dissertation finally discusses the integrability of conceptual findings to transition studies and presents an integrated framework to analyse structures and dynamics in mature sustainability transitions.

Conclusion The thesis provided key theoretical and empirical insights on actor- and system-level aspects of mature sustainability transitions in socio-technical energy systems. It contributed to a discussion on dynamic resilience concepts for socio-technical energy systems, a more systematic analysis of agency in sustainability transitions and a more nuanced picture of incumbents' agency in socio-technical energy systems in mature sustainability transition.

Keywords

Resilience, mature sustainability transition, agency, socio-technical energy systems, iterative theory building, mixed methods, indicator set, framework development, energy regions, change agents, urban utility companies, incumbents, Austria, Germany, Switzerland.

Résumé

Motivation En Suisse, en Allemagne et en Autriche, comme dans de nombreux pays européens, la transition énergétique vers la durabilité est un processus à long-terme qui se déroule depuis plusieurs décennies. Par contre, elle n'a atteint que dans les dernières années le niveau du " régime " et, partant, les technologies et structures de gouvernance établies. Ce processus de transition fondamentale entraine des dynamiques et des changements complexes, interconnectés et non-linéaires, à de multiples échelles dans la sphère technique et sociale du système énergétique.

Objectifs de la recherche Cette thèse contribue à une meilleure compréhension conceptuelle et empirique des structures et des dynamiques dans le cadre des transitions avancées vers la durabilité, au niveau des acteurs et du système.

Méthodologie Cet objectif de recherche est abordé en utilisant une approche itérative de construction théorétique des théories. Celle-ci est basée tant sur des théories préexistantes que sur des résultats empiriques afin de développer des nouvelles considérations théoriques. Les analyses empiriques ont été réalisées selon une approche par méthodes mixtes, ce qui a permis d'obtenir de riches preuves empiriques ainsi que la triangulation des résultats. La recherche a été structurée en quatre modules, chaque module abordant une question de recherche. Les principales sources des données ont été la littérature scientifique, des données structurelles et les documents régionaux ainsi que les transcriptions des workshops d'expertise et de plusieurs séries d'entretiens semi-structurés avec des experts. Les données empiriques provenaient de trois cas : des régions énergétiques en Autriche et en Allemagne, du réseau d'agents de changement en Allemagne, et des entreprises de services publics urbains en Suisse et en Allemagne. Les principales méthodes d'analyse utilisées dans cette thèse ont été : l'analyse qualitative de la littérature scientifique, l'analyse des documents et l'analyse qualitative du contenu.

Résultats Au niveau de l'analyse de la structure systémique pour la fonctionnalité et les dynamiques de transition, cette thèse présente un ensemble d'indicateurs qui permet d'analyser et de mesurer la résilience d´un système énergétique – dans ses sphères technique et sociale. Ce set d'indicateurs est basé sur les caractéristiques clés du système : sa diversité et sa connectivité. L'application empirique de ces indicateurs a fourni des aperçus riches sur la structure sociotechnique du système et ses changements au fil du temps ; elle a permis de remettre en discussion les méthodes appropriés pour l'analyse empirique. Au niveau de l'analyse des dynamiques pour la transition, cette thèse fournit d´un côté un cadre analytique re-conceptualisé qui facilite l'analyse systématique des déterminants au niveau des acteurs et du système, ainsi que sur la réaction associée du système. En mettant l'accent sur l'action et le rôle des " incumbents " dans les transitions avancées vers la durabilité, cette thèse a fourni entre outre des conclusions tirées de l'exploration empirique des entreprises des services publics urbains et a dégagé des categories analytiques pour les acteurs publics dans les industries de réseaux (en transition). La thèse discute enfin de l'intégrabilité de ce cadre analytique re-conceptualisé et les categories analytiques au sein des études de transition vers la durabilité. Elle présente un propre cadre analytique intégré pour l'analyse des structures et dynamiques des transitions avancées vers la durabilité.

Conclusion Cette thèse a fourni des aperçus empiriques et théoriques clés sur les aspects des transitions avancées vers la durabilité dans les systèmes énergétiques sociotechniques – au niveau des individus et du système. Elle contribue à une discussion plus approfondie sur les dynamiques de la résilience dans le cadre des systèmes sociotechniques énergétiques, une analyse plus systématique du rôle de l'action dans la transition de durabilité et à donner une image plus nuancée sur les " incumbents " et leurs actions dans les systèmes énergétiques en transition vers la durabilité.

Mots-clés

Résilience, transitions avancées vers la durabilité, action, systèmes énergétiques sociotechniques, développement itératif des théories, méthodes mixtes, ensemble des indicateurs, développement des cadres analytiques, régions énergétiques, agents de changement, entreprises des services publics urbains, incumbents, Autriche, Allemagne, Suisse.

Zusammenfassung

Problemstellung In Deutschland, der Schweiz und Österreich, wie in vielen anderen europäischen Ländern, findet seit Jahrzehnten ein Prozess der Transition des Energiesektors statt, hin zu mehr Nachhaltigkeit. Dieser Transitionsprozess erreichte jedoch erst in jüngster Zeit die Ebene des „regimes" - der etablierten Technologien und Governanzstruktur - des Energiesektors dieser Länder. Dieser fundamentale Wandlungsprozess verursacht komplexe, interdependente und nicht-lineare Dynamiken auf verschiedenen Ebenen des Energiesystems und hat dabei sowohl gesellschaftliche als auch technische Aspekte. Die Energietransition ist damit zu einer „fortgeschrittenen Nachhaltigkeitstransition" geworden und stellt neue Herausforderungen an Forschung und Entscheidungsträger in der Praxis.

Forschungsziel Diese Dissertationsarbeit hat zum Ziel, zu einem verbesserten konzeptuellen und empirischen Verständnis der Strukturen und Dynamiken in fortgeschrittenen Nachhaltigkeitstransitionen beizutragen – auf Akteurs- und Systemebene.

Methodologie Um dieses Forschungsziel zu bearbeiten, wendet diese Dissertationsarbeit einen iterativen Theoriebildungsansatz an, der sowohl auf Basis bestehender Theorien und Frameworks als auch empirischer Evidenz, neue theoretische Konzepte entwickelt. Die empirischen Analysen wurden dabei mit einem „mixed-methods" Ansatz durchgeführt, der eine vielfältigere empirische Grundlage ermöglicht und Triangulationen erlaubt. Hauptdatenquellen dieser Dissertationsarbeit waren Forschungsliteratur, regionale Strukturdaten und Dokumente sowie Transkripte von Expertenworkshops und mehrerer Runden semi-strukturierter Experteninterviews. Die empirische Evidenz stammte dabei von drei Fällen: Energieregionen in Deutschland und Österreich, einem Netzwerk von „Change Agents" in Deutschland sowie grossen Stadtwerken in Deutschland und der Schweiz. Hauptanalysemethoden, die in dieser Dissertationsarbeit verwendet wurden, sind qualitative Literaturanalyse, Dokumentenanalyse und strukturierende qualitative Inhaltsanalyse.

Resultate Für die Analyse der Systemstruktur, die sowohl Funktionalität als auch Transitionsdynamiken unterstützt, präsentiert diese Dissertationsarbeit ein Indikatorenset, welches die Analyse und Messung der Resilienz soziotechnischer System in Transition erlaubt – basierend auf den Systemcharakteristika Diversität und Konnektivität. Die empirischen Analysen lieferten vielfältige und ertragreiche Erkenntnisse zur soziotechnischen Systemstruktur und ihrer Veränderung und diskutiert darüber hinaus geeignete qualitative und quantitative Methoden für die empirische Analyse. Für die Analyse der Transitionsdynamiken im Spezifischen entwickelt diese Dissertationsarbeit einerseits ein re-konzeptualisiertes Framework zur systematischen Analyse der Determinanten von Akteurshandeln sowie seiner Auswirkungen - auf individueller und systemischer Ebene. Mit dem besonderen Fokus auf die Rolle von incumbents in fortgeschrittenen Nachhaltigkeitstransitionen, wurden andererseits vielschichtige Ergebnisse der empirischen Exploration grosser Stadtwerke erarbeitet und daraus analytische Perspektiven für öffentliche Incumbents in Netzwerkindustrien, die sich in Nachhaltigkeitstransitionen befinden, entwickelt. Schliesslich diskutiert diese Dissertationsarbeit die Integrierbarkeit des Frameworks sowie der analytischen Perspektiven in Konzepte der Transitionsliteratur und präsentiert ein eigenes, integriertes Framework zur Analyse von Struktur und Dynamiken in fortgeschrittenen Nachhaltigkeitstransitionen.

Fazit Diese Dissertationsarbeit präsentiert zentrale theoretische und empirische Erkenntnisse zu Kernaspekten von fortgeschrittenen Nachhaltigkeitstransitionen auf Akteurs- und Systemebene von soziotechnischen Energiesystemen. Diese tragen zu einer weiteren Debatte über dynamisierte Resilienzkonzepte für soziotechnische Energiesysteme bei sowie einer systematischeren Analyse von Akteurshandeln in Nachhaltigkeitstransitionen bei und fördern ein nuancierteres Bild des Handelns und der Vielfalt von Incumbents in soziotechnischen Energiesystemen in fortgeschrittenen Nachhaltigkeitstransitionen.

Schlagworte

Resilienz, fortgeschrittene Nachhaltigkeitstransition, agency, soziotechnische Energiesysteme, interative Theoriebildung, mixed methods, Indikatorenset, Framework-Entwicklung, Energieregionen, Change agents, grosse Stadtwerke, Incumbents, Österreich, Deutschland, Schweiz.

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List of abbreviations

CEO	Chief Executive Officer
CH	Switzerland
CHP	Combined heat power
CMASOP	Cognitive mapping approach for analysing actors' systems of practices
DE	Germany
DSO	Distribution grid operator
EEG	Erneurbare-Energien-Gesetz
EFA	Energy flow analysis
EU	European Union
EVU	Energieversorgungsunternehmen
EWG	Energieregion Weiz-Gleisdorf
EWZ	Elektrizitätswerke Zürich
GWh	Gigawatt per hour
HES	Human-environment systems
ITB	Iterative theory building
IWB	Industrielle Betriebe Basel
kWh	Kilowatt per hour
KWK	Kraftwärmekopplung
MLP	Multi-level perspective on sustainability transitions
MMA	Mixed methods analysis
NGO	Non-governmental organisation
ÖEL	ÖkoEnergieland
PV	Photovoltaics
RQ	Research question
SES	Socio-ecological systems
SIG	Services Industriels de Genève
SNA	Social network analysis
STES	Socio-technical ecological systems
STS	Socio-technical systems
SWM	Stadtwerke München
TEF	Triple embeddedness framework
TSO	Transmission grid operator
TWh	Terawatt per hour
UUC	Urban utility companies
VKU	Verband Kommunaler Unternehmen
VSE	Verband schweizerischer Elektrizitätsunternehmen

SYNOPSIS

Chapter 1 Introduction

1.1 Problem statement and research aim

On the entire globe, energy systems undergo fundamental social and technological changes. The international community agreed on the fact that in order to mitigate climate change, its energy supply basis needs to become less environmentally harmful and more sustainable (United Nations Sustainable Development, 2016). In many countries, the share of renewable energies and energy efficiency efforts have increased over the last years, accompanied by approaches to phase out fossil fuels for electricity production, heat and mobility. In addition, some European countries, as e.g. Germany, and Switzerland, have decided to phase-out their nuclear power plants. In this context, the energy transition towards more sustainability is not a niche phenomenon any more, but it has entered the socio-political, economic and technological mainstream. However, despite the clear political goals and the available technological solutions for more sustainability, the energy transition stagnates in many European countries at exactly this point of entering the mainstream: political subsidy schemes are scaled back, incumbent firms and political parties try to control the speed and scope as well as the effects of the energy transition, people are hesitant to invest in new technologies, utility companies have high debts due to the transition dynamics and renewable production needs to be throttled down to maintain grid stability (dpa, 2018a, 2018b; Stalder, 2018b, 2018a).

Markard (2018) describes this situation of a mature transition as "the second phase" of a sustainability transition and emphasises that it offers "qualitatively different challenges" then the first, earlier phase of the energy transition: "scope and speed of change increase, … changes are more widespread and profound, … technologies in different stages [interact], established technologies decline as well as traditional business models and institutions (e.g. centralisation), … incumbents could afford to ignore the first phase but are profoundly affected by the second, … struggles among key players of the sector increase … and even though elementary structures change, consumers still expect 'full functionality' (for example, uninterrupted service, affordable prices)" (Markard, 2018, p. 631). In the context of this mature sustainability transition situation, "system integration" of the new technologies and institutions as well as the "functioning and re-configuration of the entire sector" are of key relevance for the long-term and large-scale success of the energy transition (Markard, 2018, p. 631). While undergoing fundamental changes, the energy system needs to remain technological functional and reliable. A mature sustainability transition - more than any early phase transition – is also a societal challenge and key questions arise of how to organise a democratic, evolutionary and peaceful, planned and affordable energy transition, which does not compromise on the technological and social functionality of the energy sector. This is critical for the economic situation and welfare of any society. Germany, Switzerland and Austria, as many other countries, therefore adapted their laws on technological and social functionality of the energy sector from "supply security and economic efficiency" into a triangle of "supply security, economic efficiency and sustainability" - which includes the sustainability transition goal (§1 Energiewirtschaftsgesetz EnWG Germany (2018), Article 1 Energiegesetz EnG Switzerland (2018), §4 and §5 Elektrizitätswirtschafts- und –organisationsgesetz ElWOG Austria (2018)).

The mature sustainability transition of the energy sector poses systemic problems, for which there are no simple solutions. It aims for the maintenance of the social and technological functionality while continuing the transition towards sustainability on a large-scale. An energy system in a mature sustainability transition creates feedbacks and trade-offs (e.g. hydropower production compromises biodiversity or e-mobility creates new resource dependencies) (Markard, 2011, 2018). If the energy transition should be successful on a large scale, it is thus inevitable to employ a systemic and holistic understanding of the system structure, which supports functionality as well as the dynamics for transition – considering both its technological and social spheres and their co-evolution. Transition studies are working on socio-technical transition towards more sustainability and base themselves on complex system science (Markard et al., 2012; Rotmans et al., 2001; Rotmans and Loorbach, 2009). To investigate socio-technical systems such as the energy system, they employ a complex system understanding, considering both system structure (or configuration) and system processes (or dynamics). Transition studies conceptualise socio-technical systems as consisting of i) the (real-world) social and technological system structure, ii) the concerned actors and iii) the related rules as well as the interactions among these three system elements, which cause the dynamics in a socio-technical system (Geels, 2004; Markard, 2011). The interactions among the three system elements explain that the system structure is made through the actors' agency, which again is guided by rules and the rules and the system structure again define the scope of action for the actors (Geels, 2004). The system structure and the transition dynamics are therefore closely interlinked. Transition studies' system understanding considers both structures and dynamics on the actor-level (e.g. motivation, narratives, resources etc.) in the social and technological sphere of a system. It provides a valuable, holistic conceptual basis to investigate key aspects of energy systems in mature sustainability transitions and facilitates the analysis of this contemporary socio-technical systemic phenomenon. This builds the overall research aim of this dissertation:

Research aim of this dissertation is to understand key aspects (structures and processes) of mature sustainability transitions in the energy sector from both the system and the actor perspective.

1.2 Conceptual fundamentals

To tackle this research aim, the dissertation employs a conceptual framework, which is based on transition studies. Transition studies consider sustainability transitions as a co-evolution of the social and technological spheres of a complex system aiming for a system development towards more sustainability (red and blue lines in figure 1-1) (Markard et al., 2012). The socio-technical system is conceptualised as the interaction of structures (technical system, the socio-technical regime and actors) and processes (interrelations) on the actor and system-level (compare the rhombus in Figure 1-1) (Geels, 2004). The transition path, on which the socio-technical system transitions towards more sustainability, is generally thought of as an ideal typical "s-curve" with different phases (Rotmans et al., 2001). For a more detailed overview on the main strands and conceptual frameworks in transition studies see section 2.1.2.). This dissertation conceptualises energy systems as complex socio-technical systems transitioning towards more sustainability.

As mentioned in in section 1.1, for an energy system in a mature sustainability transition, socio-technical functionality is critical and needs to be maintained throughout the entire transition process. This is especially the case in the later phase of the transition, when transition dynamics reach a large(r)-scale. An energy system in a mature sustainability transition does not only need to keep up transition dynamics but must also ensure system functionality (Markard, 2018). Functionality is therefore added to the "traditional" transition concepts in the conceptual framework of this dissertation (compare third axis in Figure 1-1).

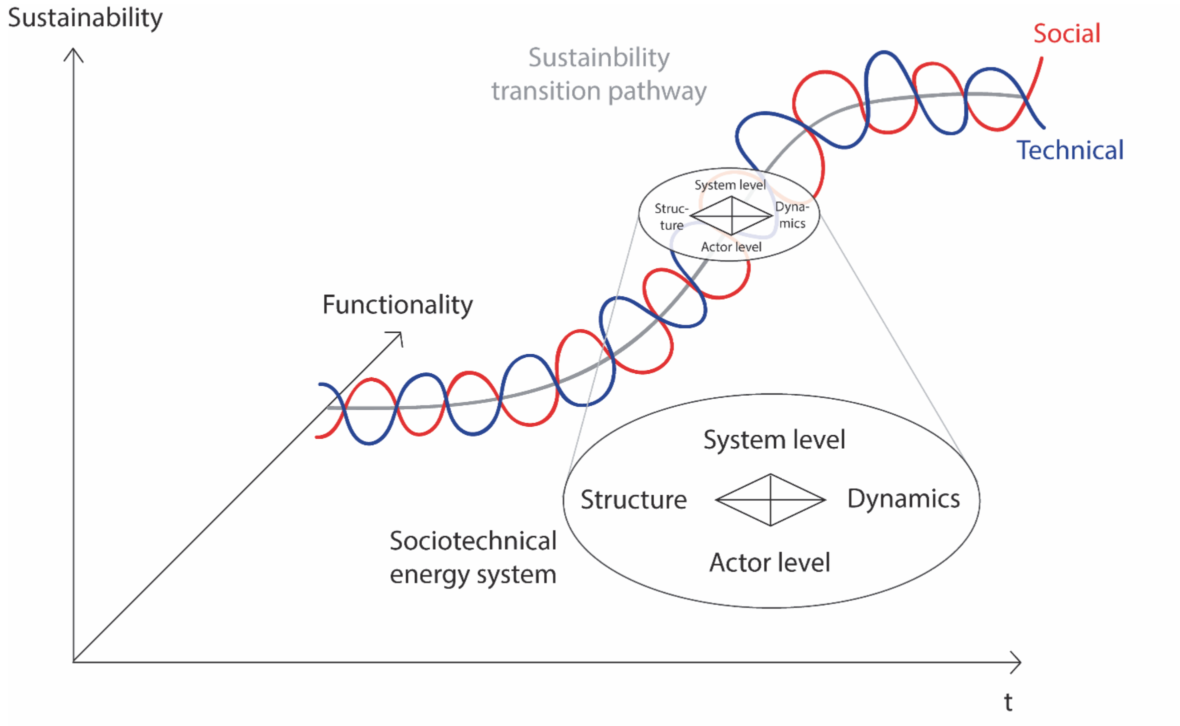

Figure 1-1: Conceptual framework of the dissertation, based on transition studies (author's own elaboration)

Mature sustainability transitions of energy systems are a contemporary phenomenon – the transition of the energy system is already advanced, it is however not yet completed – and there are no frameworks or theories focussing on the particularities of the maturing transition up to now (Markard, 2018). This dissertation approaches the research object of mature sustainability transitions in energy systems through an explorative approach, by conceptualising "system functionality" for socio-technical systems in transitions and analysing key influence factors on transition dynamics in the phase of a mature sustainability transition.

For doing so, my thesis is embedded in two strands of literature. First, in resilience literature, which comprises a wide range of system functionality concepts, supporting the conceptualisation and operationalisation of system functionality in mature sustainability transitions. Second, transitions literature especially focuses on the role of agency in transitions and provides an understanding of agency embedded in the systemic context (considering systemic aspects, too), which facilitates the analysis and better understanding of transition dynamics in mature sustainability transitions (see Figure 1-2).

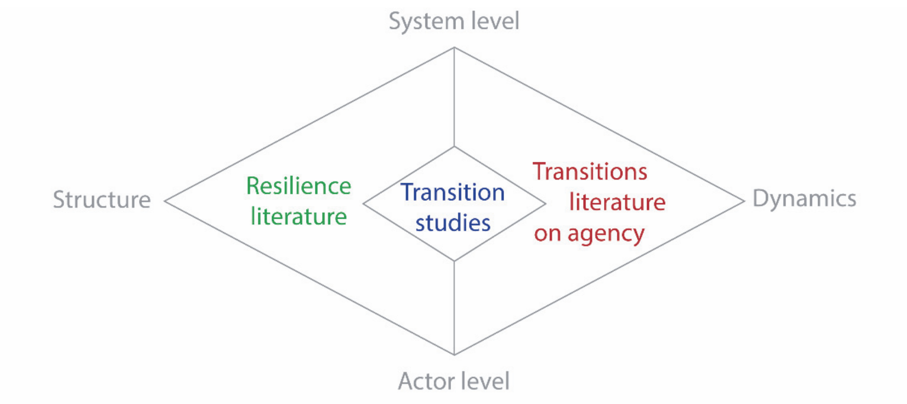

Figure 1-2: Contextualisation of dissertation in scientific literature strands (author's own elaboration)

1.3 Reflexion

1.3.1 Research object and epistemological background

The current socio-technical transition of the energy sector is a highly complex and intertwined phenomenon. Societal norms influence technology development as well as related regulation and vice versa. Moreover, the ongoing energy transition is a contemporary phenomenon, which is constantly changing and has a lot of regulatory and technological uncertainty. Doing research on such a phenomenon is almost like an "open-heart surgery" or like "designing the plane while flying it" (Herr and Anderson, 2005, p. 65, cited by Wittmayer, 2016, p. 57). While research is done, the research object is changing and the researcher is inherently part of the research object, too. Research results can even decisively influence the evolution of the research object. Policymakers and actors in industry are not sure "where the plane will fly to" and how it will look like. They might even actively look for support from research. Researching the contemporary energy transition dynamics can therefore not be done with "classical" disciplinary approaches, where the researcher is distant and can objectively analyse his research object. Research on such complex contemporary societal phenomena instead has a political component and responsibility. Research therefore needs to be transparent about the fact, that it is deeply intertwined with its research object.

Transition studies focus on such complex socio-technical transitions and many scholars explicitly work on contemporary transition processes. In transition studies, as in many other younger research domains who are working on complex societal phenomena, new inter- and transdisciplinary research approaches are proposed, which push the boundaries of classical mono-disciplinary scientific knowledge more towards co-production of knowledge among different disciplines and in collaboration with practice partners and experts in the field. "Avelino (2011: 22) contends that we 'cannot afford' to choose sides between positivist approaches and interpretative approaches to science in the face of questions concerning persistent (complex, normative) problems and transition processes. Rather, she argues for 'combin[ing] different epistemological paradigms and explor[ing] the whole spectrum of what was, what is, what seems to be, what people want and what we think that will be or ought to be' (ibid., cf. Loorbach 2007)" (Wittmayer, 2016, p. 57).

The energy transition is a goal oriented, politically driven, normative societal transition. People define political goals for transitioning their energy system towards more sustainability. In transition studies, the concept of sustainability is nowadays paramount and so normativity plays a key role. There are two large transition studies domains, scholars who are doing research "about" transitions and scholars who do research "for" transitions (Wittmayer, 2016, p.58). The former are more engaged in analysis, explanation and theory building in a "classical" distant manner, seeing normativity as part of their research object. The latter are also actively engaging in practice to support transition endeavours based on their scientific studies and are explicit about their own normativity. Their research is based on the tradition of action research, mode 2 research or transformative research (Wittmayer 2016, p. 29).

Transition studies in general is inter- and transdisciplinary and "interparadigmatic" (Wittmayer, 2016, p. 59), so that it pushes classical epistemological boundaries. Many transition scholars' work can be positioned in the tradition of "critical pragmatism" (Wittmayer, 2016, p. 59), where the societal concern and respective research interest is at the core and define the research design, not any kind of disciplinary or epistemological school.

1.3.2 Research approach and role of the empirics

With my thesis, I aim at understanding, explaining and supporting theory building on contemporary socio-technical transition dynamics in the energy system. I locate myself in the context of transition studies "about" transitions and I follow the "critical pragmatism" orientation since the contemporary phenomenon I study goes far beyond disciplinary boundaries and classical scientific knowledge. I employ interdisciplinary theories and approaches, ranging from system sciences, network industries, sociology, organisational studies and environmental psychology. Expert knowledge takes centre stage of my thesis, to investigate the complex interrelations and causalities behind the highly political phenomenon of energy transitions.

My research is inherently interpretative and iterative (see section 3.1.1). I see my work as a constant dialogue with the phenomenon I study. "In this puzzling-out process, the researcher tacks continually, constantly, back and forth in an iterative-recursive fashion between what is puzzling and possible explanations for it" (Schwartz-Shea and Yanow 2012: 27, cited by Wittmayer, 2016, p. 63). In my research, I employed the so called "iterative theory building" approach (see section 3.1.1) which reflects the dialogue of the researcher with empirics but also with theoretical backgrounds.

In the different parts of my thesis, the empirics therefore played different roles.

The **conceptualisation of resilience** for energy systems in transitions and the development of the respective indicator set was at the beginning driven by theoretical considerations and scholarly discussions in our team. After the development of a common understanding of resilience and the proposition of the indicator set, we started to challenge it with empirical evidence from the Austrian energy regions. Based on the data we tested and discussed our indicators and developed our operationalisation. In a second step, we re-contacted the regional experts for validation of the indicators and their operationalisation as well as for collecting more up-to-date empirical evidence. The approach we employed here was thus deductive, however, the empirical evidence was more than "just" the basis for validation, it was the basis to develop and concretise the concept, to test it and work with the indicators in an explorative way.

For the **analysis of the change agents**, the empirics had a different role. The interviews were conducted first for an explorative understanding of the dynamics and causalities of the regional energy transition process. They were analysed in an inductive manner and finally helped to propose the framework for the systematic agency analysis (see section 5.3). Based on this in-depth understanding of the regional energy transition dynamics as well as the individual's motivations and regional structures, the empirics from the Allgäu region then accompanied the entire dissertation project. We for example applied the indicator set for resilience also to the data from the Allgäu region nd it served as a basis for comparison (see section 5.2) in a deductive manner.

Finally, the empirical evidence from the **urban utility companies**, I analysed with a mixed approach. The expert interviews I conducted, were on the one hand explorative to derive the key characteristics of urban utility companies and I openly asked for their role for system resilience and transition dynamics. At the same time, they had a deductive component, since the investigation of challenges ad strategic answers was framework-based (see section 5.4). In the data analysis, however, I again employed an inductive approach by interpreting the findings on their characteristics as well as their challenges with approaches from public corporate governance and network industries literature. The resulting analytical categories, I derived inductively and validated them in scholarly discussions. Finally, the expert workshops I conducted, also served for a discussion on the interview findings, mainly on the urban utility companies role for resilience. Moreover, the expert workshops also encompassed an explorative component: I asked the participants to discuss models on possible future roles of urban utility companies, which I inductively developed, based on my empirical findings

1.3.3 Role of the researcher

During the expert interviews, I asked experts to share their experience, evaluations and worldviews, so that I could understand the complex dynamics and causalities, which lie behind the energy transition. In this context, I kept on listening and openly showed my main goal to learn from them to minimise biases (e.g. that I would evaluate their knowledge). In the expert workshops, I shared the synthesis of my insights from these interviews. We discussed the implications and potential future avenues of the transition. In this context, I very much aimed at the co-production of knowledge and an open discussion, also to avoid a biases (e.g. that my results were perceived as correct only because they are considered "scientific"). Moreover, I gained deep insights from participating in a "Certificate of Advanced Studies" course "Governing the Energy Transition", in which I participated in 2017. In this course many experts from practice (utility companies, politicians, service provider) took part and together, we listened to other experts, who presented the latest dynamics in the sector. Through the respective discussions, I did not only understand the sector's politics and technological background more in detail, but also I got many insights in the local specificities of the Swiss energy system.

For the study of the contemporary energy transition, my role as a researcher is necessarily normative. In social science, it is absolutely crucial to get close contact to the "research object" to access the in-depth insights on causalities. This "data" is often tacit knowledge of experts and so the researcher depends on the expert's willingness to share "this data". The researcher needs to create proximity to its "research object". During the interviews, I therefore shared my worldviews and norms to create trust, transparency and an equal situation for the interviews. I nonetheless tried as much as possible to keep a neutral stance and create a collegial atmosphere. I did not consider my interview partners as "neutral object of research" but as knowledgeable individuals, I encountered with respect and willingness to learn.

I understand my role as a researcher as the one who listens carefully with a doubtful but respectful attitude, who tries to work on an overview and sort the complex causalities to get to an intersubjective truth. Very much as a good journalist. The researcher, however, differs from a good journalist or a good consultant with his or her ability to link the empirical findings to theory. To me, a good researcher (especially in social sciences) links the observed and analysed phenomena (back) to theory, tries to come up with theory-based explanations and helps to develop the meta-perspective on the research object. This should then again be "translated" to practice by explaining how theory can help to see patterns, which might better organise the messy reality. A good researcher, thus, engages in translating the findings not only from practice to theory but also from theory to practice and supports reflexivity.

I see my role as a researcher as broker and translator between theory and practice. This translation work can however not be neutral, since it is fundamentally influenced by my own societal and educational background as well as the learnings from my research. I don't see myself as an action researcher, however, by studying the resilience of renewable energy systems, the success of change agents and the contribution of local and publicly owned utility companies, my set of norms is already obvious: I want the energy transition to remain successful on the large scale while remaining democratic, equitable and locally embedded. These normative fundamentals stem from my educational background and the holistic sustainability understanding, which I developed there. For me, sustainable development is the ongoing balancing act between different socio-political, economic and ecological interests of actors from different regions in the world but also among different generations – to work on the idealistic aim of equity. After having finished my thesis, it is still my personal conviction, that bridging actors are key players for successful transitions – those who are able to "translate" the old to the new and vice versa, who link innovation to the regime and who are able to embed the large transition dynamics in the local context.

1.3.4 Embeddedness of the thesis

This thesis is embedded in two different contexts: I began my dissertation at LMU University in Munich, Germany, where it was part of a third-party-funded project (Transition processes towards sustainable energy systems / Transformationsprozesse zu einem nachhaltigeren Energiesystem TranE). This project aimed at analysing the drivers and barriers for the local energy transition in the Allgäu region (Germany), both from a governance perspective and point of view of the individual change agents. At the same time, this project was embedded in a research consortium called "For Change", which comprised 13 interdisciplinary projects. Beside their individual project work, they all also worked together to develop an interdisciplinary understanding of resilience (http://www.forchange.de/). In the TranE project, we linked the resilience and transitions thinking, which finally resulted in the indicator set, developed in publication 1-3.

After the first year, a part of our team at LMU moved to EPFL in Switzerland and I continued my dissertation in the newly funded HERUS lab at EPFL. Here, the urban focus became very important. While continuing the work on resilience of energy systems in transitions, I complemented my study on individual agency from the Allgäu region with the analysis of urban utility companies. At the beginning, I was just curious to explore the key actor for urban energy systems – which I already knew from Germany. Over the years, I realised that not only in Germany but also in Switzerland, urban utility companies are the key players for both resilience and transition of urban energy systems. Although there was a decisive institutional and geographical change in my dissertation, which caused some difficulties regarding continuity, I finally could reorient my research in such a way that it became even more complete.

1.4 Structure of the thesis

This thesis is structured as follows:

Part A: Synopsis After having introduced the research motivation, the research aim and the general conceptual framework of this dissertation earlier in chapter 1, **chapter 2** first provides an overview on the scholarly literature related to the concept of resilience (section 2.1.1) and agency (section 2.1.2). It shows research gaps and derives the four key research questions of this dissertation. Finally, to present the red thread, chapter 2 explains the general research approach (section 2.2) and elaborates on the individual contribution of the six publications, structured according to the four modules of this dissertation (section 2.3).

Chapter 3 highlights the methodological implementation of this dissertation in four steps: Section 3.1 presents the general methodological approaches. Section 3.2 exemplifies the data collection methods and section 3.3 the analysis methods, employed in this dissertation. Finally, section 3.4 shows how the methodological approaches, methods and data bases have been applied in the four modules.

Chapter 4 provides a brief overview on the empirical cases used in this dissertation.

Chapter 5 presents the key findings of this dissertation and shows how the four research questions were addressed and answered. It is structured according to the four main research questions (section 5.1 - 5.4). At the end of every section it provides a concise overview box on key findings of the module and its contributions to the overall research aim (sections 5.1.2, 5.2.1, 5.3.1 and 5.4.1).

Chapter 6 discusses the relevance of the findings, first for the study of resilience (section 6.1) and agency (section - 6.2) and second in a synthesised manner with regard to the overall research aim of understanding structures and dynamics in mature sustainability transitions of energy systems (section 6.3).

Chapter 7 provides the thesis' conclusion, first by giving a summary of the entire thesis (section 7.1) and second by discussing limitations and avenues for further research (section 7.2). Finally, the thesis concludes by an overarching reflection on the thesis results' implication for practice (section 7.3).

Part B: Publications The six publications of this thesis are attached in part B. The list of the publications provides a concise overview (part B).

Part C: Appendix The appendix provides **supplementary empirical material,** which has not been presented in the publications but has been key for their results. Its presentation is structured according to the four modules of this dissertation (section A). The appendix comprises **additional non-peer-reviewed publications** - which are not part of the official thesis publications, but are very helpful for a more detailed understanding of energy transitions (section B) and finally it provides additional personal **information about the thesis author** (section C).

1.5 Guideline for the reader – publication overview

	Title	Language	Keywords	Target group	Page
Synopsis	Agency and resilience in mature sutainability transitions.	English	Mature sustainbility transtions, resilience thinking, incumbents, iterative theory building, framework development	Researchers	22
Publication 1	An indicator-based approach for analyzing the resilience of transitions for energy regions. Part I: Theoretical and conceptual considerations	English	Resilience, energy transition, socio-technical system, diversity, connectivity, indicators	Resilience and transition scholars Regional and urban planners interested in theoretical foundations	101
Publication 2	An Indicator-Based Approach for Analysing the Resilience of Transitions for Energy Regions. Part II: Empirical Application to the Case of Weiz-Gleisdorf, Austria	English	Resilience, energy transition, energy region, diversity, connectivity, Austria	Regional planners, policymakers and regional developppers Resilience and transition scholars International interested public	122
Publication 3	It's an Endurance Race": An Indicator-Based Resilience Analysis of the Energy Transition in the Allgäu Region, Bavaria	English	Resilience, socio-technical system, transition, connectivity, diversity, indicators, energy region, Allgäu	Regional planners, policymakers and regional developppers Resilience and transition scholars International interested public	143
Publication 4	Und Aktion! – Konzeptualisierung der Rolle individuellen Akteurshandelns in sozio-technischen Transitionen am Beispiel der regionalen Energiewende im bayerischen Allgäu	German	Agency, human-environmental systems framework, socio-technical systems, multi-level perspective, perception, motivation, strategies, energy transition, Allgäu	Regional developpers and policymakers, change agents Transition and environmental psychology scholars Interested (German) public	153

Publication 5	Grosse Stadtwerke - theoretische und empirische Exploration eines besonderen Akteurs in der Energiewende Deutschlands und der Schweiz	German	Urban utility companies, public corporate governance, network industries, corporate characteristics, challenges, strategies, roles for energy transition, Germany, Switzerland	Urban, national and european policymakers, municipal adminitration, managers of urban utility companies Transition, network industry and public coporate governance scholars Interested (German and Swiss) public	171
Publication 6	Dinosaurs in transition? A conceptual exploration of local incumbents in the Swiss and German energy transition	English	Incumbents, triple embeddedness framework, public corporate governance, network industries, energy transition, urban utility companies, Germany, Switzerland	Transition scholars, network industry and public coporate governance scholars International policymakers and managers of utility companies interested in theoretical foundations	199
Additional publication 1	Ein indikatorengestützter Ansatz zur Resilienzanalyse von Energiesyste-men in Transition	Deutsch	Resilience, transition, indicators, diversity, connectivity, regional energy systems, energy transition, Allgäu, socio-technical systems	Regional planners, policymakers and regional developppers Interested (German) public.	xxxiv
Additional publication 2	Analyzing the resilience of a transition: an indicator-based approach for socio-technical systems	English	Resilience, transitions, socio-technical ecological systems, indicators, energy, tourism, interdisciplinary methods	Regional planners, policymakers and regional developppers interested in methods Resilience and transition scholars	lxi
Additional publication 3	"“A particular species” urban utility companies in Germany and Switzerland	English	Urban utility companies, characteristics, challenges, strategies, Germany, Switzerland	International policymakers and managers of utility companies interested in the German and Swiss case Interested international public	xc
Additional publication 4	Zielkonflikte bei den Stadtwerken	German	Urban utility companies, target conflicts, liberalisation, public services, supply security, resilience, future models, energy transition, Switzerland	Swiss policymakers on the local and the federal level, managers from urban utility companies Interested public	xcvii

Chapter 2 Theoretical background and conceptual design

2.1 Literature overview, research gaps and research questions

In order to better understand structures and dynamics of mature sustainability transitions on the system- and on the actor-level, this dissertation is relying on two literature strands: resilience literature and transition studies focussing on agency. This dissertation draws on both strands of literature to work on two areas, which are of critical relevance for the study of mature sustainability transitions of European energy systems: the conceptualisation of system functionality of energy systems undergoing fundamental changes and a better understanding of transition dynamics in the mature phase of a sustainability transition.

2.1.1 Resilience of socio-technical energy systems in transition

The **notion of resilience** is widely used in scholarly and non-scholarly discourses. Summarising the subsequent section, it describes the ability of an individual, an entity or an entire system to recover from shocks and return to the initial state, as well as to maintain its key functionality or identity. Various scholarly disciplines as e.g. psychology, engineering sciences, ecology and sociology employ concepts of resilience in very specific ways (for an overview see for example Weiß et al., 2018; Folke, 2016; Hosseini et al., 2016). The analysis of resilience in energy systems is hitherto predominantly based on the concept of engineering resilience. Engineering resilience is commonly conceptualised as the ability of a technological system (e.g. the electricity grid) to return to its initial state and way of functioning after facing an external shock. Holling (1996) defines engineering resilience as a concept, which "concentrates on stability near an equilibrium steady state, where resistance to disturbance and speed of return to the equilibrium are used to measure the property [of resilience]" (Holling, 1996, p. 33). Applied to energy systems, Afgan and Veziroglu (2012, p. 5461) describe "energy resilience [as] the ability of an energy system to provide and maintain an acceptable level of service in the face of various challenges to normal operation". Panteli and Mancarella (2015, p. 60) exemplify that resilience "is the ability, to anticipate, absorb and rapidly recover from external high-impact low-probability shocks". In contrast, they differentiate the concept of reliability, which is the ability of the system to operate while undergoing "high-probability and low impact events" (Panteli and Mancarella, 2015, p. 60). Engineering resilience is thus particularly concerned with system reactions to extreme events and shocks, respectively. This process is commonly conceptualised in four phases: preparation, absorption, recovery and adaptation (Sharifi and Yamagata, 2016; Linkov et al., 2013). The most common framework to system abilities in engineering resilience is the so called 4R framework, which describes that a resilient system is characterised by robustness, redundancy, resourcefulness, and rapidity (Panteli and Mancarella, 2015).

In the **context of energy systems**, engineering resilience is mostly used for the analysis of critical infrastructures - mainly the power grid (Strbac et al., 2015; Panteli and Mancarella, 2015; Zio, 2016; Nan and Sansavini, 2017; Roege et al., 2014), urban infrastructure planning (Kharrazi and Masaru, 2012; Scott et al; Sharifi and Yamagata, 2016; Ouyang et al., 2012) and risk and disaster management (McLellan et al., 2012; Park et al., 2013). Scholars are mainly engaged in developing frameworks to conceptualise critical infrastructure resilience and energy system resilience (Roege et al., 2014; Panteli and Mancarella, 2015; Linkov et al., 2013; Zio, 2016), operationalising it in various measures and indicator sets (Sharifi and Yamagata, 2016; Molyneaux et al., 2016; Schlör et al., 2018; Erker et al., 2017a) and empirically analysing critical infrastructure resilience (Strbac et al., 2015; Molyneaux et al., 2012; Erker et al., 2017b). Finally, the analysis and conceptualisation of the interconnectedness and interdependency of critical infrastructures, so called systems-of-systems approaches, have received particular interest (Nan and Sansavini, 2017; Zio and Sansavini, 2011; Vespignani, 2010; Rinaldi et al., 2001; Kröger, 2008; Little, 2004).

Engineering resilience, however, is a static concept, which focuses on recovery and a return to the initial system state. For the analysis of energy systems, which undergo deliberate and purposive transitions, aspects of change and system transformation are of key importance. They are under-conceptualised in engineering resilience, since the focus in the past has been on restoring functionality of a given system after a critical shock, not on conceptualising and understanding functionality during a purposive transition. The social sphere of the energy system is underrepresented in engineering resilience. Social aspects, such as governance structures, competences and learning, which are important for system recovery are considered (especially in risk assessment studies), however, the social sphere "only" serves and contributes to the resilience of the technological system (see e.g. McLellan et al., 2012; Park et al., 2013). Engineering resilience therefore lacks a resilience concept of the social sphere in a socio-technical system.

Research gap 1: Lack of resilience conceptualisation for socio-technical energy systems undergoing a purposive transition

Another strand of systemic resilience literature, the so called adaptive (socio-ecological) resilience literature (Sharifi and Yamagata, 2016) provides very helpful conceptualisations regarding this gap. Not only does it offer an elaborated conceptualisation of the social sphere in the socio-ecological systems approach (see e.g. the socio-ecological systems framework (Ostrom, 2009) or the Human Environment Systems Framework (Scholz and Binder, 2003)), but it also conceptualises dynamics, change and transformation as being an integral part of system resilience. The conceptualisation of an equally weighted social sphere as well as resilience understanding encompassing change are of great value for the study of socio-technical energy systems in transition.

The core definition of "**adaptive resilience**" dates back to Walker et al. (2004), who state that "resilience is the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Walker et al., 2004, p. 1). Walker et al. (2004) exemplify, that a system's resilience also depends on the resilience of its sub- and superordinate systems (which is further developed in the "panarchy concept" by Holling and Gunderson, 2002). Based on Walker et al. (2004), Folke et al. (2010) developed a dynamic resilience conceptualisation, which they called resilience thinking. Besides robustness, resilience thinking includes adaptability and transformability as "prerequisites" of resilience. In addition, Folke et al. (2010) elaborate the panarchy concept and distinguish between specific and general resilience: specific resilience is related to a particular subsystem, whereas "general resilience, in contrast, does not define either the part of the system that might cross a threshold, or the kinds of shocks the system has to endure. It is about coping with uncertainty in all ways" (Folke et al., 2010, p. 6). They argue that a too narrow focus on specific resilience might not allow to prevent a larger system collapse. In contrast, specific shocks might open up opportunities for system change, learning and recreation, which can increase the system's general resilience. With this dynamisation, change and transformation have become integral parts of the socio-ecological resilience concept. In 2015, scholars from the Resilience Alliance and the Stockholm Resilience Center operationalised resilience thinking in seven principles: i) maintain diversity and redundancy, ii) manage connectivity, iii) manage slow variables and feedbacks, iv) foster complex adaptive systems thinking, v) encourage learning, vi) broaden participation, vii) promote polycentric governance systems (Simonsen et al., 2015; Biggs et al., 2015). At the same time, more and more scholars also work on a stronger conceptualisation of resilience thinking for the social sphere (Cote and Nightingale, 2012; Fath et al., 2015). In this context, purposive change and deliberate non-return to the initial state as well as a more nuanced understanding of system functionality and identity become ever more relevant.

The rich resilience conceptualisation presented above, which is continuously further developed in the socio-ecological systems community. However, it has not been applied and operationalised for socio-technical systems yet, except for a few conceptual contributions (e.g. Wiese, 2016; Hodbod and Adger, 2014; Smith and Stirling, 2008). Among these, Wiese (2016) is the only scholar who has worked on energy systems. She operationalised the resilience thinking approach for energy research and has shown how the seven principles developed by the Resilience Alliance can be applied to energy systems. Her first application of resilience thinking to energy systems necessarily remained on a general level without providing concrete operationalisations or indicators for empirical research. Other approaches, employing the socio-ecological systems perspective to energy systems, focus on the ecological aspects of energy systems and do not apply the resilience concept (Alvial-Palavicino et al., 2011; Acosta et al., 2018)

Research gap 2: Lacking operationalisation of resilience thinking for the empirical analysis of energy systems, conceptualised as socio-technical systems in transition.

As mentioned earlier, European energy systems are undergoing deliberate, purposive and fundamental transitions on a large scale. New technologies and institutions become mainstream and challenge the pre-existing system. In order for the transition to remain successful in its mature phase, the social and technological functionality of the energy system – as a critical infrastructure system – are inevitable. Conceptualising and operationalising resilience thinking for socio-technical energy systems thus contributes to a better understanding of mature sustainability transitions and enriches related scholarly theory building. The theoretical conceptualisation of socio-technical energy system resilience can serve as a basis for decision-makers to examine the functionality of the energy system, which they steer through the sustainability transition process. Additionally, the empirical analysis provides an exemplification and concrete insights, which increases the applicability of the concept in practice. Accordingly, this dissertation tackles the following two research questions:

Research question 1: How to conceptualise and operationalise resilience of socio-technical energy systems in transition? (working on research gap 1)

Research question 2: How to empirically analyse the resilience of socio-technical energy systems in transition? (working on research gap 2)

2.1.2 Agency in sustainability transitions of socio-technical energy systems

Transition studies literature "emerged at the intersection of innovation studies, evolutionary economics, science and technology studies, sociology, and history of technology. It is based on system thinking, it emphasises the interrelatedness of social, technological, institutional and political changes, it highlights path-dependency and lock-in, and points to the inevitability of conflicts among actors" (Markard, 2018, p. 628). Markard et al. (2012) provide a rich and comprehensive overview on major strands of transition studies, which are strategic niche management (Hoogma et al., 2004; Kemp et al., 1998), transition management (Rotmans et al., 2001; Loorbach, 2010; Loorbach and Rotmans, 2010), the technological innovation systems approach (Markard et al., 2015; Hekkert et al., 2007) and studies employing the multi-level-perspective (Geels, 2004, 2002, 2011). Transition studies are mainly concerned with the analysis of profound transitions in sectors like energy, water supply, transport, which they conceptualise as socio-technical systems. Markard et al. (2012, p. 956) exemplify that "such systems consist of (networks of) actors (individuals, firms, and other organisations, collective actors) and institutions (societal and technological norms, regulations, standards of good practice), as well as material artefacts and knowledge (Geels, 2004; Markard, 2011; Weber, 2003). The different elements of the system interact and together they provide specific services for society". Markard et al. (2012) explain that the transition of socio-technical systems "differ from technological transitions in that they include changes in user practices and institutional (e.g., regulatory and cultural) structures, in addition to the technological dimension" (Markard et al., 2012, p. 956).

With the rise of the **sustainable development concept** and the intensifying political attempts to transform infrastructure sectors, such as the energy sector, towards more sustainability, socio-technical transitions were re-framed as sustainability transitions. "The term 'sustainability transitions' has been coined to refer to such purposive transitions, that is, socio-technical transitions that are associated with sustainability goals" (Markard, 2018, p. 628). Markard et al. (2012, p. 956) define sustainability transitions as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption". Markard (2018) exemplifies that sustainability transitions are characterised by their i) context dependency (differences among regions, sectors), ii) contestedness (there are winners and losers), iii) normativity (value-laden, depend on societal preferences) iv) complexity and uncertainty (sustainability problems are often ill-defined, socio-political processes unpredictable) v) policy- centeredness (public policies play an important role). Rotmans et al. (2001) defined the seminal concept of "the transition curve", which represents the four phases of a sustainability transition – predevelopment (an innovation evolves), take-off (the adoption rates of the innovation increase), acceleration and stabilisation (the innovation becomes mainstream) – which are widely used to temporally structure the sustainability transition process.

Another powerful and widespread concept to explain the dynamics and processes of sustainability transitions is the so **called multi-level perspective on sustainability transitions** (Geels, 2002, 2011). Based on Giddens' structuration theory (Giddens, 1984) and concepts from innovation theory (Kemp et al., 1998), it describes three levels of structuration in socio-technical systems – the highly structured landscape (e.g. fundamental societal beliefs and norms, which cannot be changed by actors), the medium-structured regime (e.g. the mainstream norms, rules and technologies in use) and the least structured niche (e.g. innovative technological and social solutions, alternative beliefs). It provides a meso-level theory, with a central understanding that sustainability transitions are caused by a major event or changes in the landscape, which open a window of opportunity, in which niches can enter the regime and evoke a regime shift (Geels, 2005b; Geels, 2002, 2004, 2010, 2005a; Geels and Schot, 2007). The socio-technical regime is a key concept of the multi-level perspective but also used widely in the entire transition studies literature. The socio-technical regime can be seen "as the 'deep-structure' or grammar of socio-technical systems, and are carried by the social groups" (Geels, 2002, p. 1260). It encompasses different forms of institutions (formal or informal rules) as well as belief-systems or norms, which are established in the sector (e.g. the energy sector). Socio-technical regimes are meta-regimes, which are embedded in and draw institutions from other, related sectors (e.g. ICT, trade, science, etc.) (Geels, 2002). "The core idea behind the regime is that it imposes a logic and direction for incremental socio-technical change along established pathways of development" (Markard et al., 2012, p. 957). The socio-technical regime is thus concerned with stability. In order for a sustainability transition to take place, the regime needs to get challenged by new solutions from the niche in a first phase and needs to fundamentally change and adapt in the second, mature phase (Markard, 2018).

Although all these concepts and theories of sustainability transitions are very much thought from a systemic perspective, **actors and their agency** build an integral part of a socio-technical system and are highly important for its transition. Again based on Giddens' structuration theory, Geels (2002) emphasises that socio-technical systems are characterised by their physical basis (in Giddens' terminology the system), their rules in the socio-technical regime (in Giddens' terminology the structure) and the actors. The actors are influenced by the system and the structure but they also influence and reproduce the system and structure (Giddens, 1984). Agency, thus, plays an important role for the implementation of sustainability transitions.

As a first attempt, Farla et al., (2012) gathered in a special issue several transition studies' contributions, which were focused on the actor-level. Due to the general system-level focus of transition studies and its roots in political sciences, however, transition scholars researching actors and agency focus on the one hand mainly on systemic influence factors on actors, e.g. institutionalist studies (Fuenfschilling and Truffer, 2016, 2014), the study of power (Avelino and Wittmayer, 2016) as well as narratives (Hermwille, 2016; Kammermann and Dermont, 2018) or on the actors abilities to change the institutions (institutional entrepreneurship (Jolly et al., 2016; Bohnsack et al., 2016). On the other hand, there is an increasing amount of contributions, analysing actor constellations and interplays during transition processes and revealing how they can be managed for the transition process (e.g. on actor network and coalition formation (Musiolik et al., 2012; Markard et al., 2016)) or the formation of transition arenas of change makers (Loorbach and Rotmans, 2010; van de Kerkhof and Wieczorek, 2005). Actor-related contributions in transition studies mainly focus on the systemic determinants of agency and rather adopt a bird's-eye view on actor constellations. For a better understanding of agency, it is however important to not only look at actors from a system's perspective but also to consider determinants of agency on the level of the individual. A comprehensive framework, facilitating a systematic analysis of agency – considering both, the systemic and actor-level determinants of agency as well as the feedback of agency on the system and its role for the transition process – is still lacking.

Research gap 3: Lack of a comprehensive framework to empirically analyse system- and actor-level determinants of agency as well as the role of agency in sustainability transitions of socio-technical energy systems

In the context of energy systems, scholarly contributions concerned with the **actor-level and agency** are predominantly focussing on the different roles of actors for the transition process. Generally speaking, they can be grouped in the well-established dichotomy of challengers and incumbents, which stems from social movement theory (Gamson, 1975) and has been further developed in strategic action field theory (Fligstein and McAdam, 2011, 2012). Incumbents shape and reproduce the existing regime. It is their role to stabilise the regime and they naturally oppose any larger transition forces, which might challenge them and the existing regime. Challengers, in turn, are actors who challenge the existing regime and the incumbents with fundamentally new technological and social solutions. Between these two actor groups, governance units, which "are charged with overseeing compliance with field rules and, in general, facilitating the overall smooth functioning of the system" (Fligstein and McAdam, 2011, p. 13). Transition studies did not (yet) pick up the concept of governance units. Due to the roots of transition studies in innovation studies, a high share of contributions related to the energy transition focuses on the challengers such as grassroots movements or change agents (Arentsen and Bellekom, 2014; Coenen et al., 2010; Seyfang et al., 2014; van der Schoor and Scholtens, 2015; Martiskainen and Kivimaa, 2018). More recently, an increasing body of literature also works on the role of incumbents in the energy transition (Heiskanen et al., 2018; Lauber and Sarasini, 2014; Leitzinger, 2015; Ngaryin Mah et al., 2017; Nijland, 2013; Karneyeva, 2017; Kungl and Geels, 2018). In general, the analysis and understanding of incumbents' behaviour in sustainability transitions is gaining more and more attention (van Mossel et al., 2017).

Up to now, the **analysis of challengers and incumbents** has been mainly influenced by the normative assumption that challengers are good and incumbents are bad for transitions. More recently, an increasing number of contributions are however aiming at a more nuanced picture of incumbents' behaviour, in order to overcome the dichotomy of positive challengers and negative incumbents (Smink et al., 2015; Kishna, 2015; Smink, 2015; Wesseling, 2015; Späth et al., 2016). In this context, van Mossel et al. (2017) provide a very valuable overview on current scientific endeavours and contributions to enhance the understanding of incumbent behaviour in the context of transition studies. Contributions, which are related to the energy sector and which question the negative role of incumbents or draw a richer picture of their roles, however, could not be found in the context of the transition studies literature. From a transition management perspective, the role of incumbents is critical for the long-term and large-scale transition success in the mature phase of the transition. They are the actors in charge of implementing the transition on the regime level. Especially in the energy sector, where a sudden revolution and take-over of niche actors could compromise supply security and would not be desirable.

In the **energy context**, studies on incumbents' behaviour in transitions have so far only focused on national energy utility companies (e.g. EON and RWE, see e.g. Lauber and Sarasini, 2014; Ratinen and Lund, 2014; Kungl and Geels, 2018; Kungl, 2015). However, in states like Germany, Switzerland or Austria, which have a federal energy governance system, incumbents are also located on the Länder / cantonal and the commune level. The so called "Regionalversorger" (energy utility companies on the Länder level in Germany) or "Kantonswerke" (energy utility companies on the cantonal level in Switzerland) as well as the "Stadtwerke" and the "Gemeindewerke" (public service companies on the municipal level in both countries) play an important role for federal energy governance systems and thus for the long term success of the energy transition in these countries (Berlo and Wagner, 2011a, 2011b; Finus, 2012; Gochermann, 2016). In brief, there is not only a lack of a nuanced picture of the incumbents' roles for the energy transition process in general, but also a lacking in-depth understanding of the diversity of incumbents in the energy sector, especially for federal energy governance systems.

Research gap 4: Lack of a nuanced picture and systematic analysis of different roles and types of incumbents in the energy transition.

In conclusion, transition studies lack a comprehensive framework, which allows to empirically analyse system-level and actor-level determinants of agency in an equally weighted manner, and also takes into account the feedback of their agency on the system. Such a framework would on the one hand facilitate the systematic analysis of different actor types and contribute to a better understanding of actor-level dynamics in sustainability transitions, on the other hand it would also allow for cross-case study comparisons. Energy related transition studies, lack a more nuanced understanding of the diversity of incumbents' roles in transition and different types of incumbents in the context of the energy transition. The empirical analysis and theoretical conceptualisation of incumbents in federal energy governance systems and a more fine-grained analysis of their agency decisively contributes to an improved understanding of the diversity of actors and the incumbents' key role in mature sustainability transitions. Finally, the analysis of incumbents' agency – as those actors, who are in charge of the systems functionality, while it undergoes change – also facilitates the link to the resilience conceptualisation, mentioned earlier.

Research question 3: How to improve the systematic analysis of agency in sustainability transitions of socio-technical energy systems? (working on research gap 3)

Research question 4: How to improve the empirical and theoretical understanding of incumbents' diversity and roles in sustainability transitions of socio-technical energy systems? (working on research gap 4)

Definition of key concepts

The following overview summarises definitions of the key concepts for this thesis – based on the earlier explanations in section 1.2.

Energy resilience is the ability of an energy system to prepare for and absorb shocks on short notice and adapt and transform itself (respectively its subsystems) in the long run, so that it can maintain its functionality (secure, affordable and acceptable energy supply). A continous balancing between the system's stability and flexibility on multiple scales is decisive for resilience (e.g. storage for stabilising volatile renewable production). Reflexivity and learning capacity are key abilities to maintain this balance.

Socio-technical (energy) systems comprise all actors who are involved in the governance of the energy system, technological artefacts such as production sites, transmission or metering assets as well as related formal and informal rules, which steer the system. Formal rules include regulations or standards from within the sector but also beyond (e.g. data protection regulation). Informal rules include e.g. worldviews, norms, types of knowledge within the energy sector but also beyond (e.g. societal positions pro or against privatisation). The socio-technical energy systems under study in this dissertation are mainly regional systems. They are however conceived of as nested systems, e.g. local distribution grids are embedded in the national and supra-national transmission grids. In federal energy governance systems, the regional social sphere is likewise embedded in the national and international context. Finally, socio-technical energy systems interact also with other systems like the transport or the communication system.

Sustainability transition of an energy system is the purposive conversion of the energy supply and demand systems aiming at the reduction of CO2 emissions, higher shares of renewables, the phase out of fossil fuels and increased energy efficiency. A sustainability transition of an energy system is characterised by the co-evolution of and fundamental changes in the social sphere (rules, institutions, actor-constellations) and the technological sphere (system integration of new technologies, deconstruction of old technologies). An alignment of the social and the technological changes increases the chances of success of the transition. A sustainability transition of an energy system is embedded in other transitions in the wider society (e.g. changing awareness of climate change, demographic change or urbanisation).

Mature sustainability transition is the "later phase" of a sustainability transition, where the transition dynamics do not only affect niches of the system anymore but reach the mainstream (the regime) of the energy system and influence it on a large scale. Traditional actors (incumbents) need to react to transition dynamics and fundamental system reconfigurations are upcoming to link new solutions to the existing system structure. technologically, e.g. the nationwide change of the transmission grid and the smart meter roll-out reflect such fundamental changes. Socially, e.g. questions arise about the economic costs of the transition and the "equitable" cost distribution or the changes in the law needed for dealing with new technologies like storage units. A mature sustainability transition however does not mean that the transition is completed or already achieved its goal. The system is still in an intermediate but advanced state of transition relative to its envisaged sustainability goals.

Agency is conceptualised as all types of action, which are performed by individuals or organisations. It is influenced by systemic influence factors (rules, norms, actor-constellation, existing artefacts) and individual influence factors (motivation, abilities, resources). At the same time agency is an ongoing process of interaction between influence factors, action, feedback and evaluation. Agency is purposive und thus a characteristic of living beings, even if they might not always be aware of the full range of their actions' effects or pretend different intentions.

Incumbents are actors who have key positions, tasks and mandates for the functioning of the existing socio-technical system. Formal and informal rules are made for, with and by them, so that they have a powerful position and can influence the regime (the mainstream way of doing things) decisively more than other actors. Incumbents thus neither per se affect the transition in a negative, nor in a positive way. They are simply the "traditional actors" in the system.

2.2 General research approach

Mature sustainability transitions in the energy sector are a contemporary phenomenon. Up to now, no specific theories or frameworks exist in transition studies, which facilitate the conceptualisation or empirical analysis of structures and dynamics in energy systems in the mature phase of a sustainability transition. This dissertation combines existing work in transition studies with theoretical concepts and frameworks from other bodies of literature, namely resilience thinking and agency theory (see **step A** "**theory combination**" in Figure 2-3).

For the conceptualisation, operationalisation and empirical analysis of system functionality, the concept of resilience thinking is employed. Resilience thinking describes system functionality as being dependent on the system's abilities of maintaining robustness, adaptive capacity and transformability. The dissertation links resilience thinking to the "transition curve" and conceptualises it for socio-technical systems in transitions (research question 1). For the improved conceptualisation and empirical analysis of individual's agency, the HES framework, originating from environmental psychology is employed. The framework is reconceptualised for socio-technical systems and linked to the MLP. The HES framework comprises actor- and system-level determinants of agency and the interaction of agency with the system structure (research question 2). For a more detailed description see section 2.3.3 and section 3.4.3. For the more fine-grained understanding of incumbent's (organisational) agency in mature sustainability transitions, theoretical considerations from public corporate governance literature and network industries literature are consulted and linked to the TEF Framework (Geels, 2004). This linkage provides a more elaborate conceptualisation of actor and system-level determinants and helps to explain the agency of incumbents (research question 4). For a more detailed description see section 2.3.4 and section 3.4.4. Both, the conceptualisation of individual and organisational agency aims at a better understanding of transition dynamics in mature sustainability transitions.

Due to the contemporary nature of mature sustainability transitions in the energy sector, this dissertation confronts the theoretical considerations mentioned above with empirical evidence from socio-technical energy systems in mature transitions in an iterative process (see **step B** "**theory – empirics iteration**" in Figure 2-3). Based on a mixed methods approach, which is explained in more detail in section 3.1.2, structures and dynamics of socio-technical energy systems in mature sustainability transitions are analysed empirically on both the actor-level and the system-level. The empirical findings subsequently feed back to the theoretical considerations and support the theory building process. In doing so, the dissertation does not only explore system functionality and transition dynamics on the conceptual, but also on the empirical level (research question 2, 3 and 4).

Finally, the iterated results from the conceptual and the empirical studies feed into the proposition of new and complementary theories for the better understanding of structures and dynamics in mature sustainability transitions, which are reconnected to transition studies (see **step C** "**feedback of new theoretical concepts**" Figure 2-3). This methodological approach of "iterative theory building" is explained in more detail in 3.1.1.

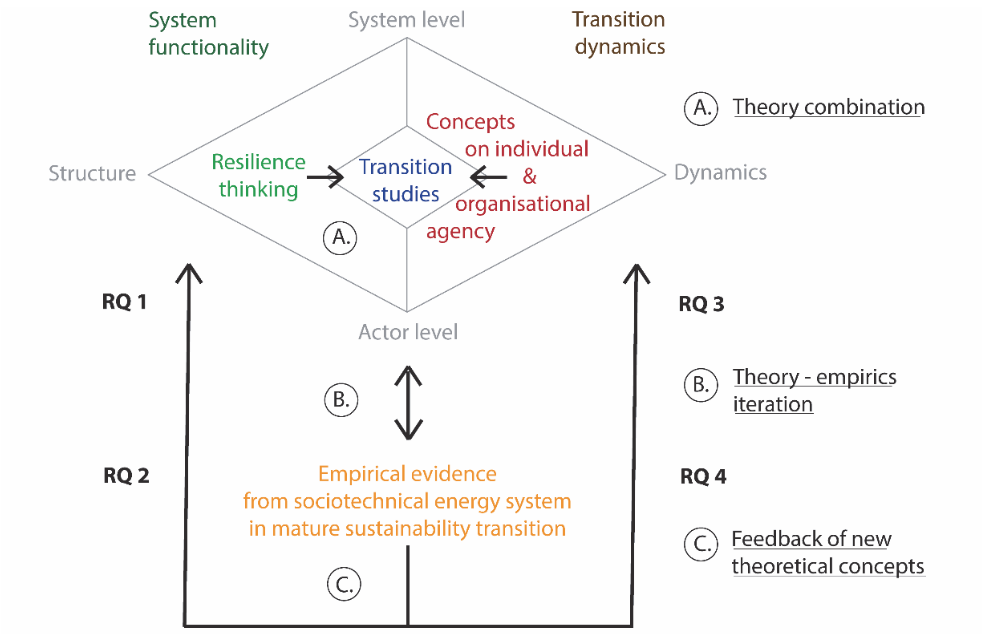

Figure 2-3: General research approach of the dissertation (author's own representation)

This dissertation is based on six publications, which are grouped in four modules according to the four research questions:

- **Module 1** Conceptualisation and operationalisation of resilience for socio-technical energy systems in transition (publication 1)
- **Module 2** Empirical analysis of resilience of socio-technical energy systems in transition (publication 2 and publication 3)
- **Module 3** Conceptualisation and empirical analysis of agency in sustainability transitions of socio-technical energy systems (publication 4)
- **Module 4** Conceptualisation and empirical analysis of incumbents in sustainability transitions of socio-technical energy systems (publication 5 and publication 6)

Module 1 and 2 focus on system functionality and more specifically on the aspects of system structure for system functionality. Module 3 and 4 focus on transition dynamics through the investigation of determinants of agency and the role of individual and organisational agency in transitions. The conceptual division between system structure and transition dynamics is made for analytical reasons and facilitates a more focussed conceptualisation and analysis.

Even though module 1 and 2 focus on system structure, they nonetheless consider transition dynamics as driving forces for changes in the system structures and at the same time as challenges for system functionality. Module 3 and 4, in turn, focus on agency and transition dynamics, but they nonetheless consider system structure as important determinants for agency and affected by agency.

The conceptual contribution of the individual publications is presented hereafter in more detail, structured according to the four modules. The integrated contribution of the publications to the overall research aim – the better understanding of actor and system-level structures and dynamics in mature sustainability transition – is presented in section 6.3 as part of the discussion.

2.3 Conceptual contributions and interrelations of individual publications

This section presents the conceptual contributions and interrelations of the individual publications of this dissertation. According to the four modules of this dissertation, the following section is subdivided into four subsections, within which the individual publications are discussed. For every publication, the subsection first presents a short summary of the publication. Thereafter, it presents the conceptual contributions of the publication as well as its linkage to the other publications of the dissertation. Finally, the subsection concludes by graphically summing up the localisation of modules and the related publications in the overall research approach (compare Figure 2-3).

2.3.1 Module 1: Conceptualising and operationalising resilience of socio-technical energy systems in transition (publication 1)

Module 1 provides a theoretical understanding of what resilience means for socio-technical energy systems in transition and how it can be operationalised for the social and technological sphere by means of an indicator set for diversity and connectivity. This indicator set can be applied to analyse the system configuration of a socio-technical energy system in transition. By basing the indicator set on the resilience concept it moreover facilitates the understanding of how the socio-technical system configuration supports system functionality and how it is related to transition dynamics.

Publication 1 Binder, Claudia R., Susan Mühlemeier, and Romano Wyss. "An indicator-based approach for analyzing the resilience of transitions for energy regions. Part I: Theoretical and conceptual considerations” Energies 10.1 (2017): 36.

Summary: Publication 1 presents a conceptualisation of resilience for socio-technical energy systems in transition. It applies the resilience thinking concept, developed in the socioecological systems community, to socio-technical systems and combines it with the “s-curve” framework on the four ideal type phases of a sustainability transition (Rotmans et al, 2001). Publication 1 formulates the system’s resilience during a sustainability transition as a result of the system’s ability to maintain stability and flexibility. It proposes an indicator set and related measures for diversity and connectivity, which can be used for studying the resilience of the technological and the social sphere of an energy system in transition. The indicator set consists of three indicators for diversity (variety, balance and disparity) and three indicators for connectivity (average path-length, degree centrality, modularity). It operationalises these indicators for energy systems, using the concept of social arenas and technology groups to allow for an equal application of the indicator set to both spheres. Finally, publication 1 discusses the meaning of different archetypical indicator levels and different constellations for the energy system resilience by developing four ideal type cases (of high and low levels of diversity and connectivity). It thus builds not only the conceptual basis for resilience in socio-technical transitions (research question 1), but also facilitates an empirical application by proposing a concrete indicator set and an operationalisation of the concept for socio-technical energy systems.

Conceptual contribution: The indicator set developed in this module allows to analyse and measure the resilience of a socio-technical energy system via the analysis of its structural configuration and its changes over time. Due to its the conceptual basis on resilience theory, the indicator set facilitates the empirical analysis of social and technological system functionality in sustainability transitions. The indicator set is also not case-specific but of general validity and can be applied to all phases of a transition process, which facilitates comparisons across different phases of the transition and across different empirical cases. The equal conceptualisation of the indicators for the social and the technological spheres supports the analysis and comparison of the social and the technological system structure and their development over time – within and across cases. By reflecting on the interdependence of system structure for functionality and the position of the system in the course of a sustainability transition (the four ideal type cases), publication 1 also provides first explorative thoughts on how system structure and transition dynamics are interlinked. Through these four ideal type cases, publication 1 finally also links the indicator set back to the transition phases (“s-curve”) framework and makes them accessible for the transitions discourse. In conclusion, publication 1 facilitates the empirical analysis and decisively enriches the understanding of system functionality and its development over the course of a transition, which contributes to theory building regarding energy systems in mature sustainability transitions (see Figure 2-4).

Linkage to other publications: Publication 1 builds the conceptual basis for publication 2 and publication 3, which then empirically apply the developed indicator set. It provides the basis for the rich system understanding on which publication 4 – 6 are built. It also draws attention to the importance of system configurations as an influence factor for agency and the interrelatedness of system structure and transition dynamics, on which publication 4 reflects for individual’s agency and publication 5 and publication 6 for organisational agency.

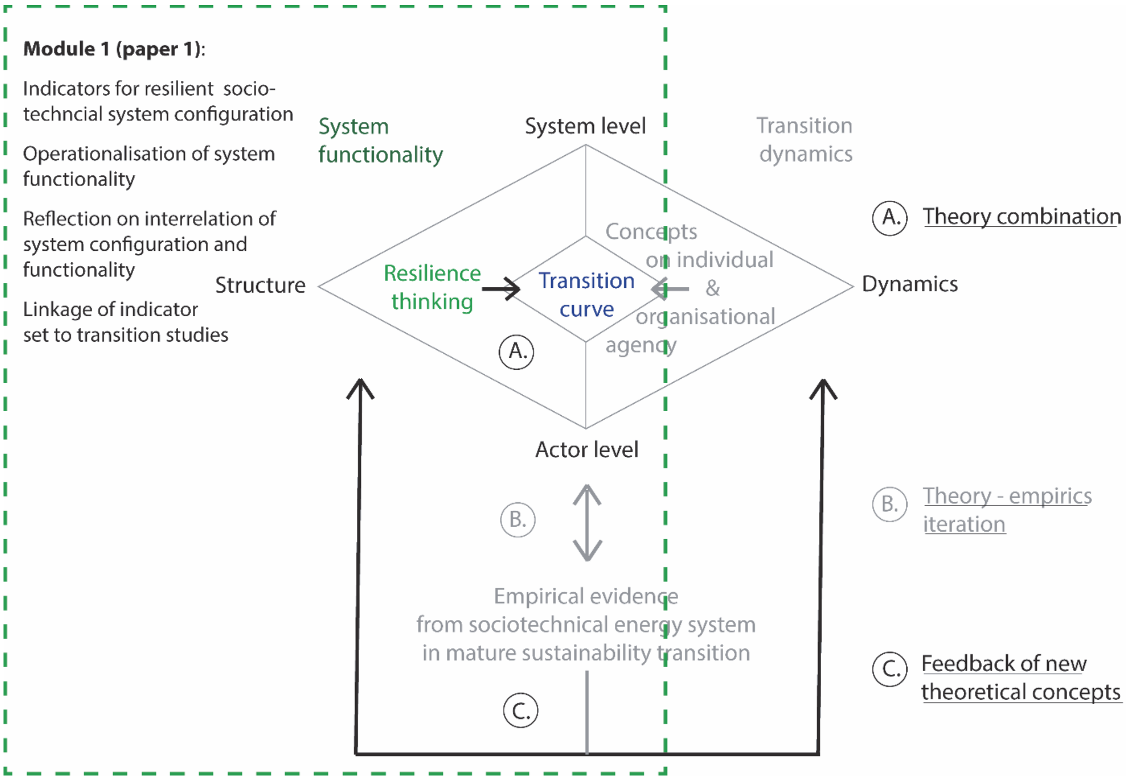

Figure 2-4: Localisation of Module 1 (publication 1) in the general research approach (author's own representation)

2.3.2 Module 2: Empirically applying and discussing the indicator set for resilience of socio-technical energy systems in transition (publication 2 and publication 3)

Module 2 provides in-depth empirical insights from the application of the indicator set - developed in module 1 - to two regional energy systems and their comparative analysis: i) within one energy region among the social and the technological system sphere, ii) different phases in their development over time and iii) among two different energy regions. Module 2 presents a set of methods for the qualitative and quantitative analysis of the indicators. It provides examples for the empirical analysis of the theoretical considerations from module 1, empirically underpins them and supports further theory building on system functionality in mature sustainability transitions.

Publication 2 Wyss, Romano, Susan Mühlemeier, and Claudia Binder. "An Indicator-Based Approach for Analysing the Resilience of Transitions for Energy Regions. Part II: Empirical Application to the Case of Weiz-Gleisdorf, Austria" Energies 11.9 (2018): 2263.

Summary: Publication 2 empirically applies the indicator set developed in publication 1 to the energy region of Weiz-Gleisdorf (for a detailed description see section 4.1). Publication 2 presents results for the energy system's social and technological configuration over the course of the four transition phases, namely predevelopment, take-off, acceleration and stabilisation. In the analysed phase (1996 – 2016), the regional technological subsystem showed a strong increase in diversity from low to high levels and a rather constant overall connectivity at medium levels. The social system, in contrast, showed a constant diversity on high to medium levels but a decreasing connectivity from high to medium levels (for a more detailed description see section 5.2.1). Finally, publication 2 assesses the derived system configurations and transition patterns by relating them to the four ideal-type cases developed in publication 1. It concludes that the current system configuration (high diversity but medium connectivity) corresponds to ideal-type case C, which describes the system state as an intermediate state in the transition. Publication 2 provides rich empirical insights into the system structure as well as its changes over the course of a transition and showed how the resilience of an energy system in transition can be analysed empirically (research question 2).

Conceptual contribution: The results from this empirical application of the indicators for socio-technical resilience present a first explorative analysis of the system configuration over the course of a transition and gives an example of an empirical analysis of system functionality in mature sustainability transitions. The regional energy systems under study are in the mature phase but the transition of their energy system is not yet completed. The empirical results show e.g. that the system structure in the technological sphere has changed decisively while the functionality could be maintained (for more detailed information see section 5.2.2). These insights help to retrace the complex interconnected system dynamics in socio-technical systems – by uncovering differences and commonalities in the transition dynamics of the social and technological subsystem for the same point in time as well as over the course of the transition. The empirical insights also allow for a reflection on causal relations between the subsystems and allow to better understand system functionality and transition dynamics in energy systems in (mature) sustainability transitions. On the methodological level, publication 2 presents qualitative and quantitative methods as well as data sources for the empirical analysis of resilience in the social and technological sphere of energy systems in transition and discusses the challenges and opportunities of the empirical application of the indicator set. In conclusion, publication 2 provides a specific system analysis approach, which considers the social and the technological sphere equally, encourages the future application of the indicator set, generates a deeper empirical understanding and supports theory building to understand system functionality in mature transitions (see Figure 2-5)

Linkage to other publications: Publication 2 is based on publication 1 and complements it with rich empirical insights over the course of a sustainability transition. Publication 2 is designed in parallel to publication 3, which focuses on one point in time and the proposition of more quantified research methods as well as the analysis of a different case study region. Publication 2 provides a deep system understanding of an energy region in Austria, which cross-fertilised the empirical analysis and system understanding in publication 4 and publication 5. Regarding the reflection on similarities among federal energy governance systems, it also informed the conceptual work in publication 6.

Publication 3 Mühlemeier, Susan, Claudia R. Binder, and Romano Wyss. "“It’s an Endurance Race”: An Indicator-Based Resilience Analysis of the Energy Transition in the Allgäu Region, Bavaria” GAIA-Ecological Perspectives for Science and Society 26.1 (2017): 199-206.

Summary: Publication 3 applies the indicator set developed in publication 1 to the empirical case of the Allgäu region, which is considered as a pioneer region in the German energy transition and is currently entering the mature phase of its sustainability transition. Publication 3 presents empirical results for the analysis of the system configuration, based on an energy flow analysis (EFA) for the technological sphere and a social network analysis (SNA) for the social sphere of the energy transition. In so doing, it applies the same conceptual frame as publication 2, but focuses on a different empirical case and employs different analytical methods. The empirical results show that the social and the technological subsystem are both characterised by high levels of diversity. The connectivity measures are, in turn, only at medium levels for both the social and the technological subsystem. Based on the ideal-type cases, developed in module 1 and statements of the interviewees from the region, the transition progress was evaluated as stagnating. The results from the system structure analysis mirror this in the lacking connectivity, which does not allow to connect new actors and the new technologies to the existing system. Publication 3 shows how the proposed indicators and the system analysis approach do not only deepen system understanding but can also support transition management initiatives.

Conceptual contribution: Similar to publication 2, publication 3 provides empirical evidence for the system’s configuration in a mature sustainability transition and enriches the understanding of both the technological and the social sphere of an energy system. Its main contribution is however a methodological one: with the EFA and the SNA, it presents two complementary methods, which facilitate a more quantitative approach to the analysis of the diversity and connectivity indicators for the technological and the social sphere. The social network analysis approach, based on interview transcripts, provides an innovative and pragmatic approach to achieve a comparable level of quantification for the social sphere. By combining the EFA and the SNA, publication 3 finally presents a standardised set of methods, which supports the measurability of the indicators and provides complementary insights compared those generated with methods proposed in publication 2. These more quantitative approaches allow to collect additional and qualitatively different data and develop a broader database. The interpretation, however, is based on the same theoretical frame as in publication 2, which supports the further empirical underpinning of the conceptual ideas, developed in publication 1 (see Figure 2-5).

Linkage to other publications: Publication 3 is based on the theoretical framework presented in publication 1. It complements the empirical application and findings from publication 2 with an alternative methodological approach and data from a different case study region. Publication 3 draws on system knowledge from Module 3 and deepens the understanding of system structure and transition dynamics in the Allgäu region.

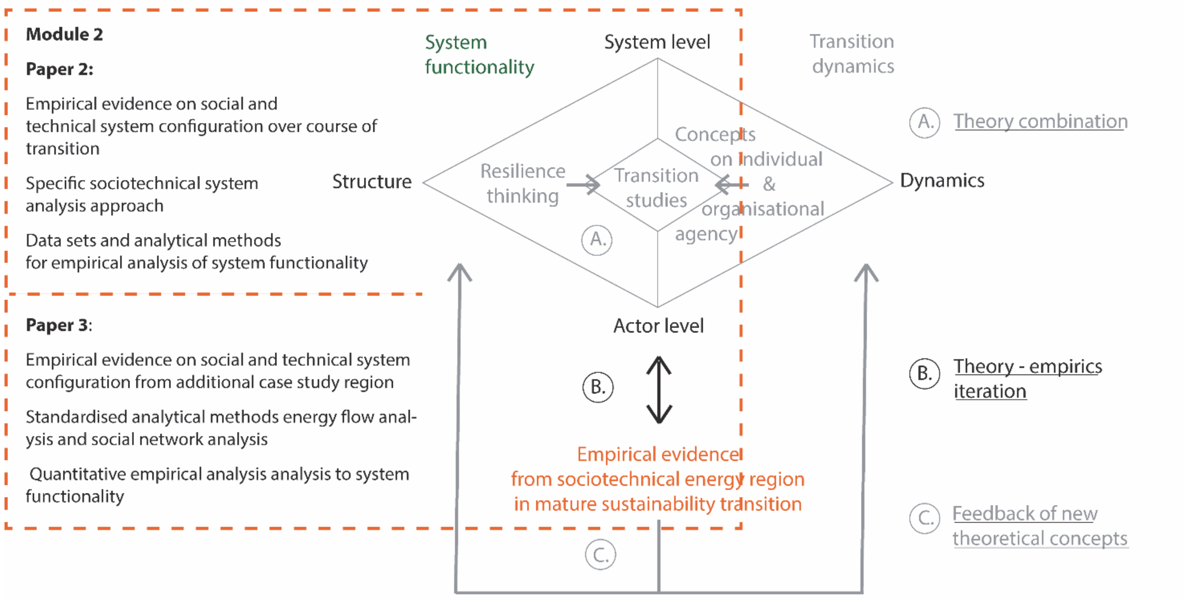

Figure 2-5 Localisation of Module 2 (publication 2 and publication 3) in the general research approach (author's own representation)

2.3.3 Module 3: Advancing the analysis of agency in sustainability transitions of socio-technical energy systems (publication 4)

Module 3 presents a framework for understanding individual's agency, interrelated with the systemic context. The systemic context influences the behaviour of the actors and their agency again influences the system in which they are embedded. This framework is based on a rich system understanding and focuses particularly on the actor-level determinants of individual's agency. Module 3 applies the framework to the empirical case of change agents in a regional energy transition. In doing so, it provides a conceptual and empirical contribution to a better understanding of individual's agency embedded in and interacting with its systemic context as one key driver of transition dynamics.

Publication 4 Mühlemeier, Susan, Romano Wyss, and Claudia R. Binder. "Und Aktion! – Konzeptualisierung der Rolle individuellen Akteurshandelns in sozio-technischen Transitionen am Beispiel der regionalen Energiewende im bayerischen Allgäu" Zeitschrift für Energiewirtschaft 41.3 (2017): 187-202.

Summary: Publication 4 reconceptualises a framework from environmental psychology, the Human-Environment Systems (HES) Framework, for the systematic analysis of determinants of individual's agency and the interaction of agency and system structure in socio-technical systems. Publication 4 first presents the framework, which comprises i) actor-level determinants (goal, strategies and perceptions of the environment) as well as systemic determinants of agency (socio-technical structure on multiple scales), ii) their relation to the actual agency (e.g. through the perception of the environment, which influences goal and strategy) as well as iii) the feedbacks of agency on the system and the related system changes, which are implicitly and explicitly evaluated by the actors and influence agency through learning (for a more detailed description see section 5.3.1). Publication 4 subsequently adapts the framework, which was originally developed for the analysis of socioecological systems, to socio-technical systems, by i) proposing an extended understanding of the environment (considering social, technological and environmental aspects equally), ii) conceptualising multiple scales in the technological sphere of the system (from artefacts to the entire technological system), parallel to the multiple scales of the social and the environmental spheres and finally iii) by conceptualising social interferences (e.g. national regulation interferes with local regulation). In an exemplary application to the case of change agents in the Allgäu region, the publication empirically analyses actor and system-level factors, which influence agency and the ways in which agency affects the system configuration. Finally, publication 4 reflects on possible links of the adapted HES framework to the MLP. In doing so, it shows the accessibility of the HES framework for transition studies and contributes to the advancement of systematic tools for studying agency embedded in its systemic context in mature sustainability transitions (research question 3).

Conceptual contribution: Publication 4 provides a framework for the systematic analysis of agency embedded in a system's context. It provides a holistic framework for the analysis of transition dynamics, which are driven by agency. The framework comprises a complex system understanding, considering system-level dynamics (feedbacks and interferences) and puts a particular emphasis on the multi-scalarity of complex systems, including the dynamics between the different system-levels. This allows for a better understanding of key dynamics and structures of energy systems in mature sustainability transitions. As a second contribution, the complex system understanding also builds the basis of the linkage of the HES framework to the MLP (based on a complex system understanding). By showing how the concept of multiple layers and their regulatory mechanisms of the HES can be linked to the structuration levels of the MLP, it integrates the HES framework in "transitions thinking" and allows to investigate more explicitly the determinants of individual's agency as a key driver of transition dynamics. Finally, the adapted HES frameworks makes a third key contribution, which lies in the conceptualisation of actor-level determinants of agency (goal, strategy, perception of the systemic context and learning processes), as well as the explicit understanding of the interaction of the systemic context with individual's agency (through perception and evaluation of short- and long-term feedbacks). This decisively improves the understanding of agency in the systemic context of sustainability transitions, which was discussed as a weakness in transition studies (see publication 4). Finally, the empirical examples enrich the theoretical considerations with concrete examples for the Allgäu region. The diverse but yet strongly overlapping goals and strategies of the actors, their embeddedness in the "old system" or the high connectivity within the actor network, were all fundamentals of their success in pushing transition dynamics. They help to understand how individual's agency contributes to transition dynamics and how this is dependent on certain actor- and system-level determinants (see Figure 2-6)

Linkage to other publications: Publication 4 draws on the complex system understanding of system structure and dynamics, presented in publication 1. It also provides the empirical system knowledge for publication 3. It develops a conceptual frame for agency embedded in the systemic context and the interaction of system-level and actor-level structure with agency, which publication 5 and 6 take up for organisational agency.

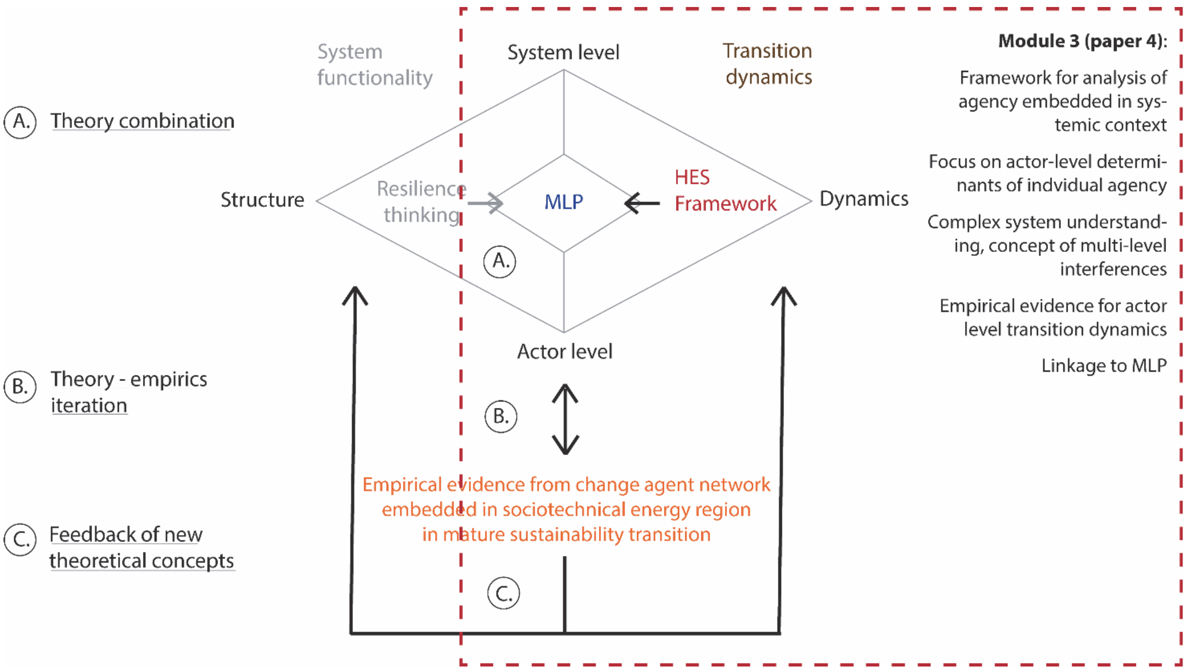

Figure 2-6: Localisation of Module 3 (publication 4) in the general research approach (author's own representation)

2.3.4 Module 4: Improving the understanding of incumbents in sustainability transitions of socio-technical energy systems (publication 5 and publication 6)

Module 4 transfers the agency understanding of module 3 - embedded and interacting with its systemic context - to the organisational level. Module 4 presents important insights from an in-depth empirical study of urban utility companies (UUC) in Germany and Switzerland. Based on the empirical results, it reveals generalised actor- and system-level determinants of the UUC agency and develops theoretical, structural and procedural analytical categories. It deepens the empirical understanding and theoretical conceptualisation of agency in mature sustainability transitions.

Publication 5 Mühlemeier, Susan. „Grosse Stadtwerke - theoretische und empirische Exploration eines besonderen Akteurs in der Energiewende Deutschlands und der Schweiz" Zeitschrift für Energiewirtschaft (2018) DOI: 10.1007/s12398-018-0237-z

Summary: Publication 5 presents key insights of an in-depth, comparative empirical analysis of UUC in Germany and Switzerland. It explores the UUCs' current situation in the mature phase of the energy transition by investigating the structural and cultural characteristics of these companies, their key organisational, economic and political challenges as well as their strategic answers to these challenges. It herewith also sheds light on their role for the overall transition process. Publication 5 unfolds important determinants of the agency of UUC, which are a key actor type in the Swiss and German energy sector and deeply embedded in the existing system structures. This helps to better understand the agency of these actors on the one hand, as well as the more general structures and dynamics in the two (federal) energy systems, on the other. To structure and generalise the empirical findings on the key determinants of UUCs' agency, publication 5 builds on theoretical considerations from the public corporate governance literature as well as the network industries literature and conceptualises UUC as public companies in network industries. Based on this theoretical basis and the empirical insights, publication 5 proposes structural and procedural analytical categories, which summarise the particularities of UUCs' agency in the context of the energy transition: structural (multiple roles of the owner, network industry, federal governance system, multi-utility) and procedural (liberalisation and corporatisation, cultural and organisational change, tensions between market and monopoly organisation). For a more detailed overview see section 5.4.1). Publication 5 reflects on the different roles of UUC for the energy transition and on the influence of their agency on the systemic transition. Finally, publication 5 empirically investigates and theoretically conceptualises key determinants of a key (incumbent) actor in the Swiss and German energy transition and supports the scholarly endeavour of drawing a more nuanced picture of the different types and roles of incumbents (RQ4).

Conceptual contribution: The empirical insights, presented in publication 5, provide a nuanced and enriched empirical understanding of the UUCs' agency. The main conceptual contribution of the publication is the development of analytical categories which are derived from the particular case of UUC, but generally applicable to other public incumbents in the energy sector or other network industries (which are organised through a federal governance structure). These analytical categories capture particularities on the actor-level (public company, multi-utility) as well as on the system-level (federal governance structure, network industry) and allude to transition dynamics on the actor-level (organisational and cultural change) as well as on the system-level (liberalisation, digitalisation). Publication 5 thus takes an actor perspective on transition dynamics in mature sustainability transitions of the energy sector and improves the conceptual understanding of these transitions. This improved understanding also facilitates a more successful management of a mature sustainability transition since the collaboration with the key actors will be more effective. Finally, the empirical evidence presented in publication 5 also alludes to the key roles the UUC play in linking system functionality and transition dynamics on the local level. On the one hand, UUC ensure the system's functionality on the local level (e.g. as network operators). On the other hand, they are pushed to facilitate the sustainability transition on the larger scale, due to their public ownership structure (their linking role is discussed in more detail in section 6.3). Publication 5 contributes to a more nuanced empirical knowledge base and theoretical categories for understanding UUC. These categories are derived from specific cases but have a general validity to understand UUCs' agency as key drivers of transition dynamics in federal energy systems (see Figure 2-7).

Linkage to other publications: Publication 5 transfers the actor- and system-level agency determinants and feedback logic, presented in publication 4 for individual's agency, to the level of organisational agency. Publication 5 draws from the rich system understanding of federal energy governance systems, which was developed in Publication 1, 2 and 3.

Publication 6 Mühlemeier, Susan. Public incumbent actors in network industries – investigating urban utility companies in the German and Swiss energy transition. Environmental Innovation and Sustainability Transitions (EIST) (under review)

Summary: Publication 6 focuses more explicitly on the conceptual contribution of the analytical categories, developed in publication 5. Publication 6 conceptualises UUC as public incumbents in network industries in sustainability transitions. For this, it first explains how the TEF can be applied to investigate the agency of UUC in the systemic context of the energy transition. It elaborates on the theoretical anchoring of the analytical categories in the public corporate governance and network industries literature and shows their explanatory value for the study of UUC, exemplified by concrete empirical examples. Publication 6 also explains the methodological approach of iterative theory building in order for the reader to understand the development process of the analytical categories. Subsequently, publication 6 shows how the analytical categories can be linked to the TEF and made accessible for transition studies. For every analytical category, it shows how they can be linked either in a complementary or an exemplifying manner to the different building blocks of the TEF (for an overview table see publication 6). Publication 6 emphasises that the elaborated analytical categories are thought of as theoretical considerations, which can be employed in addition to but also independently from the TEF. Publication 6 concludes by reflecting on the explanatory value of the TEF together with the analytical categories to understand other public incumbent actors in the energy sector and other network industries (such as telecommunication or railways). This comparative approach paves the way for future comparative studies, which can improve the understanding of their agency. In conclusion, the TEF and the complementary analytical categories jointly provide a holistic framework to analyse in a more accurate way the agency of public incumbents in the systemic context of a transitioning energy sector.

Conceptual contribution: Publication 6 links the analytical categories developed in publication 5 with the TEF and improves the conceptual understanding of the specific actor- and system-level determinants of agency of public incumbents in network industries. The TEF, for example, puts an emphasis on the importance of the regime (the rules) as an integral part of the system configuration. The analytical categories exemplify that this is of particular importance for network industries with their highly regulated natural monopolies and high share of (regulated) public actors. With this linkage, publication 6 provides a holistic framework to understand incumbents' agency in a sustainability transition, which is of general validity but nonetheless appropriate for the particular energy case. By linking the analytical categories explicitly to the building block of the TEF, publication 6 also makes them accessible to the transition studies' discourses. This linkage gives an example of how existing frameworks in transition studies can be tailored to the specificities of the energy sector to understand its mature sustainability. The linkage also encourages the usage of existing theoretical considerations on agency embedded in its systemic context in a complementary manner, to support theory building on transition dynamics in mature sustainability transitions. Finally, publication 6 draws attention to the similarities of public incumbents in the energy sector with other infrastructure sectors and alludes to commonalities of the system structures in network industries. It points out that the comparison of structurally similar sectors and their key actors can help improve the understanding of mature sustainability transitions (see Figure 2-7).

Linkage to other publications: Publication 6 deepens the conceptual understanding of the characteristics, which were developed in publication 5. As publication 5, it adds the actor-specific perspective on mature sustainability transitions to the mainly system-focussed perspective in publications 1, 2 and 3, while considering actor- and system-level determinants equally.

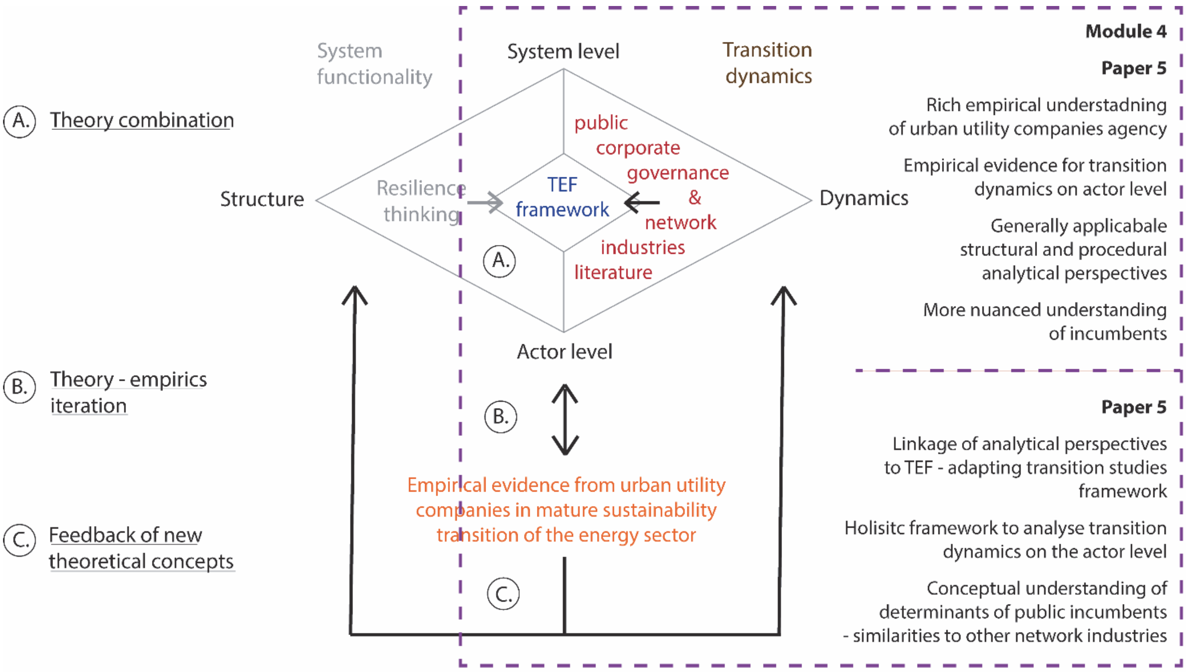

Figure 2-7: Localisation of Module 4 (publication 5 and publication 6) in the general research approach (author's own representation)

In conclusion, Figure 2-8 presents an overview of the conceptual contribution of the modules and the individual publications. Module 1 contributes on a theoretical level to the conceptualisation and operationalisation of system functionality. Module 2 contributes on the empirical level to the analysis of system functionality. Module 3 contributes on the theoretical and empirical level to the conceptualisation of individual's agency for transition dynamics. Module 4 contributes on the theoretical and empirical level to the conceptualisation of incumbents' organisational agency for transition dynamics.

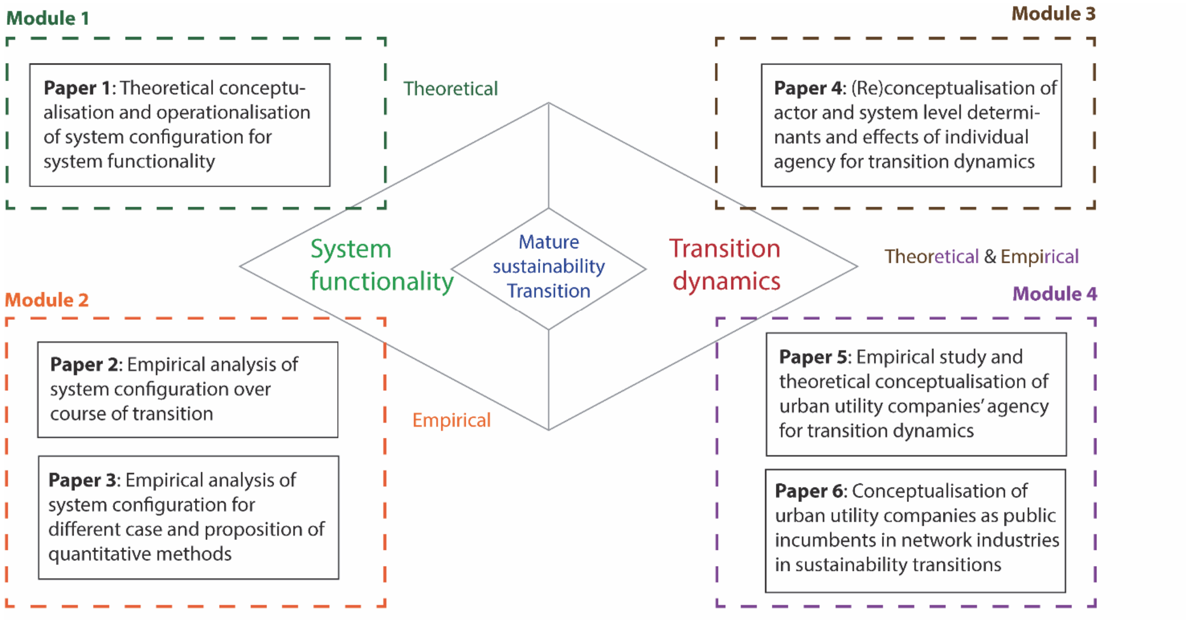

Figure 2-8: Overview on conceptual contribution of modules and individual publications (author's own representation)

Chapter 3 Methodology

The subsequent chapter first presents the dissertations' overarching methodological approaches iterative theory building and mixed-methods analysis (section 3.1). Subsequently, it explains the data collection methods of primary and secondary data (section 3.2) as well as the analytical methods (general – applied in all modules and specific – applied in individual modules) of this dissertation (section 3.3). Finally, it provides a detailed overview on the implementation of each individual module (section 3.4).

For a graphical summary of the methodological implementation of this dissertation see Figure 3-9.

3.1 Methodological approaches

3.1.1 Iterative theory building

Iterative theory building is a methodological approach to develop hypotheses and mid-range theories, based on an iteration of theoretical and empirical analyses and interpretation of related findings (Kerssens-van Drongelen, 2001; Miles and Huberman, 1994, p. 12; Eisenhardt, 1989). Kerssens-van Drongelen (2001) exemplifies that theory building in general has three steps: exploration, explanation and validation. These three steps are also true for iterative theory building. She describes that in iterative theory building these three steps happen in several iterative cycles. Such a cycle comprises a sequence of literature search, provisional research propositions, empirical analysis, reflection, literature search and finally a first provisional theory building. The second cycle starts again with a refined research proposition, is followed by another empirical analysis, reflection, literature search and refined theory building. These cycles can be repeated as often as necessary (for a graphical overview see (Kerssens-van Drongelen, 2001, p. 505)). Her key message is that theory building is not done before the execution of the empirical research, but it is rather done in parallel. The same is true for theory validation, which is not solely done at the end but is integrated into the research process (Kerssens-van Drongelen, 2001, p. 503). Iterative theory building is therefore closely related to theory building from case study research (Kerssens-van Drongelen, 2001). Iterative theory building is employed in areas and contexts in which a certain level of prior knowledge, frameworks and theories exists, which, however, are not yet sufficient to describe and understand the object of research (Eisenhardt, 1989, p. 548).

Iterative theory building is rooted in the tradition of grounded theory, which was originally coined by Glaser and Strauss in their seminal work "the discovery of grounded theory" first published in 1967 (Glaser and Strauss, 1999). Grounded theory describes the process of inductive theory building, starting the investigation of a research question from the open analysis of empirical evidence. By employing theoretical sampling, grounded theory scholars continuously build theoretical categories based on the collection, the structuring and subsequent interpretation of the empirical findings. Hence, grounded theory scholars start their inductive theory building process with no or (at least) little pre-existing theoretical concepts, continue several rounds of interpretation of empirical findings, theory building and re-analysis of empirical evidence until "the point of saturation" is reached (Flick, 2009, p. 428). For new areas of research and new empirical fields, this allows the development of solid theories, grounded on rich empirical evidence, which is fitting the empirical case, is understandable, general and allows for control in everyday life: "[it] must enable the person, who uses it to have enough control in everyday situations to make its application worth trying it" (Glaser and Strauss, 1999, p. 245). While also emphasising the iterative character of theory building processes, which are based on empirical evidence, iterative theory building, however, explicitly acknowledges the pre-existence of knowledge, theories and frameworks and does not "start from zero".

Iterative theory building is very suitable for the scope of this dissertation, for which indeed a rich palette of pre-existing conceptualisations and frameworks is available (as presented in section 2.1), but which were not yet applied and re-conceptualised for i) the empirical context of socio-technical energy systems in transition, ii) the systematic analysis of an agency in transitions as well as iii) the more nuanced understanding of incumbents in socio-technical energy systems in transition. For all these areas, theory building, respectively conceptualisation is needed and is provided by this dissertation, acknowledging the already existing rich theoretical basis. In this context, Iterative theory building builds the key methodological approach of this dissertation.

3.1.2 Mixed-methods analysis

As mentioned earlier, iterative theory building is largely based on empirical analysis and its findings, for which a mixed-methods approach has been applied in the context of this dissertation. Mixed-methods approaches employ qualitative and quantitative data bases and methods as well as several qualitative - or quantitative – methods. This process is called triangulation (Flick, 2009; Miles and Huberman, 1994). Mixed-methods approaches are rooted in the pragmatic research tradition. Pragmatism scholars propose the combination and integration of qualitative and quantitative data and methods as a third way in research and as a possibility to overcome the orthodoxy of either purely qualitative or purely quantitative research (Flick, 2009). Based on Rossman and Wilson (1991), Miles and Huberman (1994) mention three reasons for mixed-methods approaches: "triangulation", "richer detail" and "to initiate new lines of thinking" (Miles and Huberman, 1994, p.41). Miles and Huberman (1994) propose three main levels of mixed methods approaches: "quantizing" (qualitative data are quantified), "linkage" (qualitative and quantitative data are compared) and "study design" (qualitative and quantitative methods are combined on the level of the overall research design). Regarding this combination on the research design level, they propose four archetypes of mixed-methods research designs which can be grouped in two areas based on their order of application: parallel order (e.g. case study analysis, where qualitative methods and data sources are conducted and collected for one common case study description) or consecutive order (e.g. qualitative hypothesis general, quantitative hypothesis-check, qualitative interpretation) (Miles and Huberman, 1994). Flick (2009) presents eleven ways of qualitative-quantitative integration based on Bryman (1992) and points to the ongoing debate in the "qualitative-quantitative" problem. However, what started in the 1980ies as a philosophical debate, nowadays is a debate of methodological appropriateness for different research objectives and questions.

In the context of this dissertation, a mixed-methods approach to empirical research was employed, to serve the aim of gaining richer empirical evidence and respective insights as well as to initiate new lines of thinking and thus supporting the iterative theory building process. It was mainly implemented through linkage (the comparison of qualitative and quantitative data) and a parallel order research design.

3.2 Data collection methods

3.2.1 Primary data: Results of semi-structured expert interviews and group discussions

Semi-structured expert interviews

Semi-structured expert interviews are a specific type of qualitative interviews, whereby expert interviews are conceptualised as a subgroup of more general semi-structured interviews (Flick, 2009, p. 165; Meuser and Nagel, 1989). Semi-structured interviews are based on interview outlines which structure the interview, but also allow for spontaneous additional questions as well as changes in the order of the questions. Semi-structured interviews allow for "open questions" as well as for "theory-driven questions" (Flick, 2009, p. 153). In expert interviews, interviewees are considered as experts, meaning "persons, who are particularly competent as authorities on a certain matter of facts […] Experts have technological process oriented and interpretive knowledge referring to their specific professional sphere of activity. Thus, expert knowledge does not only consist of systematised and reflexively accessible specialist knowledge, but it has the character of practical knowledge in big parts" (Flick, 2009, p. 166). Expert interviews can be employed for "exploration", the "collection of context information" or "theory-generation" (Flick, 2009, p. 166; Bogner and Menz, 2002, pp. 36–38). The standard procedure of collecting primary data through semi-structured expert interviews comprises the following steps: interview outline design, sampling of interviewees, conduction and documentation of interviews, transcription.

The actual data basis, thus, consists either of notes or audio- or film-records and their transcripts. Transcripts are the written representation of oral and/or visual data (Kvale and Brinkmann, 2009, p. 178) and can be produced in different ways. According to their level of detail these range from selective, summarising protocols with a low level of detail to "pure verbatim protocols", word by word protocols, which can also contain additional information on the context of the claims (e.g. "long silence before answering") (Mayring, 2014, p. 45; Höld, 2009; Kvale and Brinkmann, 2009, p. 180).

In this dissertation, several rounds of semi-structured expert interviews were conducted, based on pre-defined outlines, which were developed based on theoretical concepts and empirical evidence from structural data on a regional level and documents (see section 3.2.2). The interviews were conducted aiming for exploration and collection of the context knowledge of actors (case-specific insider knowledge on the energy transition). Interviewees were contacted based on snowball sampling. Per interview series, the same interview outline was used for all interviewees. The interviews were conducted with researchers and decision makers from industry, politics, associations, consultancies and NGOs, face to face, in neutral meeting rooms in the experts' offices to allow for a maximum of comfort and time efficiency for the interviewees. The interviews were conducted in an open dialogue, encouraging critical thoughts and open answers. The interviews were recorded and anonymised, to support an open and secure atmosphere for the interviewer and the interviewees, in line with generally accepted interviewing ethics (Kvale and Brinkmann, 2009, pp. 61–79). The recordings were transcribed in anonymised word by word protocols, respectively summarising protocols for module 4, using the text analysis software MAXQDA (www.maxqda.com)

Group discussion

The group discussion represents a particular type of qualitative data collection, which "stimulates a discussion and uses its dynamic of developing conversation in the discussion as the central source of knowledge" (Flick, 2009, p. 196). Group discussions are used to create a “more natural environment, which corresponds to the way in which opinions are produced, expressed, and exchanged in everyday life. Another feature of group discussions is that corrections by the group concerning views that are not correct, not socially shared, or extreme are available as means for validating statements and views” (Flick, 2009, p. 197). Group discussions are thus generally used for the analysis of collective opinion or opinion building processes and can be employed for exploration, explanation or validation of empirical findings and their interpretations. The sampling of the group can either result in a “natural group” (people who also act together in daily life) or as an “artificial” group (sampled by the researcher), which consist of homogeneous or heterogeneous group members (Flick, 2009, pp. 197–198). An additional important aspect of group discussions is the role of the moderator (be it the researcher or a different person). The moderator can guide the group in different ways, according to its level of influence on the group discussion: “formally” (only steering the agenda), “topical” (steering the topics of the discussion) or by “steering the group dynamics” (e.g. by asking provocative questions or actively including less involved persons) (Flick, 2009, p. 199)

In this dissertation, group discussions were used for the validation of empirical results from previous research steps and their interpretation in the context of an expert workshop. The group was sampled as an artificial, heterogeneous group, including previously interviewed experts and non-interviewed experts for triangulation. The group moderation was carried out by the author of the thesis in a formal and topical way for different parts of the expert workshops. The results of the group discussions were recorded and documented by two colleagues (written protocols) in an anonymised form and transcribed in a summarising manner.

3.2.2 Secondary data: scholarly literature and structural data

Scholarly literature

Scholarly literature comprises peer-reviewed journal articles and book chapters, as well as conference publications and dissertations (Hart, 2018, p. 35). In this dissertation project, scholarly literature was accessed from the university libraries of the Ludwig-Maximilians-Universität München (February 2015 – February 2016) and the Ecole Polytechnique fédérale de Lausanne (from March 2016). The sampling was conducted in an iterative process, employing two steps: First, an online data base search (library catalogues, web of science and google scholar), which was informed by the research questions and helped to develop the conceptualisations of interest. Second, a snowball sampling search of literature, based on the references in publications identified in the first step. The scholarly literature was collected, structured and analysed using the literature management softwares CITAVI (www.citavi.com) and ZOTERO (www.zotero.org)

Structural data

Documents and structural data in general are mainly used to obtain supplementary information on the research object as well as on its context (Bowen, 2009, p. 29). Structural data in this dissertation consisted of regional structural data and documents on the empirical cases and their contexts. Regional structural data in this dissertation comprised mostly quantitative data on characteristics of a region (e.g. demographic data, employment and economic data, resource or ecological data) and official statistics on regional energy production (e.g. resources and technologies, capacities) as well as economic data (e.g. regional industry branches). All the employed structural data were freely available data. It was sampled in a non-schematic way, according to the needs in the individual modules. Documents represent a wide range of data. They can include letters, minutes, event reports, administrative of firm reports and news publication clippings (Yin, 2003, p. 86; Bowen, 2009, p. 27). Documents used in this dissertation were administrative reports, firm reports, sectoral reports, webpages of organisations, maps on electricity grids and heat networks as well as news publication clippings.

3.3 Data analysis methods

The subsequent section first presents general data analysis methods, which were used in all four modules of this dissertation and second, specific data analysis methods, which were only employed for module 2. In parallel to section 3.2, the general analysis methods are subdivided in analysis methods for primary data and analysis methods for secondary data.

3.3.1 General data analysis methods: structuring qualitative content analysis, document analysis and structuring qualitative content analysis

Primary data analysis: Structuring qualitative content analysis and theoretical coding of interview transcripts

“The central idea of Qualitative Content Analysis is to start from the methodological basis of Quantitative Content Analysis but to conceptualise the process of assigning categories to text passages as a qualitative-interpretive act, following content-analytical rules.

In this respect, the Qualitative Content Analysis is a mixed methods approach: assignment of categories to text as qualitative step, working through many text passages and analysis of frequencies of categories as quantitative step" (Mayring, 2014, p. 35). Qualitative content analysis has its roots in quantitative, software-based text analysis, which originally stems from communication science. The original goal was to analyse the increasing media data, which exponentially grew with the development of digitalisation (Mayring, 2014, p. 18). As mentioned before, key steps and concepts of qualitative content analysis is the development of categories (codes), their definition (in memos) and the process of assigning passages of the analysed text (codings) to the codes (Flick et al., 2004, pp. 266–269). This coding procedure can be conducted in an inductive way (codes are built on emergent patterns from the text – "data driven" coding) or a deductive way (codes are derived from theory or pre-existing knowledge – "concept driven" coding) (Gibbs, 2008). Qualitative content analysis is nowadays widely used for the analysis of interview transcripts and is especially suitable for the analysis of semi-structured interviews (Flick et al., 2004, pp. 253–258).

Mayring (1991) differentiates three types of qualitative content analysis: explaining (enriches text with additional material and thought for interpretation), summarising (summarises the text to the key messages) and structuring qualitative content analysis (structures the text according to key aspects). The steps of a structuring qualitative content analysis are the following: development of a code schema (theory based), definition of codes (code descriptions), pre-test of codes with a representative set of material, if necessary, revision of code scheme, coding of entire material, and finally the analysis of the results (e.g. quantification, grouping, mapping of codes and codings) (Mayring, 1991, p. 212). Althouhg structuring qualitative content analysis indeed belongs to the "concept driven" coding procedures, it allows for refinement of the codes based on the empirical analysis in the testing phase. It perfectly fits the iterative theory building process, since it acknowledges pre-existing concepts and allows for the development of new concepts.

In this dissertation, the structuring qualitative content analysis was employed for all interview transcript analyses, using the text analysis software MAXQDA. The code schemes were developed based on results of prior explorative literature analyses or empirical analyses, except for one open coding procedure in Module 3. The codes were discussed with colleagues, defined in memos for the coding procedure, tested and revised. During the coding process, the pre-existing codes were further differentiated with sub-codes, which allowed to mirror the diversity of the findings. Additional interesting findings were collected in an extra code ("additional findings"). The results were analysed, employing the mixed-methods approach through graphical representation of the codes (MAXQDA mapping tool MAXmaps), a counting of coding frequencies and summarising descriptions of the findings per codes. The results were used for concept development (exploration) and the exemplification of concept operationalisations (explanation and validation).

Secondary data analysis: Qualitative literature analysis

Qualitative literature analysis describes the process of analysing scholarly literature for literature reviews or "understanding of arguments in research" (Hart, 2018). This also includes the development of conceptual frameworks and theory building. Hart (2018) describes the following general steps of literature analysis processes: definition of search categories and key words, based on research questions, literature searches and collections, readings, analyses of arguments and if necessary an iteration of the process. Randolph (2009) seconds Hart's steps also for qualitative literature analysis processes. Based on Gall et al. (1996), he further exemplifies the step of analysis as i) the identification of theoretical constructs, ii) development of hypothetical linkages among them, iii) search for rival concepts and iv) "use colleagues or informants for corrobation" of the results (Randolph, 2009, p. 10). A qualitative literature analysis is, thus, an iterative process and can be used in every phase of a theory building process.

In this dissertation, qualitative literature analyses were integral part of the iterative theory building approach. They were employed i) to reveal conceptualisations, structuring and generalisation of the empirical findings, ii) for the identification of frameworks for empirical analysis (exploration) as well as iii) their operationalisation for the particular context (explanation). The analyses were conducted using a two methods key-word based sampling and snowball sampling in an iterative way. The results of the reading and analysis processes were documented and evaluated in scholarly discussions with colleagues.

Document analysis of structural data

"Document analysis is a systematic procedure for reviewing or evaluating documents […] [D]ocument analysis requires that data be examined and interpreted in order to elicit meaning, gain understanding, and develop empirical knowledge (Corbin and Strauss, 2008; Rapley, 2007)" (Bowen, 2009, p. 27). Document analysis is used for different purposes, including triangulation or the development of rich empirical evidence in the context of qualitative case study analysis and thus belongs to the classical instruments of case study research (Bowen, 2009, p. 29; Yin, 2003). Bowen (2009, p. 32) describes three general steps of document analysis: "skimming (superficial examination), reading (thorough examination), and interpretation". He explains that document analysis comprises two analytical approaches: content analysis (the organisation of information in categories – sorting) and thematic analysis (the recognition of emerging patterns and the construction of categories – interpretation) (Bowen, 2009, p. 32).

In this dissertation, document analysis was applied to analyse the empirical cases and for a better understanding of contexts (e.g. legal bases) (exploration and explanation), as well as for triangulation of the interview data (validation). Document analysis was not only applied to documents (as defined above in section 3.2.2) but also as a qualitative analysis for regional structural data, e.g. to get a better understanding of energy technologies used. The quantitative data were thus analysed in a descriptive manner to complement pure text data and ensure an equal representation of the technological and social sphere of the energy system under study.

3.3.2 Specific data analysis methods: Mental model analysis and social network analysis

Mental model analysis

"Mental models can be defined as pre-existing mental constructs through which people decipher information and understand the environment […] They provide a heuristic function by allowing information about situations, objects, and environments to be classified and retrieved in terms of their most important features (Cannon-Bowers et al., 1993, p. 226)" (Otto-Banaszak et al., 2011, p. 218). "Mental models are shared by communication […] and help to reduce uncertainties in decision-making by structuring expectations about behaviour of other individuals and the environment (Denzau and North, 1994, pp. 7–8)" (Otto-Banaszak et al., 2011, p. 219). Mental models are used in various disciplines to analyse shared, or conflicting perceptions on the individual and collective level (Schöll and Binder, 2009; Johnson-Laird, 1983). In socio-ecological system sciences, mental model analyses are conducted through cognitive mapping approaches (Vanwindekens et al., 2013; Özesmi and Özesmi, 2004), which represent individual and collective mental models in cognitive maps.

In module 2 of this dissertation, the Cognitive Mapping Approach for Analysing Actors' Systems Of Practices (CMASOP) by Vanwindekens et al. (2013) was employed to analyse the mental models of the regional experts on the regional energy governance system. The CMASOP proposes four steps: conducting qualitative interviews, coding the interview transcripts, deriving individual cognitive maps and merging of the individual maps to a common "social cognitive map" (Vanwindekens et al., 2013, p. 335). On the one hand, this approach allows to reveal subjective mental maps with a high level of validity on the individual level, and on the other hand, it facilitates the deduction of an inter-subjectively shared mental model of the regional governance system, which can be used for the system-level analysis of the social sphere of an energy governance system (Vanwindekens et al., 2013). The CMASOP combines the depth of individual perception with the breath of a "merged perception". The CMASOP was used in publication 2, based on a structuring qualitative content analysis on pre-existing interview transcripts and complentary "concept maps" (as graphical representations of mental models) (Johnson et al., 2006), which were developed with experts in semi-structured interviews in 2016. For further details, see publication 2.

Social network analysis

"Social Network Analysis (SNA) is a technique allowing the systematic quantitative and qualitative analysis of the links amongst actors in various contexts (Scott et al. 2009), helping to understand how the system in which those actors operate functions (Wasserman and Faust 1994)" (Kelman et al. 2016, p. 2). Social networks consist of nodes, representing entities – e.g. actors, physical or non-physical artefacts – and links, which represent the type of connections among nodes, e.g. personal contact, information exchange but also capital flows. "SNA provides useful formal tools […] for characterising networks of individuals or collectives and the strength and distribution of links within those networks" (Kelman et al. 2016, p. 2). Wasserman and Faust (1994, p.731) subdivide social networks according to i) the types of their nodes (one-mode networks have nodes of similar characteristics; two-mode networks comprise nodes of different character (e.g. actors and artefacts)) and ii) the way data were collected for the social network analysis (ego-centred networks are based on individual nodes and their links, full sample networks consist of all "all possible nodes and links of a given system".

In the context of this dissertation, a social network analysis was employed in module 2 to analyse and quantify the social sphere of the regional energy system (publication 3). Actors and organisations as well as their interrelations were identified from expert interview transcripts (Module 3). The transcripts where thus quantified, as proposed in the mixed methods approach (see section 3.1.2). The nodes consisted of actors and organisations, which were treated equally in an one-mode network (Wasserman and Faust, 1994, p. 36). A link among two nodes existed if either two actors knew each other or were members of the same organisation, respectively, an organisation member or owner of another organisation. The network representation and analyses were conducted using the software package VISONE (http://www.visone.info).

Module	Module 1	Module 2	Module 3	Module 4
Research Questions	RQ1: "How to conceptualise and operationalise resilience of sociotechnical energy systems in transition?"	RQ2: "How to empirically analyse the resilience of sociotechnical energy systems in transition?"	RQ3: "How to improve the systematic analysis of agency in sustainability transitions of sociotechnical energy systems?"	RQ4: "How to improve the empirical and theoretical understanding of incumbents' diversity and roles in sustainability transitions of sociotechnical energy systems?"
Data basis Analysis	• Data basis: Scholarly literature on resilience and transition studies, regional structural data, transcripts of 22 pre-existing and 2 additional expert interviews • Analysis: Qualitative literature analysis on resilience indicators for socio-technical systems, document analysis of regional structural data and expert interviews	• Data basis: Regional structural data , energy flow analysis data, transcripts of 22/14 expert interviews with regional actors, conceptual models of actor network • Analysis: Document analysis of regional structural data, structuring qualitative content analysis of interview transcripts, social network analysis, conceptual model analysis	• Data basis: Scholarly literature on agency conceptualisation and frameworks in transition studies and related fields, regional structural data, transcripts of 14 expert interviews • Analysis: Qualitative literature analysis, open coding of interview transcripts, structuring qualitative content analysis of interview transcripts, document analysis of regional structural data	• Data basis: Scholarly literature on incumbent agency in transition studies, organisational studies, network industries and public corporate governance, documents (sectoral and annual reports) transcripts of 38 expert interviews, results from group discussions • Analysis: Qualitative literature analysis, structuring qualitative content analysis of documents and transcripts, analysis of workshop results
Empirical cases	Energy region Weiz-Gleisdorf, Austria; ökoEnergieland, Austria	Energy Region Weiz-Gleisdorf, Austria; Allgäu region, Germany	Change agents in the Allgäu Region, Germany	Urban utility companies in Germany and Switzerland
Outcomes	• **Conceptualisation** and **operationalisation** of resilience for sociotechnical energy systems in transition • Development of **indicator set** and related **measures** for empirical analysis • Discussion of **meaning of indicator constellations** for resilience	• **Empirical application** and discussion of indicator set • **Empirical analysis** of energy regions • Presentation and discussion **of methods & data bases** for empirical application	• Re-conceptualisation of **agency framework** for sociotechnical energy systems in transition • **Empirical application** to change agents network • Discussion of integrability in transition studies through **linkage to MLP**	• Transition studies framework-based empirical analysis of **urban utility companies** • Development of **analytical perspectives** for public incumbents in network industries • Discussion of integrability in transition studies through **linkage to TEF**
Outputs	**Manuscript 1:** «An indicator-based approach for analyzing the resilience of transitions for energy regions. Part I: Theoretical and conceptual considerations»	**Manuscript 2:** «An Indicator-Based Approach... Part II: Empirical Application for the Case of Weiz-Gleisdorf, Austria» **Manuscript 3:** «"It's an Endurance Race" ... Transition in the Allgäu Region, Bavaria»	**Manuscript 4:** «Und Aktion! – Konzeptualisierung der Rolle individuellen Akteurshandelns in sozio-technischen Transitionen am Beispiel der regionalen Energiewende im bayerischen Allgäu»	**Manuscript 5:** «Grosse Stadtwerke - ... Exploration eines besonderen Akteurs in der Energiewende ...» **Manuscript 6:** «Public incumbent actors in network industries ...»

Figure 3-9: Overview on four modules, research questions, data bases, analytical methods, outcomes and related publications

3.4 Methodological implementation of the individual modules

The subsequent sections present the implementation of the methods discussed above in all four modules. All subsequent sections first present the implementation of the overall methodological approaches, i) iterative theory building and ii) mixed method analyses and then iii) the data bases, iv) data analysis methods and v) the empirical case used in the module (the detailed description of the empirical cases follows in chapter 4). For module 2 and 4, which consists of two publications, the section first presents the methodological commonalities, which apply for both publications and subsequently presents the differences for the individual publications. This procedure has been chosen to avoid redundancy in the description and better show the specifics of the individual publications. For an overview on the individual publications see also Table 3-1.

3.4.1 Module 1: Conceptualisation and operationalisation of resilience (publication 1)

Iterative theory building In order to explore theoretical conceptualisation, a qualitative literature research on scholarly research of resilience operationalisation was conducted. The results were structured and interpreted in several rounds of scholarly discussions with the co-authors of publication 1. In parallel, the empirical evidence for the case study regions was explored through an explorative analysis of the empirical data (interview transcripts and structural data). These explorative theoretical and empirical investigations resulted in the development of an indicator set and related measures. For explanation, the indicators were operationalised individually for the social and the technological sphere of energy systems, based on document analyses of the pre-existing interview transcripts and structural data. The findings were again discussed and refined in several rounds of scholarly discussion. For validation, the indicators, measures and their operationalisation for socio-technical energy systems were presented and discussed at several conferences (see bibliography). In particular, their operationalisation was discussed with experts from the case study region during the two semi-structured expert interviews with regional grid operators.

Mixed methods analysis In publication 1, qualitative data (scholarly literature, interview data) was used in parallel to quantitative data (structural data on energy system), employing several qualitative methods for triangulation (interpretative literature analysis, document analysis, scholarly discussion, semi-structured expert interviews).

Data basis Scholarly literature on ecological, engineering, socio-ecological and social resilience conceptualisations as well as on specific resilience measures for energy systems was analysed. Regional structural data, including energy production data for the energy regions Weiz-Gleisdorf and ökoEnergieland, collected during the TERIM project (Binder and Posch, 2014) (see section A.1.1 structural data on energy regions in appendix), the energy regions' webpages as well as additional online information on actors and organisations in the region, were employed. Pre-existing interview transcripts from 22 semi-structured expert interviews with key actors of the regional energy governance systems, conducted in 2011 in the TERIM project were analysed. In these interviews, interviewees were asked for their perception of the evolution of the energy transition in the region, key actors in the transition process and their relations to these actors. Additionally, transcripts from two semi-structured expert interviews with grid operators in the region, conducted in 2017 (see section A.1.3 Interviewee list in appendix) were analysed, where the grid operators were asked for a critical evaluation of the indicator set developed by the authors (see section A.1.2. in appendix).

Data analysis methods A qualitative literature analysis was conducted, revealing the different resilience concepts and operationalisations for energy systems – for their technological and social sphere. A document analysis served for the exploration of the regional energy system and the operationalisation of the indicator set. This comprised the analysis of regional structural data (mainly for technological sphere), as well as the analysis of pre-existing interview transcripts (mainly for social sphere).

Empirical Case Energieregion Weiz-Gleisdorf, ökoEnergieregion – Austria

3.4.2 Module 2: Empirical analysis of resilience of energy regions in transition (publication 2 and publication 3)

Iterative theory building For further explanation of the conceptualisation and operationalisation developed in module 1, an in-depth empirical analysis of the indicators was conducted for the socio-technical energy system in the two case study regions.

<u>Publication 2</u> presents a longitudinal study for the Energieregion Weiz-Gleisdorf, based on structural data, interview transcripts and a mental model analysis, emphasising the transition aspect, which however remained descriptive for the social sphere.

<u>Publication 3</u> presents a study for one point in time for the Allgäu region, based on structural data, interview transcripts and social network analysis. It provides an attempt to quantify the measures for the social sphere.

For validation, semi-structured expert interviews and numerous rounds of scholarly discussions with the co-authors were carried out, which provided the refinement of the indicators' operationalisation for the social and the technological sphere, as well as a deepened understanding of the meaning of the indicator's characteristics and constellations in explaining resilience.

Mixed methods analysis Qualitative data (pre-existing interview transcripts) and quantitative data (structural data on the energy system, energy flow analysis) were analysed in parallel with qualitative methods (content analysis, mental model analysis), quantitative methods (calculation of measures for technological sphere) as well as quantifying methods (social network analysis). In addition, the results were discussed with experts (semi-structured interviews). The mixed-methods approach in module 2 (publication 2 and publication 3), thus, aimed more for integration of qualitative and quantitative data.

Data basis Both publications are based on online information on regional organisations.

Publication 2: Structural data were employed, including energy production data from the TERIM project (see module 1), official energy statistics of Styria (Statistik Austria, 2016), grid maps from grid operators (www.e-steiermark.com) and online information on local district heating networks (Das Land Steiermark, 2016). Publication 2 is based on interview transcripts of semi-structured expert interviews conducted in 2011 (see module 1) and seven additional experts from the Energieregion Weiz-Gleisdorf conducted in 2016 (see section A.2.1 interview outline and section A.2.2 interviewee list in attach). The seven additionally interviewed experts were asked for their mental models of the regional governance system and its changes over time (see section A.2.4 mental model analysis data in appendix). Two additional experts were asked for data on the technological sphere and their evaluation of the changes in the technological sphere of the system.

Publication 3: Publication 3 is based on energy flow analysis data for the Allgäu region (conducted by Master student Bärbel Hinterberger (Hinterberger, 2016) (see section A.2.5 energy flow analysis graph in appendix) as well as interview transcripts of semi-structured expert interviews conducted for module 3 (see module 3)

Data analysis methods In both publications, the empirical analysis of the indicators was based on a document analysis of regional structural data (mainly for the technological sphere) as well as a structuring qualitative content analysis of interview transcripts (for social sphere) (see section A.2.3 code scheme in appendix).

Publication 2: Additionally, a mental model analysis was conducted for publication 2 (based on graphical representations) to derive the system structure of the social sphere.

Publication 3: Additionally, a social network analysis was conducted for publication 3 (based on quantification of social relations, mentioned in interview transcripts) (see section A.2.6 social network analysis data in appendix).

Empirical case Energieregion Weiz-Gleisdorf – Austria; bayerisches Allgäu - Germany

3.4.3 Module 3: Reconceptualised agency framework for socio-technical systems (publication 4)

Iterative theory building For exploration of the regional energy transition process and its actors, the interviews conducted with change agents from the region were analysed and coded in an open, inductive process. The results were structured based on scholarly discussions and the open analysis of structural data for the region. In parallel, a qualitative literature analysis of scholarly literature on agency conceptualisations (actor-structure-system interaction) in transitions studies and related fields was conducted in order to explore how agency embedded in the systemic context can be conceptualised. The theoretical and empirical exploration resulted in the identification of the HES framework for the analysis of individual's agency. For explanation (second step in iterative theory building), the HES framework was re-conceptualised for socio-technical systems and empirically applied to the case study region. In this context, a second, framework-based structuring qualitative content analysis of the interview transcripts and the structural data were conducted. For validation, the general empirical applicability of the re-conceptualised framework was discussed in publication 4 – as well as its integrability with the MLP and to the wider context of transition studies.

Mixed methods analysis In module 3, qualitative data (scholarly literature, interview transcripts, structural data) and quantitative data (structural data) were compared in parallel order, based on qualitative analysis methods (interpretative literature analysis, content analysis, qualitative content analysis, open coding) for the empirical analysis. Moreover, different qualitative methods were used in sequential order for triangulation in the theory building process (literature analysis, qualitative content analysis).

Data basis Scholarly literature on agency conceptualisations and frameworks for empirical analysis of agency (actor- and system-level determinants, systemic feedback) in transition studies and related fields was analysed (such as institutionalism, evolutionary economics, science and technology studies and sociology). Regional structural data, information on shares of renewables over time (Bayerische Staatsregierung, 2017), major regional milestones and legal bases (Mühlemeier et al., 2015) was analysed. Transcripts of 14 semi-structured expert interviews were utilised - conducted in 2014 and 2015 with regional change agents from industry, administration and associations (see section A.3.2 interviewee list in appendix), asking for their perception of the regional transition process, drivers and barriers as well as their individual role in the transition process and personal motivations and learning processes (see section A.3.1 interview outline in appendix). Additionally, survey results from a study of societal perceptions of the regional energy transition and the pioneers (Mühlemeier and Knöpfle, 2016) complemented the knowledge on the regional energy system, in a non-systematic, informative way.

Data analysis methods A qualitative literature analysis on agency conceptualisation was conducted as well as a document analysis of regional structural data and open coding of interview transcripts (revealing emergent patterns and sorting them). They built the basis, for the structuring qualitative content analysis of interview transcripts, which was conducted in a second step, based on the framework-categories (see section A.3.3 code scheme in appendix).

Empirical case Change agents network – bayerisches Allgäu

3.4.4 Module 4: Incumbents in the energy transition – analysing urban utility companies (publication 5 and publication 6)

Iterative theory building For exploration, the results from the literature analysis conducted in module 3 were complemented with results from a literature analysis of conceptualisation of incumbents and agency in organisational studies. The TEF (Geels, 2014) was identified as suitable for the analysis of organisational agency of incumbents in transitions. Based on the conceptual building blocks of the TEF, the exploration of the UUC as a specific actor type was conducted. For this purpose, a document analysis of structural data were conducted, together with a structuring qualitative content analysis of the interview transcripts. This exploration resulted in the identification of a decisive lack in the conceptualisation of the actor-specific factors in the TEF. A second round of exploration (first step of the iterative theory building process) was conducted, based on a literature analysis of public corporate governance, state-owned enterprises and network industries.

<u>Publication 5:</u> For explanation, publication 5 presents structural and processual analytical categories, which were conceptualised and operationalised, based on the results of this second literature analysis as well as the results of the empirical analysis (structural data and interview transcripts).

<u>Publication 6:</u> Publication 6 discusses the explanatory value of the TEF, as well as the value of the additional research strands. Second, it discusses the linkage of the newly developed analytical categories to the TEF.

For validation, the analytical categories were revised in scholarly discussions with experts from network industries. The empirical findings were discussed during the expert workshops, putting a particular focus on the role of UUC for the energy transition.

Mixed methods analysis In module 4, qualitative data (scholarly literature, interview transcripts, structural data, group discussion results) were combined with quantitative data (structural data). They were analysed based on qualitative methods (interpretative literature analysis, document analysis and qualitative content analysis) in parallel and sequential order. This procedure allowed for both richer detail in the empirical analysis as well as a triangulation in the theory building process.

Data basis Scholarly literature on the conceptualisation of agency (see module 3) and additional concepts of organisational agency from organisational studies were analysed as well as literature on incumbents' agency and their characteristics in transition studies, public corporate governance and network industries. In addition, documents (sectoral reports on UUC, the utility companies' firm reports, administrative reports on sector regulation, webpages of organisations) as well as regional structural data (national energy production statistics) were used. Interview transcripts were analysed, which originated from 38 semi-structured expert interviews, conducted with experts from utility companies, research institutes, political parties and associations in Germany and Switzerland in 2017 (see section A.4.2 list of interviewees in appendix). The interviews were asking for explorative (non-TEF based) aspects (characteristics of UUC, their position in the sector, their role in the transition process and for the resilience of the energy system) as well as for influence factors on their agency, grouped according to the levels, conceptualised in the TEF framework (socio-political, economic and organisational challenges and strategic answers) in the context of the energy transition (see section A.4.1 interview outlines and material in appendix). Finally, results from the two expert workshops, carried out in 2018 in Switzerland were employed for validation and discussion of UUCs' roles for transition and resilience of the energy system (see section A.4.4 workshop programme, A.4.5 participants list and A.4.6 summary of workshop results in appendix).

Data analysis methods A qualitative literature analysis of scholarly literature on conceptualisations of incumbents and their agency in transitions studies, as well as on the characteristics of UUC from public corporate governance and network industries literature was conducted. An analysis of documents and regional structural data were carried out. Finally, a structuring qualitative content analysis of interview transcripts, based on framework-categories and explorative categories, was performed (characteristics, position in the sector, role for transition, role for resilience) (see section A.4.3 code scheme in appendix).

Empirical case Urban utility companies in Germany and Switzerland

Table 3-1: Overview on data bases and analytical methods employed in the individual publications

	Publication 1	Publication 2	Publication 3	Publication 4	Publication 5	Publication 6
Data Basis						
Scholarly literature	X			X	X	X
Structural data	X	X	X	X	X	X
Interview transcripts	X	X	X	X	X	X
Group discussion results					X	X
Data analysis methods						
Qualitative literature analysis	X			X	X	X
Document analysis	X	X	X	X	X	X
Structuring qualitative content analysis		X	X	X	X	X
Mental model analysis		X				
Social network analysis			X			
Empirical Evidence						
Energy region bayerisches Allgäu			X	X		
Energy region ökoEnergieland	X	X				
Energy region Energieregion Weiz-Gleisdorf	X					
Network of change agents				X		
Urban utility companies in Germany and Switzerland					X	X

Chapter 4 Empirical cases

In this dissertation, three different empirical cases were employed in the context of the iterative theory building processes in the four modules. The cases are of different types, depending on the phenomenon under study, for which they stand for and range from the individual level (change agents) to the organisational level (urban utility companies) and the regional level (energy regions). The energy regions, presented in section 4.1, are considered as cases for socio-technical energy systems in mature sustainability transitions. Their transition process is thus in a mature phase but not yet completed. The change agent network, presented in section 4.2, is a case for the phenomenon of agency in sustainability transitions in socio-technical energy systems. Likewise, the urban utility companies, presented in section 4.3, are considered as cases for incumbents in socio-technical energy systems in transition. And although all these empirical cases are embedded in a spatial and temporal context, they should not be confused with case study regions.

4.1 Energy regions in Bavaria (Germany), Styria and Burgenland (Austria)

The region bayerisches Allgäu is a region in southern Bavaria, which consists of four “Landkreise” (administrative districts): Ost-, Ober- und Unterallgäu and Lindau as well as three “kreisfreie Städte” (district-free cities) Memmingen, Kaufbeuren and Kempten, whereby Kempten is the regional center (see Figure 4-10 for the location of the bayerisches Allgäu in Bavaria)

Figure 4-10: Location of the region bayerisches Allgäu in Bavaria, south-east of Germany (author’s own representation)

The **region bayerisches Allgäu** is considered as one of the pioneering regions in the German energy transition process. In 2017, renewable energies account for 49% of final electricity consumption in the region (Bayerische Staatsregierung, 2017). Traditionally, hydro power and wood were used for energy production, since the rural region was mainly characterised by agriculture and early – small scale – manufacturing. First initiatives and foundations of associations for renewable energies were established already in the early 1990ies. Since then, the utilisation of new renewable energies, such as wind power, solar energy and biomass increased. The technologies were not just implemented but partly also developed regionally, due to the long tradition of engineering knowhow. The region bayerisches Allgäu is particularly known for the support and embeddedness of the energy transition process in the regional society. Countless small and middle-sized enterprises and citizen cooperatives are involved in the development and production of renewable energy technologies, storage technologies and services. They are supported by many associations who push for renewable energies in the region as well as by one core organisation, the Energie- und Umweltzentrum Allgäu (eza!), which acts as a catalyst and management entity or the regional energy transition process.

The **Energieregion Weiz-Gleisdorf** is an association of originally 18 communes, which was founded in 1996 in order to foster the regional energy transition. Today, the network counts 12 communes and is institutionalised as “climate and energy model region”. Since 2007 the Energieregion Weiz-Gleisdorf is also an EU LEADER region. The Energieregion Weiz-Gleisdorf is located in Eastern Austria, in the “Bundesland” (state) of Styria with the major cities of Weiz and Gleisdorf (see red circle in Figure 4-11). The region has a long industrial and technology development tradition, which built the basis for the regional energy transition. Already in the late 1980ies a first association for technology development of photovoltaics was founded, it was followed by the establishment of a research centre and the foundation of the energy region association. The local energy transition is supported by local mayors, who signed in 2010 an energy charter to become CO2 neutral by 2050. It is moreover linked to regional development (LEADER region endeavours). Finally, the regional energy transition and particularly the technology development for renewable energies is also supported by external research partners, who collaborate with the local research centre and provide additional technological knowhow. Apart from solar energy, the energetic utilisation of biomass for renewable energy and the development of several local district heating networks were major achievements in the local energy transition.

Figure 4-11: Localisation of the Energieregion Weiz-Gleisdorf and the ökeEnergieland Austria (author's own representation)

The **ökoEnergieland** is an association of 17 communes, founded in 2005, to join forces for regional development, in areas such as energy, tourism or mobility. The ökoEnergieland is located in south-eastern Austria, in the "Bundesland" (state) of Burgenland (see red square Figure 4-11). Since 2010 ökoEnergieland is also a "climate and energy model region". The regional energy transition endeavours however already started in 1990, when the municipal council of Güssing decided to quit fossil fuels and the European Center for Renewable Energies (EEE) was founded in 1996. Since then, local actors continuously worked on the increase of renewable energies (mainly solar energy and biomass). Compared to the Energieregion Weiz-Gleisdorf the development was clearly focussed on the municipality of Güssing and expanded step by step (Hecher et al., 2016). The ökoEnergieland is a rural and peripheral region, which had its difficulties in regional development, however, the rich local energy resources (mainly biomass from agriculture - 48% of the regional surface - and wood - forest accounts for 42% of the regional surface) facilitated a regional energy transition and built the basis for a regional upwards trend. In ökoEnergieland the auto-sufficiency with local energy resources is one of the key transition goals.

4.2 Change agents in Bavaria (Germany)

The actor network of change agents, analysed in this dissertation, is located in the region bayerisches Allgäu. The change agents are working in diverse sectors: agriculture, forestry, energy production, waste management, regional development, the banking sector and regional politics or they were energy consultants or craftsmen (mainly electric installation and ventilation technologies). Most of them grew up in the region or are based there since decades, were trained as engineers and engaged themselves in volunteer work for the region and the energy transition process. The change agents can be considered decision makers with important positions as directors of companies or associations as well as policymakers. All change agents contributed over the last 20 years either to technological or social innovations in the context of the regional energy transition (e.g. research and development of new energy production and storage technologies, new financing models for renewables or new regional exchange platforms). Mostly, the change agents know each other personally and for a long time. Since most of them are also working in (several) voluntary positions, they are interlinked on multiple scales and link several social arenas already in their person (e.g. a craftsman who is leading an association and is also member of the city parliament). The change agents meet each other in multiple functions and constellations. The centre of the actor network represents the Umwelt- und Energiezentrum Allgäu (eza!) mentioned above, where all change agents are affiliated with, engaged or participate in different ways. Figure 4-12 provides a graphical representation of this network of change agents with its core organisation eza! as orange node.

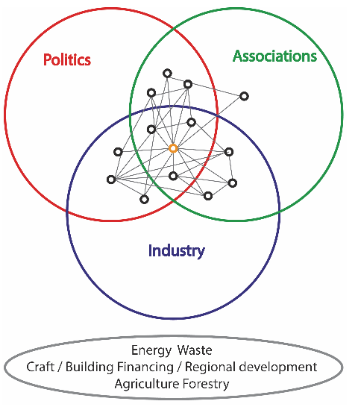

Figure 4-12: Network of change agents in the Allgäu region (author's own representation)

4.3 Urban utility companies in Germany and Switzerland

Urban utility companies (UUC) are large city-owned utility companies, which supply “their” city with critical public services (energy, water, waste management, mobility, telecommunication) and operate network infrastructures (distribution grids, gas and water networks, telecommunication or rail networks). Unlike large energy producers, which are focussed only on gas and electricity, they have a broader task portfolio (multi-utility). Unlike smaller utility companies, they operate not only the network infrastructure, but they also produce electricity and heat, trade energy and provide services on multiple scales (vertical integration). UUC are a particular phenomenon of federal energy governance systems with a bottom-up organisation and a high level of self-governance on the communal/city level. In Germany, the energy sector has been liberalised step by step since 1998 in both, production and the retail domain, so that the UUC were corporatised (change of legal form from public to private company) and their former supply territory was dissolved. Nowadays, they act in a market-based and competitive environment as international energy and utility companies in Germany and Europe, while still being owned by “their city”. In Switzerland, the electricity sector is only partly liberalised and households still have electricity and gas tariffs. The UUC in Switzerland still have regulated supply territories and most of them are organised as public firms or even departments of the city administration. In the context of this dissertation, the energy subdivisions of the following six UUC were analysed: Stadtwerke München GmbH (Munich), Rheinenergie AG (Cologne) and enercity (Hannover) in Germany as well as Elektrizitätswerke Zürich (Zurich), Services Industriels de Genève (Geneva) and the Industrielle Betriebe Basel (Basel) in Switzerland. Table 4-2 provides an overview on the characteristics of the UUC analysed in this dissertation.

Table 4-2: Characteristics of the six analysed urban utility companies (Mühlemeier, under review)

Urban utility company	**Annual turn-over**	**Foundation year**	**Ownership structure**	**Organisational form**	**Business areas**
Stadtwerke München SWM	6675 million Euro (without public transport and swimming pools) (2017)	1899 Städtische Elektrizitäts- und Gaswerke, 1939 Stadtwerke München, 1998 corporatisation.	100% city of Munich	Limited Company	Electricity, gas, district heating, services (water, telecommunication, public transport)
Rheinenergie AG and Rheinenergie group (including e.g. trade)	3647 million Euro (2016)	1873 Gas- und Wasserwerke Stadt Köln, 1960 corporatisation, 2002 Rheinenergie AG	80% City of Cologne, 20 % Innogy	Listed corporation	Electricity, gas, district heating, services (water)
Enercity AG	2101 million Euro (2017)	1922 Städtische Betriebswerke, 1970 corporatisation, 1996 enercity AG	75 % city of Hannover, 24 % Thüga, 1 % region of Hannover	Listed corporation	Electricity, gas, district heating, services (water)
Services Industriels de Genève SIG	1065 million CHF (2017)	1896 as municipal company of the city of Geneva, 1931 public company of the city, the canton and the other communes of the canton	55 % canton of Geneva, 30% city of Geneva, 15% communes of the Canton	Independent public company	Electricity, gas, district heating, services (water, waste management, telecommunication)
Elektrizitätswerke Zürich EWZ	0.859 million CHF (2016)	1890 as department of the city administration	100 % City of Zurich	City administration department	Electricity, services, (telecommunication)
Industrielle Betriebe Basel IWB	0.727 million CHF (2016)	1868 municipalisation of the gas supply, 1899 establishment of the electricity supply, 1908 separation of the electricity supply from water and gas, 1978 re-fusion in IWB	100% Canton of Basel	Independent public company	Electricity, gas, district heating, services (water, telecommunication)

Chapter 5 Results

The subsequent chapter summarises the results of this dissertation, structured according to the four main research questions and the related modules. Each section of this chapter indicates the related publications, in which further information on the results can be found (see part B – publications). At the end of each section, the contribution of the module to the overall research aim is discussed in order to lay the foundation for the reflection on the integrated contribution of the modules in section 6.3. Finally, the results and their contribution to the overall research aim are again summarised in a concise overview box.

5.1 Conceptualising and operationalising resilience of socio-technical energy systems in transition – An indicator-based approach

Module 1 tackled the **research question 1** "How to conceptualise and operationalise resilience of socio-technical energy systems in transition?". The module's full results are can be found in publication 1 (part B).

5.1.1 Results module 1 (publication 1)

Module 1 provides results on three levels: i) the conceptualisation of resilience in socio-technical energy systems in transition, ii) the operationalisation of the concept and iii) the interpretation of this operationalisation.

Conceptualisation The resilience of a socio-technical system results from the co-evolution and interplay of the social and the technological sphere of the system. Throughout the transition process, the socio-technical system shows different levels and constellations of its key characteristics diversity and connectivity. While going through the different phases of the transition, it always keeps a minimum level of diversity and connectivity in its social and technological subsystems to maintain its key abilities for resilience - stability and adaptive capacity. This conceptualisation of resilience in socio-technical energy systems in transition is based on three parts: First, the concept of a socio-technical system, which consist of entities and their links in parallel social and technological subsystems. Second, the concept of a transition, as a goal-oriented process with four phases of predevelopment, take-off, acceleration and stabilisation. Third, the concept of resilience thinking – derived from the adaptive cycle model – encompassing stability and adaptive capacity as the system's most important abilities for resilience and diversity and connectivity as the key characteristics.

Operationalisation For the analysis of resilience in socio-technical energy systems in transition, first, the concept of the social and technological subsystems was operationalised. The social subsystem was subdivided in social arenas (e.g. industry, media, politics, associations) which differ according to their way of organisation, communication and key actors. The technological subsystem was subdivided in technology groups, which group individual technologies for energy production (e.g. wind power comprises onshore and offshore wind plants of different sizes, hydro-power comprises run-over river power and pumped storage power plants). Second, the concept of resilience characteristics diversity and connectivity was operationalised by proposing an indicator set, applicable to both, the technological subsystem and the social subsystem. The indicator set operationalised the resilience characteristic diversity in variety, balance and disparity and connectivity in average path length, degree centrality and modularity. In addition, measures for quantification were proposed for every indicator and every indicator was operationalised for the social and technological subsystem. Table 5-3 and Table 5-4 summarise the six indicators, the related measures and operationalisations for the social and the technological subsystems.

Table 5-3: Indicator set for diversity and its related measures and operationalisation for socio-technical energy systems (Binder et al., 2017)

Diversity Indicator	Definition	Social System	Technical System
Variety	Category count N	Operationalisation: Number of types of social arenas present in the regional energy governance structure Role for resilience: Higher adaptability and stability through integration of different views and perspectives	Operationalisation: Number of groups of technologies present in the local energy production system Role for resilience: Integration of different technologies, basis for flexibility and adaptability
Balance	Shannon evenness $S = -\sum_i \frac{p_i \ln(p_i)}{lnN}$ Shannon Weaver (includes variety)	Operationalisation: Number of actors per social arena in comparison to overall number of actors Role for resilience: Indicator for stability, efficiency, flexibility	Operationalisation: Share of technology groups in overall energy production Role for resilience: Shows how much the region relies on one energy technology group (energy portfolio)

	$S = -\sum_i p_i \ln(p_i)$		
Disparity	$D_i = f(d_{ij})$ $f(d_{ij})$: function of distance in disparity space between categories i and j	Operationalisation: Qualitative differentiation between arenas Role for resilience: Determines stability, transaction costs and flexibility	Operationalisation: Qualitative differentiation between technologies Role for resilience: Diverse technologies – basis for adaptability to uncertain external shocks

Table 5-4: Indicator set for diversity and its related measures and operationalisation for socio-technical energy systems (Binder et al., 2017)

Connectivity indicator	Definition	Social System	Technical System
Average Path Length	Average path length $l_G = i > jl(i,j)n(n)(n-1)^2$ with average path length in the network being the arithmetical mean of all the distances. $l_G = \frac{1}{n(n-1)} \sum_{i \neq j} d_{ij}$	Operationalisation: Number of steps it takes to reach other actors from other arenas along the shortest path. Role for resilience: A shorter path length facilitates the sharing of knowledge and experience.	Operationalisation: Length of the transmission lines between production and consumption sites. Role for resilience: A shorter path length speeds up the propagation of harmful supply perturbations.
Degree Centrality	Degree Centrality $C_D(n_i) = d(n_i) = \sum x_{ij} = \sum x_{ji}$ The degree centrality of a node is calculated by summing up the connections that a node has to other components in the network. One can distinguish between in- and out-degree centrality. The Average Degree, which is an indicator of the overall density of the network, can be defined as: $\bar{d} = \frac{\sum_{i=1}^{g} d(n_i)}{g}$	Operationalisation: Number of connections of actors within one arena to actors in other arenas in comparison to overall possible number of connections. Role for resilience: A higher centrality reflects a higher coordination power.	Operationalisation: Number of connections to other producers or / and consumers in the distribution network. Role for resilience: High degree centrality, Nodes represent intervention points.
Modularity	Modularity Index $Q = \sum_i (e_{ii} - a_i)^2$ Where e_{ii} is the fraction of edges in the network between any two nodes in the module i, and a_i the total fraction of links originating from it and connecting nodes belonging to different ones.	Operationalisation: Measure of the tendency of actors from different arenas to form subgroups, which are detached from the rest of the network. Role for resilience: Higher modularity increases the creation of new ideas within partially secluded subgroups.	Operationalisation: Measure of autonomy of certain parts of the distribution network Role for resilience: Higher modularity allows an autonomous functioning of parts of the system (islanding).

Interpretation The meaning of different indicator constellations for the resilience of the energy system in transition was discussed against the four proposed ideal-type cases: case a) high diversity and high connectivity represents a resilient system in successful transitions, case b) low diversity and low connectivity represents a non-resilient system, which is locked-in or stuck in transition, case c) high diversity and low connectivity represents a partly resilient system, which is undergoing transition, most probably in the early phase of a transition and finally, case d) low diversity and high connectivity represents a partly resilient system, which might by stabilised at the end of the very beginning of a transition.

5.1.2 Contribution to the dissertation's overall research aim

Results from module 1 contribute on four levels to the overall research aim of the dissertation: First, the developed understanding of resilience for socio-technical systems in transitions, which requires the balance between stability (robustness) and flexibility (adaptive capacity and transformability) in order to maintain the resilience over the course of a transition. It builds a **conceptual basis** to understand system functionality in the context of mature transitions. In the mature phase of a sustainability transition, especially critical infrastructure systems such as the energy system need to remain functional while integrating new technological and social solutions on the large scale (e.g. supply security while increasing the share of renewable energies). Stability and flexibility are substantial in order to manage this balancing act and allow for continued transition dynamics without endangering the functionality of the energy system.

Second, the proposed indicator set for diversity and stability allows to **analyse the system configuration for system functionality**, conceptualised as the balance of stability and flexibility. A high diversity of energy production technologies can only operate in a secure manner if they are connected, either to the overall system (e.g. the grid which is highly connected) or among themselves on a local level (e.g. on the household or quartier level). The qualitative differences of the technologies can be balanced through their connection to other technologies (e.g. base or peak load or different resource bases). The indicator set allows to analyse the diversity and connectivity of the existing system, uncovers potential mismatches and helps to design the system in such a way that it allows for both stability and flexibility.

Third, the proposed indicator set describes both the **social and the technological sphere** of the system, employing the same measures. This allows to directly compare the social and the technological system structure. The functionality analysis can be done separately, but also in an integrated manner, by analysing feedbacks and interferences among the two spheres (e.g. the social system is dominated by a few and well connected actors, who are highly connected and might explain why the diversity of the technological system is also rather low). Due to its theoretical foundation, the proposed indicator set is not case specific but of general validity and thus allows for comparisons between different cases.

Finally, by means of the four proposed ideal-type cases A – D, which represent theoretical indicator constellations for different levels of diversity and connectivity, certain system configurations are linked to specific transition phases (e.g. in the predevelopment phase, the diversity is low but increases over the course of the transition, when new technologies and actors enter the system). The cases exemplify how system configurations may be linked to transition dynamics and progress. Diversity and connectivity levels in both the technological and the social subsystems can be used as a basis to position the system within the transition process. They also allude to potential deficits for the further transition progress.

In conclusion, module 1 facilitates the empirical analysis of energy systems' resilience and decisively enriches the understanding of system functionality as well as its development over the course of a transition. This contributes to theory building on energy systems in mature sustainability transitions.

Key findings

- Resilience of socio-technical energy systems in transition can be conceptualised in two key system abilities (stability and adaptive capacity) and two key characteristics (diversity and connectivity).
- For analysing the resilience of a socio-technical energy system in transition, diversity and connectivity can be operatiosnalised with two indicator sets, comprising indicators and measures for variety, balance and disparity (diversity) and average path length, degree centrality and modularity (connectivity).
- Socio-technical systems can be conceptualised as complex systems with social and technological subsystems, which can be operationalised in social arenas (social subsystem) and technology groups (technological subsystem).
- The resilience of a socio-technical energy system in transition results from the co-evolution of the social and technological subsystems and the maintenance of a minimum level of diversity and connectivity throughout the transition process.

Contribution: Module 1 provided a theoretical understanding of resilience for socio-technical energy systems in transition and how it can be operationalised equally for the social and technical sphere through an indicator set for diversity and connectivity. This indicator set could be applied to analyse the system configuration of a socio-technical energy in transition. Through its basis on the resilience concept it moreover facilitateed the understanding of how the socio-technical system configuration supports system functionality and how it is related to the transition dynamics.

5.2 Empirically applying and discussing the indicator set for resilience of socio-technical energy systems in transition – Empirical evidence from energy regions in Austria and Germany

Module 2 tackled the **research question 2** "How to empirically analyse the resilience of socio-technical energy systems in transition?". The module's full results can be found in publication 2 and 3 (part B).

5.2.1 Results module 2 (publication 2 and publication 3)

Module 2 provides results on three levels: i) empirical findings from the analysis of the social and technological system configuration of two energy regions in transition over the course of a transition as well as for one point in the mature phase of the transition, ii) the presentation of different qualitative and quantitative methods and data bases for the empirical application of the indicator set and iii) reflections on the benefits and difficulties of the empirical application of the prosed indicators set.

Empirical analysis The empirical analysis of the resilience of socio-technical energy systems in transition was conducted for two case study regions – first, a longitudinal study of the Energieregion Weiz-Gleisdorf (publication 2) and second, a cross-sectional study of the region bayerisches Allgäu (publication 3).

Over the course of the four phases of the sustainability transition, the energy system of the Energieregion Weiz-Gleisdorf showed an enormous increase of the diversity of the technological subsystem from low to high levels and a slightly increasing connectivity on medium levels. The social system however was characterised by a constant high to medium level of diversity and a decreasing connectivity from high to medium levels (see Figure 5-13)

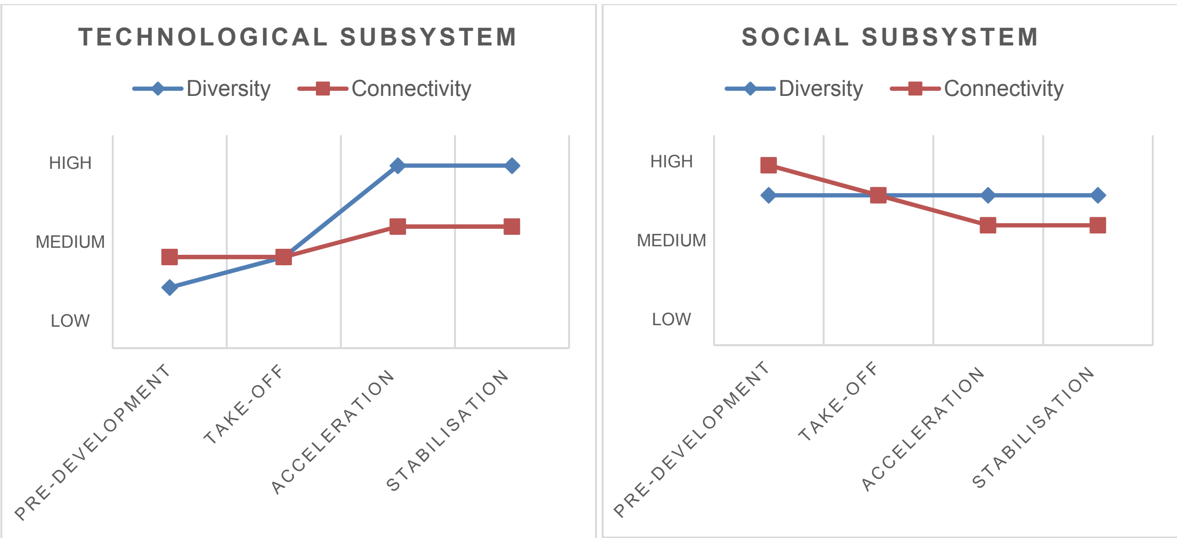

Figure 5-13: Results for diversity and connectivity indicators over the four transition phases in the Energieregion Weiz-Gleisdorf (Wyss et al., 2018)

In the Energieregion Weiz-Gleisdorf, the social subsystem involved the social arenas politics, industry, associations and research, which remained constant over the course of the transition (variety = 4). Media was only perceived as an important social arena in the take-off phase. These social arenas were characterised by high qualitative differences (e.g. the industry arena was organised based on market logics, the politics arena based on hierarchy and the associations arena based on networks, (see Table 5-5)), which resulted in a constant high disparity. The balance of the social arenas was at the beginning high, with no arena being perceived as dominant. Over the course of the transition, the balance decreased, since the industry and the politics arena included more actors, which were perceived as important for the social system. The average path-length of the social system was at the beginning of the transition very low: all actors knew each other. Over the subsequent transition phases it increased and new actors were involved. At the beginning, the politics arena was decisively more connected to the other arenas as any other and had the highest degree centrality. Over the years, the industry arena became well connected, too, so that the overall degree centrality developed from high to medium levels. Finally, the modularity was at the beginning low and increased over the course of the transition to mediums levels, since more and more project-based collaboration emerged, which did not involve the entire actor network.

Table 5-5: Disparity of social arenas in the Energieregion Weiz-Gleisdorf (Wyss et al., 2018)

Social Arena / Charac-teristics	Industry	Associations	Research	Politics	Media
Core Actors	Energy producers, cooperatives, construction and production firms	Regional energy associations, LEADER groups, Industry associations	Regional innovation centre, Universities, research institutions, Research departments in firms	Municipalities, the provinces, the EU	Regional newspaper
Coordination of Actors	Market	Network	Network	Hierarchy	Market
Main Goals within the Arenas	Investing in renewables, providing energy and energy-related products	Coordinate and represent regional actors, provide funding, integrate external actors	Developing and testing of new technologies, introducing new knowledge in the region	Regulating, subsidizing, investing in energy plants / research projects	Informing the public, opinion building on political decisions and observed behaviour in industry
Time Horizon for Activities	Medium-term	Long-term	Medium-term	Short-term	Short-term
Spatial Reference of Actors	Local–international	Local–regional	Regional -national	Local—international	Local–regional

At the beginning of the transition in the Energieregion Weiz-Gleisdorf the technological subsystem involved only one technology (hydropower), variety was thus low at 1. So were balance and disparity. Over the course of the transition, variety increased decisively in the acceleration phase to 9 (respectively 10) production technologies, among which wind, photovoltaics, solar and waste heat. The Shannon weaver index increased from 0 and 0,01 to 0,8 in the acceleration phase (see Figure 5-14). Accordingly, the disparity increased, since very different technologies entered the system (for an overview on the disparity of the five most important technologies, see table 5-6). The diversity of the technological subsystem increased decisively over the course of the transition, due to the regional evolution of new renewables. The connectivity in the technological subsystem was low at the beginning. The centralised electricity grid had high path-length and no modularity, while in the heat system there were both highly centralised grid-bound technologies (e.g. gas) and off-grid technologies (e.g. wood, oil). Over the course of the transition, the level of connectivity increased to medium levels: in the heat system the amount of grid-bound solutions increased with the establishment of district heating and the level of centrality in the electricity grid decreased slightly with meshing endeavours on the medium voltage level.

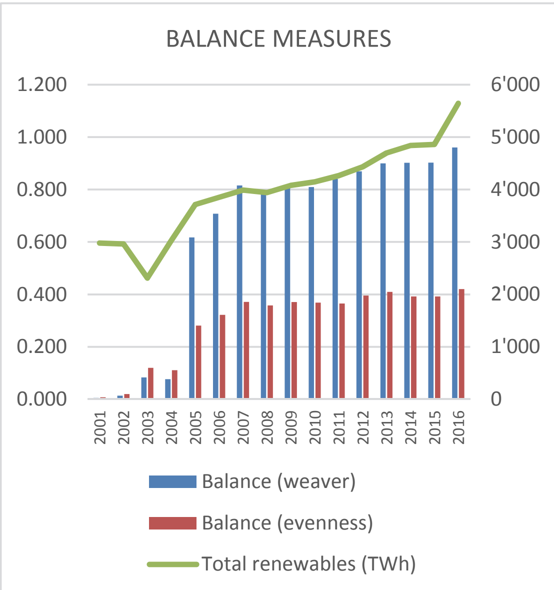

Figure 5-14: Results for technical balance, Energieregion Weiz-Gleisdorf (Wyss et al., 2018)

Technology / Disparity attribute	Hydro-power	Biogas	CHP	Photo-voltaic	Solar heat
Energy conversion efficiency	0.85	-	0.85	0.08-0.16	0.5-0.7
Resource base	Water	Biomass	Bio-mass	Sunlight	Sun-light
Direct CO_2 emissions	No	Yes	Yes	No	No
Land consumption	Low	High	High	Medium	Me-dium
Dependency on weather events	Medium	Medium	Me-dium	High	High
Costs (cent/kWh)	15.6-17.8	13.5-21.5	12.2	7.8-14.2	22

Table 5-6: Results for technical disparity Energieregion Weiz-Gleisdorf (Wyss et al., 2018)

In the current phase, the socio-technical energy system of Weiz-Gleisdorf therefore shows a mixed indicator constellation of high diversity and medium connectivity. This alludes to the ideal-type indicator constellation of case C (see module 1) and indicates that the system has a medium overall resilience and is seemingly in an intermediary phase of transition, possibly at the brink of stabilisation towards a fully renewable energy system.

Similar findings were derived for the region bayerisches Allgäu. The study of the current structure of socio-technical system showed that the social subsystem consists of the same arenas: politics, associations, industry (energy and non-energy industry), research and media (variety = 5). This results in a medium to high level of variety and related disparity. The balance is medium, since most actors are involved in associations. Results of the social network analysis showed that the averaged path-length is 2,9 and thus at medium levels. Centrality measures are also at medium levels, with one association and several politicians identified as actors with high degree centrality (see Figure 5-15). The modularity was medium, with 7 identified modules, whereby almost every module included actors from all social arenas.

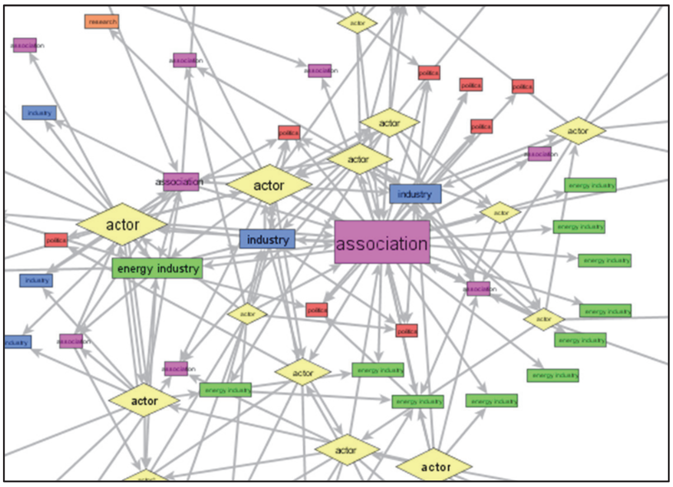

Figure 5-15: Results for social network analysis, degree centrality of social subsystem in the Allgäu region (Mühlemeier et al, 2017)

The technological subsystem was characterised by a high level of variety (hydro power, photovoltaics, wind power, combined heat power, biomass heat, solar heat and heat pumps, variety = 7). Accordingly, the disparity was also high. The total balance of renewables was rather low (only 36% of the electricity consumed in the region was produced from renewables and 5 % of the heat demand), the relative balance among the renewables was medium, since the regional shares were more balanced. Regarding the connectivity, the results were more ambivalent. The average path-length on the high-voltage level of the grid was low, whereas on the low-voltage level, path-lengths are high, with similar results for the gas grid. The district heating, however, has low path-lengths due to the danger of transportation losses. Centrality is likewise high for the electricity and the gas grid, for which modularity is low (no modules possible). In the overall heat system however, modularity is high, since the individual heat technologies are not connected, in contrast to the electricity grid. For an overview on the results see table 2 and table 3 in publication 3. In conclusion, the level of social and technological diversity in the region bayerisches Allgäu is very high, whereas social and technological connectivity are at medium levels. These findings likewise allude to case C, medium resilience and intermediary phase of the transition.

The comparison of the two regions shows that they are currently both characterised by high levels of diversity and medium levels of connectivity, which indicates that they are in an intermediate phase of the transition. Interviewees in the Allgäu region perceived that the transition dynamics decreased decisively in this later phase of the transition and almost came to a halt. In order for the transition to continue successfully and keep up the transition dynamics, higher levels of connectivity are required in the social subsystem (include more and divers actors, also opponents), as well as in the technological subsystem (allow for more modularity in the electricity grid as well as sector and grid coupling). At the same time, the high level of diversity – especially in the technological subsystem - needs to be managed carefully to maintain system functionality. Local modular grids with disperse technologies (complementary but also redundant) could for example decisively help to maintain the overall systems resilience, while still catering for a high level of diversity. Finally, the comparison of the two cases showed an equal indicator constellation for the mature phase of the transition and similar problems regarding the transition dynamics. Based on these two cases, we derived a first pattern, which is however not representative. Further empirical analyses based on the proposed indicator set would be very valuable to build a solid basis for understanding system configuration patterns in mature sustainability transitions, which would then facilitate related theory building.

Methods and data bases The following data bases and research methods are proposed for the empirical application of the indicator set, developed in module 1. For the technological subsystem, structural data on the regional energy production (existing plants, their installed capacity and degree of efficiency) or data from a regional energy flow analysis are recommended as well as maps or quantitative data tables in relation to the regional electricity and heat network structures. This data basis allows to calculate the proposed measures for the diversity and connectivity indicators, except for disparity, which requires a qualitative evaluation of the differences among the technology groups (see table 5-6).

For the analysis of the social subsystem, a full sample social network analysis would be an ideal quantitative equivalent for the data from the energy flow analysis. However, such an analysis is very time-consuming and resource-intensive. Thus, module 2 proposes different, qualitative and semi-quantitative methods for analysing the social subsystem. As a data basis, interview transcripts of semi-structured expert interviews and documents on the regional energy governance system were utilised. In publication 2, the analysis of the interview transcripts and documents was enriched with mental model analyses (explained in section 3.3.2). This approach allowed to triangulate the results from the interview transcripts and to aggregate the individual perceptions to reach intersubjective comparability of the results (see Figure 5-16). In publication 3, the qualitative data basis was quantified and analysed with a social network analysis approach (also explained in section 3.3.2). The social network analysis results in quantified data for the social subsystem, comparable to the quantitative data of the technological subsystem and thus facilitates comparability within, but also across cases.

The two approaches provide an innovative and efficient way to analyse the indicators for the social subsystem (over time), without having to carry out (several) full sample social network analyses. The data basis for the technological and the social subsystem, however, differ in their characteristics (technical data = secondary panel data, social = primary cross-sectional data). Publication 2 shows how the system transition analysis, nonetheless, can be conducted in a coherent way for the social and the technological subsystem by dividing the transition process in periods and taking measures at representative points in time. Module 2 provides important findings on how to apply the indicator set in concrete empirical analyses.

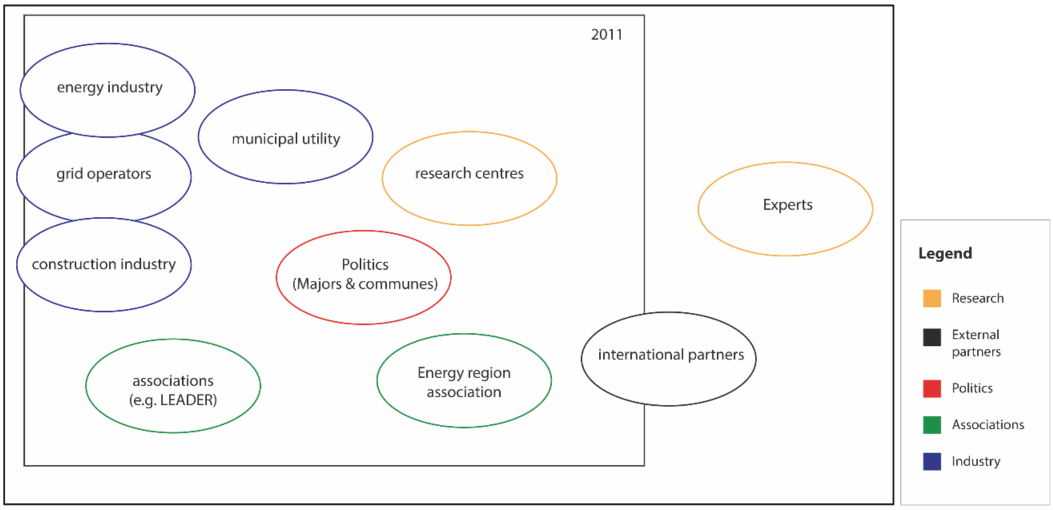

Figure 5-16: Results for mental model analysis of social system in Energieregion Weiz-Gleisdorf (Wyss et al., 2018)

Reflections on benefits and difficulties Module 2 provides important findings on the reflection of benefits and difficulties of the empirical application of the indicator set. The indicator set provides a very valuable toolkit for practitioners in policy making and regional planning to achieve a holistic system understanding of their region and a rich basis for strengthening its resilience throughout the transition process. At the same time, there are some difficulties in applying the indicator set in a fully quantified manner based on empirical analyses. The need for a rich data set, the qualitative differences of social and technological data mentioned above as well as different system boundaries for data collection (social = regional, technological = states level or national) complicate the analysis. On the other hand, the different quality of the indicators – connectivity indicators cannot simply be added up as an index – as well as the lacking consideration of supra-regional influence factors and actor-level determinants posed additional difficulties in the interpretation of the results. For a more detailed description of the empirical analysis in the region bayerisches Allgäu see the additional publication 1 (in German) in appendix (section B.1). For a more in-depth reflection on the methodological implementation of the indicator-based empirical analysis of resilience in socio-technical energy systems and a discussion of their application to the tourism sector see the additional publication 2 (English) in appendix (section B.2).

5.2.2 Contribution to the dissertation's overall research aim

Results from module 2 contribute on four levels to the overall research aim of the dissertation.

First, they provided rich empirical insights on the **development of the indicators over the course of a sustainability transition** in the social and technological sphere of the system. Based on two cases studies, they also provide examples for the system structure in the mature phase of a transition. Although the results do not yet build a representative empirical evidence base, they show the same trend in both case study regions: the diversity of the technological system increases decisively while its connectivity is not changing at the same pace. The social diversity remains rather high, while the connectivity decreases. These results build the basis for a first understanding of system structure in mature transition phases and pave the way for future analyses, which would underpin deeper theory building.

Second, the results provide empirical evidence for the reflection on **the interrelatedness of system structure and system functionality** on the one hand **and transition dynamics** on the other hand. The results show that especially the production structure of the technological system has changed decisively, while its functionality has not been endangered. The empirical case of the electricity grid alludes to the fact that the multi-scalar connectivity of the electricity grid plays a key role in maintaining the system's functionality by compensating for fluctuations due to the changes in the production structure on the local level (e.g. volatilities, overproduction and shortages could be balanced off). The empirical evidence refines the understanding of system structure for functionality in mature sustainability transitions, by showing the importance of multi-scalar connectivity. The empirical evidence on the social subsystem's structure, in turn, shows that the actor network pushing the sustainability transition is indeed divers, however certain social groups are not represented (e.g. NGOs, schools or churches) and the overall amount of actors is still relatively small. Related thereto, the actor network is well connected among the eganged individuals, however it lacks connectivity to the wider society. (Lacking) diversity and connectivity of the actor network are both structural explanatory variables for the perceived stagnation in the transition dynamics (obviously external variables such as policy changes are also relevant).

Third, module 2 presents and discusses different qualitative and quantitative methods, which **facilitate the empirical application of the indicator set** for both subsystems and supports the empirical analysis of system structures in mature sustainability transitions. On the one hand, the explorative and descriptive analysis of publication 2 allowed to generate rich insights on the changing system structure. On the other hand, the quantified and more standardised analysis in publication 3 allowed to obtain a different perspective and complementary insights on the system. By this, module 2 presents a rich set of methods to analyse system structure, which supports future research and further theory building endeavours on mature sustainability transitions. In conclusion, module 2 provides rich empirical evidence and proposes a set of qualitative and quantitative methods for the analysis of social and technological system structures over the course of a sustainability transition. It empirically underpins the understanding of system structures in mature transition studies and paves the way for future theory building.

Key findings

- Over the course of the sustainability transition, the energy system of the *Energieregion Weiz-Gleisdorf* showed a decisively increasing diversity of the technological subsystem from low to high levels and a slightly increasing connectivity on medium levels. The social system was characterised by a constant high to medium diversity and a decreasing connectivity from high to medium levels. In the later phase of their transition, the *Energieregion Weiz-Gleisdorf* and the region *bayerisches Allgäu* both showed high diversity and medium connectivity and can thus be considered as systems in an intermediary phase of the transition, possibly at the brink of stabilisation of the renewable energies regime.
- A mixed methods approach, using quantitative data on the regional energy production for the technological subsystem and qualitative data for the social subsystem, provided a good approach for the exploration of the rich empirical data basis.
- Social network analysis as well as mental model analyses provided innovative methodological approaches for an efficient and less resource intensive, semi-quantitative analysis of the social subsystem and could be linked to an energy flow analysis for the technological subsystem.

Contribution Module 2 provided empirical insights from the application of the indicators set to the social and the technical sphere of two regional energy systems and their comparative analysis. Module 2 furthermore presented a set of methods for the qualitative and quantitative analysis of the indicators. It gave examples for the empirical analysis of the theoretical considerations from module 1, empirically underpinned them and supported theory building on system functionality in mature sustainability transitions.

5.3 Advancing the analysis of agency in sustainability transitions of socio-technical energy systems – Application of the HES framework to change agents in a regional energy transition

Module 3 tackled the **research question 3** “How to improve the systematic analysis of agency in sustainability transitions of socio-technical energy systems?”. The module’s full results are can be found in publication 4 (part B).

5.3.1 Results module 3 (publication 4)

Module 3 provides results on three levels: i) re-conceptualisation of the HES framework for the analysis of agency on socio-technical energy systems in transition, ii) results from the empirical application of the adapted framework and iii) propositions for linking it to the multi-level perspective of sustainability transitions (MLP) (Geels, 2002) to facilitate its integrability in transition studies.

Re-conceptualisation The re-conceptualisation of the human-environment systems (HES) framework for socio-technical energy systems promotes the conceptualisation of agency as embedded in and interacting with a complex systemic environment and combines the actor-level perspective as well as the system-level perspective on agency. It conceptualises agency as a function of actor-level determinants (goal and strategy) and system-level factors (environment perception). Actions influence the environment and cause short- and long-term feedbacks, which are evaluated again by the actors and cause learning effects. These evaluations and learning processes, finally, influence the individual goals and strategies for future actions. The HES framework conceptualises the systemic environment of actors as multi-level environment, where interferences between the levels might occur and supplementary interact with the actors (see Figure 5-17).

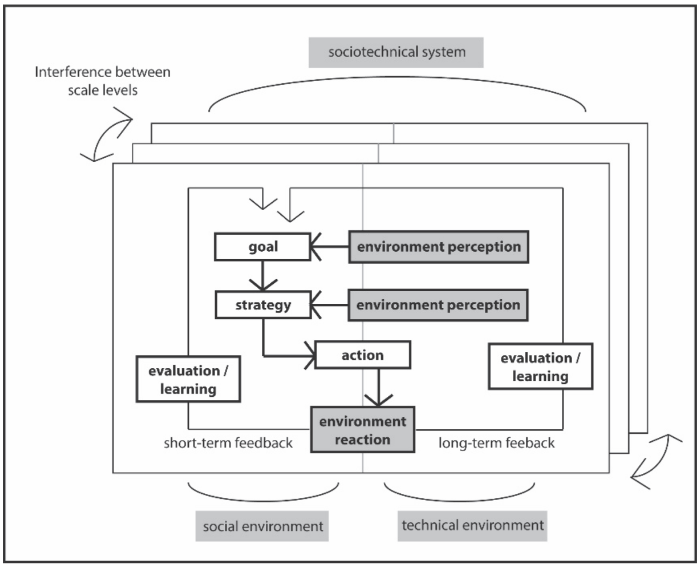

Figure 5-17: HES framework – reconceptualised for socio-technical systems in transition (author’s own representation)

In module 3, the re-conceptualisation of the HES framework for socio-technical systems was done in two steps: First, expanding the environment understanding, including technological aspects and conceptualising the ecological sphere as integrated in the technological sphere (which is the common system conceptualisation in socio-technical systems literature). Second, conceptualising multiple levels in the technological sphere, equivalent to those of the HES framework: from individual, to organisation and society, respectively from technological components, to artefacts and technology groups (for an overview table see publication 4).

Empirical application The exemplary empirical application was done through an analysis of a network of change agents and their socio-technical environment in the region bayerisches Allgäu. This application provided insightful findings on influence factors and effects of individuals’ agency in systemic transitions. The empirical study revealed key individual goals (e.g. technology development for renewable energies, and regional business development, based on ecological convictions) and strategies (e.g. expand and disseminate knowledge and knowhow, form strategic alliances, mobilise regional capital for independency) which were similar or overlapping for all change agents (see Figure 5-17). It presented findings for the environment feedbacks perceived by the actors and their related evaluations. Positive factors were perceived e.g. in the positive reinforcement from the network of change agents, the support from regional organisations and the wider regional society, whereas negative factors were seen in media reports on early technology failure or the lacking feedback and difficulties to hand over to the next generation (see Figure 5-18). The study also alluded to interferences among system-levels (e.g. the negative effect of the conservative energy policies on the state level or lobbyism of large energy companies, whereas the national policies where perceived as rather supportive) and individual learning processes (e.g. focus on the regional scale and reduce the voluntary engagement). The empirical application of the reconceptualised HES framework, thus, revealed insightful findings on the network of change agents and key determinants of their agency. The application moreover proved the frameworks' applicability and added-value for the study of agency embedded in the systemic context and provided an example for a systematic, framework-based agency analysis in the context of sustainability transitions.

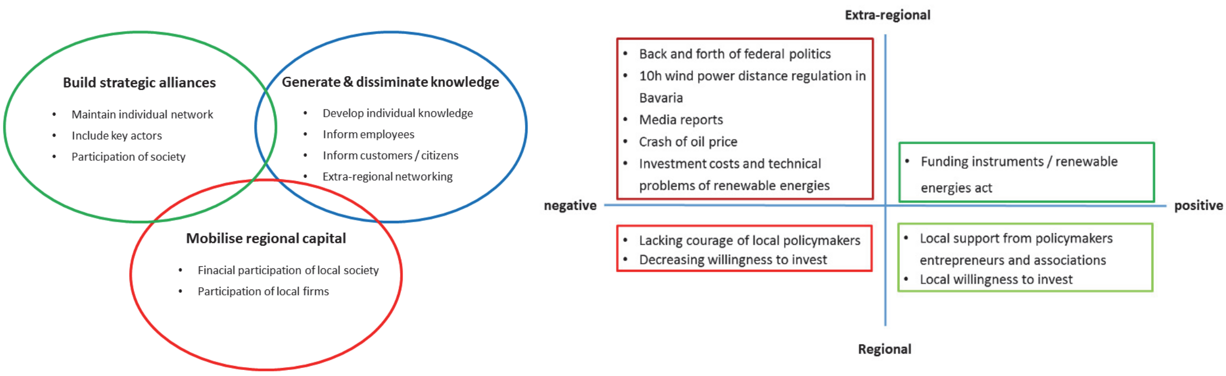

Figure 5-18: Strategies and perceptions of change agents in the Allgäu region (author's own representation – not published)

Integrability: Module 3 finally proposed a linkage of the re-conceptualised HES framework to the MLP, to combine its individual psychology background with the sociological background of the MLP and conceptually further develop the systematic analysis of agency in sustainability transitions. In this context, the HES concept of multiple hierarchical levels and interferences among them was linked to the structuration levels and their interactions in the MLP (see Table 5-7).

Table 5-7: Social levels and related regulation levels of the HES assigned to structuration levels of the MLP

HES framework	Regulation mechanisms	MLP	Structuration level
Individual, Organisation	Individual norms, values, goals	Niche	Little structuration, hardly institutionalised actor networks, independency from the mainstream regime logic, fast changes
Institution, society	Nationally shared legal, economic, political and cultural practices	Regime	Dominant rules, norms, regulations on how politics, markets or the energy supply works, slow changes
Supra-national level	Supranational values and visions (e.g. human rights)	Landscape	Fundamental values, world views, long-term trends, very slow changes

Based on an iterative theory building process, module 3 provided important findings for the advancement of a systematic agency analysis in the context of sustainability transitions and gave an empirical example of its application. It emphasised the importance of the actor-level and showed the complexity of determinants of agency in the context of sustainability transitions. The findings of module 3 build the conceptual basis for the in-depth analysis of incumbent agency in module 4.

5.3.2 Contribution to the dissertation's overall research aim

Results from module 3 contribute on three levels to the overall research aim of the dissertation:

First, with the adaptation and operationalisation of the HES framework to the context of socio-technical systems, module 3 provides a **comprehensive framework to analyse agency**, embedded in its systemic socio-technical context within sustainability transitions. It allows to comprehensively analyse individual's agency, which is of great value for the better understanding of key dynamics and structures of energy systems in mature sustainability transitions. For this, three conceptual components of the HES framework are important: i) The conceptualisation of the interlinkage among individual's agency and systemic changes: agency causes systemic feedbacks (short-term and long-term) on multiple systemic levels, which are again perceived and evaluated by the actor and influence the individual's agency through learning effects, ii) the complex system understanding comprising multiple levels, their interferences and different feedbacks over time iii) the actor-level determinants of individual's agency (goals, strategies, perceptions and evaluations as well as learning processes), which explain how agency is not only driven by systemic but also by actor-level influence factors. This conceptualisation helps to explain how individual's agency and systemic changes are interlinked, provides an analytical heuristic to understand how transition dynamics are driven by individual's agency and supports theory building on transition dynamics in (mature) sustainability transitions.

Second, module 3 **connects the adapted HES framework to the MLP** through the linkage of the individual socio-technical levels and regulatory mechanisms of the HES to the structuration levels of the MLP. This supports a more explicit analysis of interferences and especially of social interferences, which are less clearly defined in the HES framework, but well developed in the MLP. The conceptualisation of actor-level determinants of agency, a key element of the HES framework, in turn, is not part of the MLP. The linkage of the MLP and the HES framework allows, for example, to conceptually understand the influence of policy changes or societal opinions for individual's agency, as well as to grasp the effect of agency on the different levels and in the different spheres of the system in transition (e.g. the establishment of a new organisation, a new power plant or the development of new technology). This linkage facilitates more analytical accuracy and clarity on the complex interrelations of socio-technical systems in sustainability transitions and supports theory building on determinants of agency as well as the influence of agency on the transition progress.

Third, module 3 also provides **empirical insights on individual's agency** in the context of sustainability transitions from the point of view of change agents in the Allgäu region. On the one hand, the results show determinants of their (successful) agency, such as the embeddedness in a highly connected and divers actor network, with strongly overlapping but still divers goals and strategies, combining a conservative mind-set with the openness for new solutions and finally a strong embeddedness in the local context and established structures. The change agents e.g. aimed at maintaining the regional value creation by developing social and technological solutions for regional renewable energies and connect them to the existing system. On the other hand, the results also show the change agent's evaluation of (negative) systemic feedbacks in the mature phase of the transition and their way of learning how to adapt their agency and reduce their efforts to push the regional energy transition. Module 3 herewith provides empirical evidence to reflect on the (difficult) role of "pioneers" or so called "challengers" in mature sustainability transitions.

Key findings

- Re-conceptualisation of the HES framework for socio-technical systems promotes the advancement of systematic analysis of agency embedded in the systemic context, considering system- and actor-level determinants as well as systemic feedbacks of agency.
- Re-conceptualisation of the HES framework was done through an expanded understanding of the systemic environment (social, technical and environmental) and conceptualisation of hierarchical levels for the technological subsystem.
- Exemplary empirical application proved suitability and usefulness of the framework.
- Empirical analysis of change agents in the region *bayerisches Allgäu* showed shared goals and strategies among the agents, evaluations of positive and negative feedbacks on different hierarchical levels and interferences among them as well as learning processes of the change agents.
- Integrability of re-conceptualised HES framework in transition studies context is possible through a linkage of its hierarchical levels to the structuration levels of the MLP.

Contribution: Module 3 presented a framework for understanding individual's agency, embedded in the systemic context, whereby the system influences the behaviour of the actors and their agency, in turn, influences the system in which they are embedded. This framework is based on a rich system understanding and focuses particularly on the actor-level determinants of individual's agency. Module 3 applied the framework to the empirical case of change agents in a regional energy transition. In doing so, it provided a conceptual and empirical contribution to better understand individual's agency embedded in and interacting with its systemic context as one key driver of transition dynamics.

5.4 Improving the understanding of incumbents in sustainability transitions of socio-technical energy systems – Empirical exploration and theoretical conceptualisation of urban utility companies in Germany and Switzerland

Module 4 tackled the **research question 4** "How to improve the empirical and theoretical understanding of incumbents' diversity and roles in sustainability transitions of socio-technical energy systems?". Full results can be found in publication 5 and 6 (part B).

5.4.1 Results module 4 (publication 5 and publication 6)

Module 4 provides results on three levels: i) the empirical exploration of urban utility companies (UUC) in the context of the energy transition, ii) the conceptualisation of analytical categories for public incumbents in network industries and iii) the re-integration of these categories in the triple embeddedness framework and the wider transition studies context.

Empirical analysis The empirical exploration of UUC in Germany and Switzerland, carried out in module 4, was based on the triple embeddedness framework (TEF) by (Geels, 2014). The TEF conceptualises firms as embedded on three levels: the industry regime, the economic task environment and the socio-political environment. The TEF explains (incumbent) firms' behaviour in sustainability transitions as strategic answers to external pressures from these different levels (for a more detailed explanation see publication 6). In order to carry on the integrated agency concept, developed in module 3, the empirical analysis was complemented by an exploration of the UUCs' characteristics (actor-level determinants of agency) and their role for the transition process (feedback of agency to the system transition).

Key characteristics of UUC can be summarised in local public ownership, being a multi-energy and multi utility company (horizontal integration) as well as network operator and producer (vertical integration), being embedded in market and monopoly logics and facing diverging expectation from the owner (see Figure 5-19).

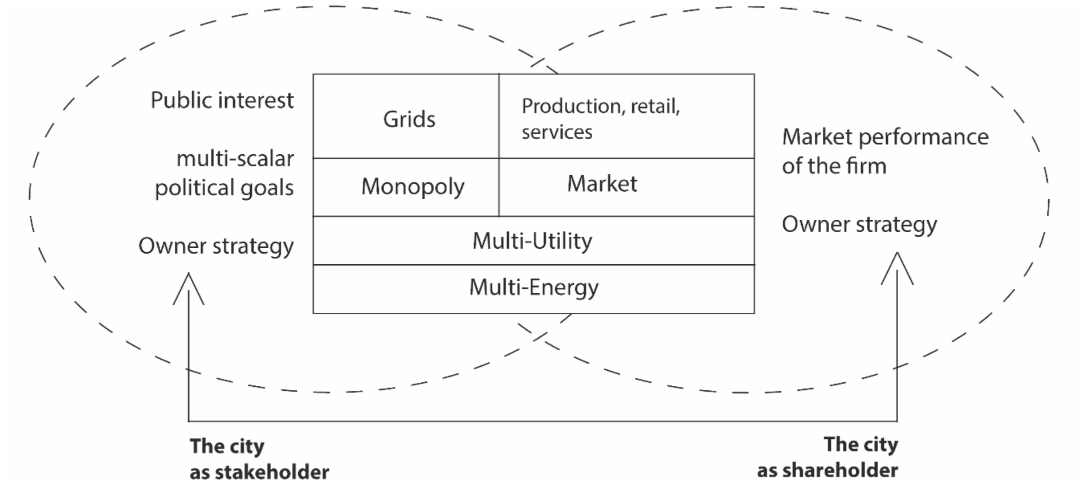

Figure 5-19: Characteristics of urban utility companies (author's own representation based on (Mühlemeier, 2018))

Challenges they face can be subdivided in global challenges, which are also true for other actors in the energy sector (e.g. liberalisation, decentralisation, decarbonisation, digitalisation) and specific challenges, which result from their characteristics (e.g. diverging regime logics between monopoly and market, mismatching owner expectations or the overlap of administration and entrepreneurial mind-sets). Strategic answers they gave can be grouped in the areas of adaptation (e.g. organisational change for competition - establishment of innovation department; or mind-set change, higher qualified and more diverse job profiles) but also valorisation of their characteristics (e.g. using multi-energy for sector coupling and related product development or their proximity to politics and society for framing or product development) and stability (e.g. re-focussing on the local context, the connection to politics, emphasising their role for system stability and public services). Regarding their role for the system transition, key findings can be again subdivided in two areas, their role for the system in transition (e.g. guarantee local supply security, public services, stable local revenues) and the transition process itself (e.g. invest locally and internationally in renewables, support technology development and local pilots, implement network adaptation). Finally, their roles can be summarised as them being "intelligent followers" in the transition process and the "engineers" and "social workers" of the transition process (quotes from the expert interviews).

For further details on the empirical results regarding challenges and strategic answers see also additional publication 3 (appendix section B.3 – in English). Further detail on target conflicts and their potential future roles can be found in additional publication 4 (appendix section B.4 – in German).

Conceptualisation The results of the empirical exploration were subsequently interpreted against the theoretical background of public corporate governance and network industries literature. UUC were conceptualised as public incumbent companies in network industries. This conceptualisation resulted in the development of six analytical categories, which capture the specifics and facilitate an in-depth understanding of public incumbent companies in network industries. The analytical categories can be grouped in structural categories (multi-dimensional roles of owner, infrastructure network operation, federal governance structure) and processual categories (corporatisation and cultural change, conflict of public interest and market performance, democratic control and competitiveness) (see Table 5-8).

Table 5-8: Analytical categories for urban utility companies as public companies in network industries (from publication 6).

Analytical category	**Theoretical reference**	**Empirical evidence**
Structural categories		
Multidimensional roles of the owner	(Lienhard, 2009)	The city administration encounters the UUC as owner, legislative (different parties), executive (different ministries) and judicative with diverging interests.
Infrastructure network operation: natural monopolies and re-regulation	(Finger and Künneke, 2011; Finger and Jaag, 2015; Künneke, 2009)	The natural monopoly of networks results in public ownership and in the analysed cases the network operation by UUC. The UUC operate in market and monopoly, influenced by strong regulations. A recent example: renewable energies and digitalisation trigger the discussion on how to manage and finance grid balancing (e.g. with strategic reserves or smart steering measures like virtual power plants).
Federal governance – multiple political goals and means	(Schäfer and Otto, 2016; Rave, 2016).	Due to the bottom-up subsidiary organisation of the sector, UUC are traditionally regulated on the municipal level, however liberalisation, energy transition and digitalisation are regulated top-down on a European and national level, which causes mismatching regulations.
Processual categories		
Corporatisation and public entrepreneurship	(Bernier and Hafsi, 2007; Greiling et al., 2013)	The liberalisation entailed the corporatisation of many UUC and still causes their adaptation to market-based logics, including organisational change (e.g. establishment of innovation management) and cultural change (e.g. developing new competences).
Public service vs. profitability	(Schedler et al., 2011; Schedler et al., 2007; Schedler and Finger, 2008)	The city administration as owner and political player has diverging expectations on profitability of the UUC and its compliance with energy transition goals, e.g. the investment in renewable energies, energy efficiency measures or the divestment from non-renewable energies.
Democratic control vs. competitiveness	(Rentsch, 2017; Jensen and Meckling, 1976)	The city administration wants to execute as much democratic control as possible but wants the UUC to be as competitive and profitable as possible. Thus, there are e.g. discussions on the composition of the administrative board (share of policymakers, engineers or business experts).

Integrability: Finally, the developed analytical categories were linked back to the TEF to complement the framework with actor-level determinants and additional analytic dimensions for the particular application of the TEF on public incumbent companies in network industries. The analytical categories exemplified and complemented the TEF on four levels: i) vertical embeddedness – industry regime (e.g. the category "federal governance" complements, that external institutions also can stem from other federal levels), ii) horizontal embeddedness – socio-political and economic environment (e.g. the "multiple roles of the owner" category exemplifies the importance of the intersection of socio-political and economic environment and the particularity of the owner acting in both spheres) iii) core vs. peripheral position of firms (e.g. the "infrastructure network operator" category complements the aspect of the networks' physical reality to the monopolist position), iv) strategic answers and learning (e.g. the "public service vs. profitability" category complements the TEF by alluding to the “natural” paradoxes in their strategic answers). Publication 6 also provided a concise overview table on this linkage. The empirical exploration of UUC as one particular group of incumbents in federal energy governance systems and the resultant conceptualisation of the six analytical categories contributed to a more refined empirical and theoretical understanding of incumbents in socio-technical energy systems in transition. The linkage of these categories to the TEF, finally, allows to integrate them in the wider transition studies context and contributes to enhanced theory building and understanding of incumbents in sustainability transitions.

5.4.2 Contribution to the dissertation’s overall research aim

Results from module 4 contribute on four levels to the overall research aim of the dissertation:

First, they provide a **rich understanding** of a key actor in federal energy governance systems, i.e. UUC, as well as determinants of its agency. This uncovers not only a specific type of incumbent and its particularities for an international audience (UUC were hardly considered in transition studies, so far) but also shows the diversity of incumbent actors and contributes to a deeper understanding of their agency in the context of mature transitions. On the one hand, UUC are key actors for the technological system functionality (e.g. a local grid operator) as well as for the social system functionality (e.g. through their public services obligation). On the other hand, and this differentiates them from the classical incumbents, which are considered opponents to transitions, the UUC are public firms, owned by the city and often pushed by their owners to support and act for the sustainability transition. They play an important role in connecting new solutions (e.g. prosumers, power-to-x solutions) to the existing system (e.g. the grid, the urban infrastructure). The rich empirical evidence from module 4 thus reveals the diverse roles of the UUCs for system functionality and transition dynamics in mature sustainability transitions and build the basis for further theory building.

Second, module 2 provides a **theoretical conceptualisation** of actor- and system-level determinants of the urban utility companies’ agency, by conceptualising them as public companies in a network industry. The structural and procedural analytical categories developed in this module capture structural determinants on the actor-level (public company, multi utility) as well as on the system-level (federal governance structure, network industry) and allude to transition dynamics on the actor-level (organisational and cultural change) as well as on the system-level (liberalisation, digitalisation). They facilitate generalisation of the case specific findings, allow for cross-case comparison and support theory building to understand urban utilities as well as the wider context of public incumbents in network industries. By focussing on one key regime actor (in federal energy governance systems), they contribute to an improved understanding of structures and dynamics in mature sustainability transitions, for which these actors play a crucial role for the integration of sustainable solutions to the system and for the large-scale success of the transition.

Third, module 5 presents concrete propositions, how the **analytical categories can be linked** in a complementing or exemplifying manner **to the building blocks of the TEF**, which embeds them in sustainability transition studies. This linkage improves the conceptual understanding of the specific actor- and system-level determinants of public incumbents’ agency in network industries in the context of sustainability transitions. The TEF, for example, puts a particular focus on the importance of the so called “industry regime” (regulations, values, mind-sets in the industry) as determinants for agency. The analytical categories show that regulation plays an important role in the energy sector and therewith exemplify and complement the TEF regime notion. This is due to the “natural” monopoly in networks. The analytical categories show that different levels of regulation influence the agency of public incumbents, because of the federal governance structure. The combined theoretical basis of TEF and the analytical categories provide a rich analytical heuristic, which is case-specific to federal energy sectors, but still general enough to facilitate comparison within the sector and to other network industries. The comparison of public incumbents in structurally similar (network) industries can additionally improve the understanding of mature sustainability transitions. Finally, the linkage to the TEF provides an example of how existing transition studies frameworks can be complemented with other theoretical backgrounds and be applied to the specific case of energy systems in mature sustainability transitions.

Key findings

- Urban utility companies can be characterised by their public ownership, their horizontal and vertical integration and the parallelism of monopoly and market regimes.
- Besides global challenges in the context of the energy transition, urban utility companies also face specific challenges, which are related to their key characteristics. Their strategic answers can be grouped in the areas adaptation, valorisation of their specificities and stability.
- Urban utility companies play important roles for the system's stability during the transition as well as for the progress of the transition process.
- Six structural and processual analytical categories can be derived from the conceptualisation of urban utility companies as public (incumbent) companies in network industries.
- The six analytical categories can be linked to the main building blocks of the TEF in an exemplifying and complementary manner.

Contribution Module 4 transfered the agency understanding of module 3 (embedded an interacting with its systemic context) to the organisational level. Module 4 presented important insights from an in-depth empirical study of urban utility companies in Germany and Switzerland. From this empirical basis, it revealed generalised actor- and system-level determinants of their agency and developed theoretical, structural and procedural analytical categories. In doing this, it deepened the empirical understanding and theoretical conceptualisation of agency in mature sustainability transitions.

Chapter 6 Discussion

The following chapter discusses the relevance of the dissertation's findings for the study of resilience in socio-technical energy systems in transitions (section 6.1) and for the study of agency in sustainability transitions of socio-technical energy systems (section 6.2). Within the two sections, the contributions are discussed following the structure of the research gaps. Subsequently, section 6.3 synthesises the findings and discusses their relevance for the study of actor- and system-level structures and dynamics of mature sustainability transitions - in order for the thesis to be closed by a reflection on its contribution to the overall research goal.

6.1 Relevance of the results for the study of resilience of socio-technical energy systems in transition

Module 1 and 2 worked on the conceptualisation, operationalisation and empirical analysis of a (dynamic) resilience concept for socio-technical energy systems in transition. For this conceptualisation, they drew on the resilience thinking concept from socioecological systems literature and contribute to a dynamisation and equal conceptualisation of the social and the technological subsystem, which facilitate a better understanding of resilience in socio-technical energy systems in transition (research gap 1). The operationalisation of the resilience concept in an indicator set and its empirical application provided a tool kit and discussed methods for the empirical analysis of resilience in socio-technical energy systems in transitions (research gap 2). Finally, the findings from conceptualisation, operationalisation and empirical application fed back into and contribute to a more informed discussion of pre-existing theoretical concepts. In engineering resilience, they discuss the resilience vs. reliability orthodoxy, and the 4R framework, in resilience thinking literature they discuss the concept of specific and general resilience as well as system identity and for both, they discuss the conceptualisation of social resilience.

In conclusion, the findings of this dissertation contribute to the study of resilience on three levels: i) a better understanding of resilience of socio-technical systems in transition (dynamisation, equal conceptualisation of social and technological sphere), ii) tools for empirical analysis (empirical application) and iii) the discussion of pre-existing theoretical concepts in engineering and resilience thinking (4R concept, specific and general resilience, system identity). Subsequently, these contributions are presented in detail.

Research gap 1: Lack of resilience conceptualisation for socio-technical energy systems undergoing a purposive transition

As elaborated in section 2.1.1, resilience literature related to energy systems and critical infrastructures mainly focuses on the retrieval of the (technical) system's functionality after external shocks as well as on how structural aspects of the technological system and management processes in the social system can support this retrieval. Energy system related resilience literature, however, does not yet consider aspects of deliberate and purposive transitions and its effects on the systems' resilience, nor does it provide an equal conceptualisation of the social and the technological subsystem in energy systems. The dissertation's findings contribute to this first research gap on two levels: i) the better understanding of resilience in socio-technical systems in transitions through the dynamisation of the static resilience concept in energy related research and the equal conceptualisation of the social and technological subsystems, respectively strengthening of the social perspective for energy systems resilience; ii) a discussion of pre-existing concepts in engineering resilience, i.e. the resilience vs reliability orthodoxy and the 4R framework of key concepts in energy systems resilience: robustness, redundancy, resourcefulness and rapidity.

Dynamisation of energy resilience The operationalisation of resilience for socio-technical energy systems in transition, based on the conceptualisation of resilience thinking for energy systems, contributes to a dynamisation of the static resilience concept, which is predominant in energy resilience research. It changes the focus from passive and reactive system behaviour in face of extreme, system external shocks (e.g. a blackout) towards active, deliberate and system-internal dynamics (e.g. the effects of subsidy schemes for renewable energy systems). It facilitates a better understanding of resilience in energy systems, which undergo a purposive transition. The findings of this dissertation challenge the predominant orthodoxy of reliability and resilience, where resilience is only relevant for high-impact and low-probability shocks and reliability comes only into play for low-impact but high-probability shocks (Panteli and Mancarella, 2015). In the context of a deliberate transition, however, high-impact changes with high probability are the order of the day, and they occur in a non-linear order and self-enforcing magnitude (e.g. digitalisation opened new possibilities of liberalisation and pushed the expansion of renewables at the same time). The findings show that the resilience of an energy system, which undergoes a deliberate transition, does not only consist of the ability to react to shocks and return back to business-as-usual as quickly as possible, but also to adapt gradually to fundamental and emergent changes on the long run. The presented conceptualisation and operationalisation of resilience for socio-technical energy systems in transition therefore enriches and complements the existing concepts for energy resilience and increases reflexivity, especially regarding the social dynamics of an energy system.

Equal conceptualisation of social and technological subsystems Engineering resilience mainly focuses on the assessment of technological resilience, whereas the resilience of the social subsystem is not of particular interest. The dissertation's findings however show, that the general resilience of an energy system results from the interplay and co-evolution of the specific resilience of the social and the technological subsystem. The proposed indicator set and its equal conceptualisation of the social and the technological subsystem allows to assess the technological and the social subsystem individually as well as together and particularly analyse their function for the overall resilience. The indicator set provides a tool to assess the system's and its subsystems' resilience for one point in time but also during a process (e.g. the reaction to a shock). Furthermore, it also facilitates the cross-subsystem comparison (due to the same indicator sets for both subsystems) and supports insights from the analysis of structures and dynamics in the two subsystems. The social and the technological subsystem are both considered complex systems so that the logics and organisation mechanisms of one subsystem can be transferable to the other. The role of a broker agent for the connectivity among social arenas, for example, can be transferred to the technological subsystem, where brokering technologies such as power-to-gas/-heat increase the connectivity and contribute to the system's resilience. Finally, the equal conceptualisation of the social subsystem also contributes to a strengthening of the social aspects in the context of engineering resilience and facilitates their systematic analysis.

Discussion of 4R The findings of this dissertation also contribute to a discussion of the – in engineering resilience – predominant 4R framework, which describes the key abilities of a resilient system as: robustness, redundancy, resourcefulness and rapidity (see e.g. Panteli and Mancarella, 2015). Especially, findings from Module 2 show, how a certain level of diversity and connectivity allows for a compensation of drop-outs in the system (robustness) and provides a wide range of different and accessible resources (resourcefulness). Redundancy is particularity dependent on the indicators disparity (qualitative difference) and balance (share in total amount of entities). For example, technology groups can only substitute each other if they are connected and similar enough regarding their qualities and production capacity (e.g. hydropower can substitute coal, since the storability of its resource allows base-load supply and with high efficiency rates it also provides enough capacity). Finally, rapidity is critical for the reaction to extreme shocks and the return to business-as-usual, however, in the context of a long-term transition e.g. persistence is equally, if not more important, to adapt the system and transform it in such a way, that it can endure the shocks on the long run. This aspect relates back the dichotomy of reliability vs. resilience, which needs to be reframed and broken up for the analysis of socio-technical energy systems in transition.

Research gap 2: Lacking operationalisation of resilience thinking for the empirical analysis of energy systems, conceptualised as socio-technical systems in transition.

The concept of resilience applied in this dissertation is rooted in the socioecological resilience literature, where robustness, adaptive capacity and transformability are key abilities of resilient systems and systems consist of equally weighted social and ecological subsystems, which undergo constant changes. The resilience thinking concept, however, has not yet been (re)conceptualised for socio-technical systems and also lacks an explicit operationalisation for empirical analysis (see section 2.1.1). The dissertation's findings contribute to this research gap on two levels: i) the operationalisation and empirical application of the indicator set as well as the discussion of benefits and challenges of the application contribute to the development of a toolkit for systematic empirical analysis; ii) the discussion of specific and general resilience, the system identity concept and finally to an improved conceptualisation of social resilience in both adaptive and engineering resilience.

Empirical application The operationalisation of resilience for socio-technical energy systems in a concise indicator set provides indicators and related measures, which can be applied to the social and the technological subsystem to analyse resilience. The findings of this dissertation therefore provide a tool for a systematic empirical analysis of resilience in socio-technical systems. The empirical application of the indicator set reveals on the one hand empirical insights on the different levels of diversity and connectivity in the social and the technological subsystems throughout the transition process and contributes to a more precise empirical understanding of resilience in socio-technical systems during a transition process. On the other hand, it provides and discusses different qualitative and quantitative methods, which facilitate the empirical analysis. Particularly, the quantification of qualitative data on the social subsystem enriches the method set available to empirically analyse resilience. The applicability of the indicator set in the empirical analysis also shows their explanatory power for socio-technical systems and points out that the general resilience of the energy system results from the co-evolution of the social and the technological subsystems as well as thesubsystems' specific resilience. Only if the specific resilience(s) of the subsystems are aligned, the general resilience of the overall system can be maintained throughout the transition process. The co-evolution of subsystems for transition is a "classical" concept from socio-technical system research and mirrors, how the findings of this dissertation also contribute to a further linkage and integration of concepts and approaches of the socio-technical system's and socioecological system's literature (Smith and Stirling, 2008; Chappin and Ligtvoet, 2014).

Specific and general resilience The equal conceptualisation and combined analysis of the indicator set for the social and the technological subsystem contribute to an enhanced understanding of specific and general resilience in resilience thinking literature (Folke et al., 2010). As mentioned above, the specific resilience of the social and the technological subsystem need to be aligned in order for the overall system to maintain the necessary level of robustness and adaptive capacity. The equal consideration of the social and the technological subsystem facilitates the explicit analysis and comparison of specific resilience in the two subsystems, to reveal interferences or re-enforcing mechanisms and feedbacks among them and insights about their role for general resilience.

Social resilience The equally weighted analysis of the social subsystem contributed to a more nuanced picture of social resilience and the functionality of the social subsystems in the context of resilience thinking literature. More explicitly as in the technological subsystem, functionality is also a partly relative concept in the social subsystem. During a deliberate transition, actors can discuss, agree and disagree on system functions, which they want to keep stable or change (e.g. affordability of electricity). Actors can decide which system resilience they want and what they are willing to do, accept or pay for it. These discussions have again implications for the rules and the governance structure of the system, for social resources and relations (e.g. the market design), but also affect the technological subsystem (e.g. acceptance for costs of renewables caused subsidy scheme and expansion of new energy production technologies). The findings of this dissertation provide not only a tool kit and analytical basis to systematically assess the resilience of the social subsystem, they also draw attention to the particularities of the social subsystem, its functionality and resilience and the social construction of these concepts. In doing so, the dissertation contributes to the enhanced conceptualisation and theory building on social resilience in the resilience thinking literature (e.g. Cote and Nightingale, 2012; Adger, 2000).

System identity With this, the findings trigger a discussion of the predominant concept about system identity in resilience thinking literature, where system identity is related not only to functionality but also to the structure of the system (Walker et al., 2004). In the context of deliberate transitions, however, the system's structure is purposefully changed, e.g. liberalisation allowed for the entrance of new actors and renewable energy subsidy schemes promoted the decentralisation of the energy system. As presented above, the system's functionality can be re-defined by the actors of a system, too. The findings of this dissertation contribute to a more informed discussion on the relativity of the resilience concept in face of social dynamics and the need for a reconceptualisation of system identity in the resilience thinking literature.

Overall resilience conceptualisation Finally, the operationalisation and empirical application of the indicator set showed in general, that a resilient system maintains a certain level of diversity and connectivity in the social and the technological subsystem throughout the entire transition process, to support robustness and adaptive capacity at the same time. The findings contribute to a reflection on the level of diversity and connectivity needed to maintain the abilities during the different phases of the transition. They provide a first interpretation and reveal tendencies of how system characteristics change during a transition process (e.g. increase of technological diversity, stable social diversity). However, they do not yet provide a robust theory or even quantification of the levels of diversity and connectivity needed for system resilience in the different transition phases. Further empirical evidence and theory-based reflections are needed to refine the relationship among the system characteristics and the system abilities. Figure 6-20 summarises the conceptualisation of resilience for socio-technical energy systems in transition.

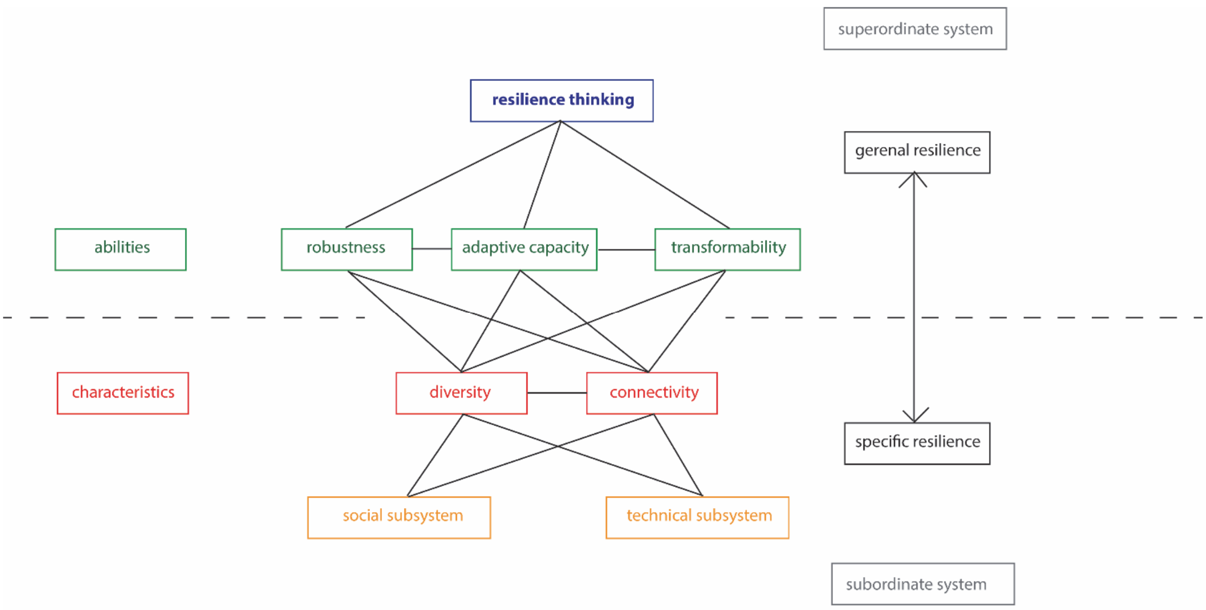

Figure 6-20: Concept of resilience of socio-technical energy systems in transition (author's own representation)

6.2 Relevance of the results for the study of agency in sustainability transitions of socio-technical energy systems

Module 3 and 4 provided a conceptualisation of frameworks for the systematic study of actor- and system-level determinants of agency and its effects on the system in transition as well as an in-depth empirical analysis of agency on the individual and organisational level. In doing so, they contributed to an improved empirical and theoretical understanding of agency in sustainability transitions in general (research gap 3) and more particularly of the role of incumbents in sustainability transitions (research gap 4). The findings drew on the original concept of actor-rules-system-interactions in transition studies and the related frameworks MLP and TEF. Module 3 complemented the MLP with a framework from individual psychology, for the improved conceptualisation of agency on the individual level. Module 4 complemented the TEF with analytical categories for incumbents, derived from public corporate governance and network industries literature for an enhanced conceptualisation of incumbents' agency. The theoretical footing was iterated with empirical findings from the in-depth study of change agents (module 3) and UUC (module 4). Besides the enhanced conceptualisation of agency in sustainability transitions, the dissertation also contributes more systematic approaches to the empirical study of agency in transition studies. Finally, the linkage of the findings back to transition studies frameworks (TEF and MLP) facilitates accessibility of the findings for transition scholars and contributes to a more informed discussion on established concepts in transition studies, such as the conceptualisation of higher structuration levels, the image of incumbents and the underlying economic paradigm of transition studies.

In conclusion, the dissertation's findings from module 3 and 4 contribute to the study of agency on three levels: i) a better understanding of influence factors and impacts of agency on the system transition towards more sustainability, ii) a more systematic empirical analysis and iii) the feedback into transition studies and discussion of pre-existing concepts. The subsequent section discusses these contributions in detail, structured according to the individual research gaps.

Research gap 3: Lack of a comprehensive framework to empirically analyse system-level and actor-level determinants of agency as well as the role of agency in sustainability transitions of socio-technical energy systems

As presented in section 2.1.2, transition studies indeed provide a rich conceptual bases for the analysis of agency in the context of systemic transitions and conceptualise socio-technical systems as consisting of actors, artefacts and rules as well as the related interactions. They however lack a comprehensive framework for an empirical analysis of the triangle of actors, artefacts and rules – respectively, an operationalised framework for the analysis of agency considering both, actor- and system-level determinants as well as the feedback of agency to the system. Overall, transition studies lack a better conceptualisation and consideration of the actor perspective in the context of sustainability transitions. The dissertation's findings contribute to this third research gap on two levels: i) re-conceptualised framework for the systematic study of agency and empirical example of such a systematic study, ii) strengthened conceptualisation of the actor-level, which contributes to a better understanding of higher structuration levels in sustainability transitions.

Systematic study With the conceptualisation of the HES framework and the development of the analytical categories for public incumbents in network industries, the dissertation strengthens and refines the actor-level perspective in transition studies, by providing concrete concepts for the empirical analysis of actors and their agency and the linkage of these concepts to established transition studies frameworks. The findings provide examples for comprehensive and empirically applicable approaches for the systematic analysis of actor- and system-level determinants of agency as well as the analysis of feedbacks of agency on the system. Their empirical application gives an example of such a systematic, framework-based but still complex and in-depth agency analysis in the context of sustainability transitions. In tradition of Geels' actors-rules-artefacts interaction triangle, this also works on the long-standing claim, of lacking operationalisation of Gidden's structuration theory (see e.g. Pozzebon and Pinsonneault, 2016), since the findings provide concrete concepts for the analysis of influences of structure on agency (actor- and system-level determinants) and the influence of agency on the structure (feedback of agency, role of agency for transition), while explicitly considering the system (social networks and physical reality of artefacts in the energy sector). Overall, the findings of this dissertation contribute to a more complex but also structured analysis of agency. They finally allow for cross-case study or cross-sectoral comparison, which is recently claimed as a fundamental need for the further development of transition studies (Markard, 2018). This framework-based cross-sectoral analysis of agency e.g. in infrastructure sectors can decisively contribute to improve the understanding of dynamics in other infrastructure sectors as e.g. the telecommunication sector, the public transport sector or the water sector, which are all considered as network industries and thus as based on similar actor types, rules and types of artefacts.

Higher structuration levels The dissertation's findings also contribute to a better understanding and facilitate theory building on the higher structuration levels of socio-technical systems in transitions – the regime and the landscape in MLP terms. By drawing analytical attention to individual motivations, aims and evaluation of feedbacks from the environment, the HES framework provides the basis to analyse actor-level factors, which shape the landscape and the regime. In transition studies, the poor conceptualisation of the landscape is a long-standing claim for further development (e.g. Geels, 2011). By focussing on the actor-level dynamics, this further conceptualisation of the landscape can be promoted. Similarly, the analytical categories of module 4 provide a richer understanding and conceptualisation of regime dynamics. On the one hand, they help to understand incumbents' agency, on the other hand, they also help to understand, why the incumbents reproduce the regime in a certain way and thus, why the regime is structured as it is. The focus on the actor-level dynamics does not only allow a better understanding of the higher structuration levels in socio-technical systems in transition, it also provides the basis for changing them and fostering mature sustainability transitions. Knowing the psychological dynamics of individual's agency or the particularities of the technological regime of public companies in network industries allows for more informed policy making, campaign design and media reports. Finally, the conceptual findings of this dissertation link transition studies literature to environmental psychology, public corporate governance and network industries literature (depending on the actor type under study). This opens doors for further integration, complementary use and cross-fertilisation between the different strands of literature, which decisively contributes to a more informed analysis, better understanding and improved theory building on individual and organisational agency in the context of transition studies.

Research gap 4: Lack of a more nuanced picture and systematic analysis of the different roles and types of incumbents in the energy transition.

With regard to the specific analysis of incumbents in the context of sustainability transitions, transition studies started off with a too simplistic and purely negative picture of their agency as only hampering the transition. Recently, transition scholars refined this picture and work on more nuanced analysis of incumbents' agency in sustainability transitions. This more fine-grained understanding was however not yet applied to the energy sector and studies on incumbents in the energy transition only focus on national champions, such as Alliander, EON or RWE. A more nuanced picture of the different types and roles of incumbents in the energy transition is still lacking (see section 2.1.2). The dissertation's findings contribute to this fourth research gap on three levels: i) empirical and conceptual findings for a more nuanced picture on incumbents, ii) the assessment of the role of agency in transitions and iii) a discussion of predominant assumptions in transition studies based on findings from the example of UUC.

More nuanced picture The empirical findings of the explorative analysis of UUC as particular type of incumbent in federal energy governance systems provided rich insights into their characteristics, challenges, strategies and different roles for the sector and its transition. UUC for example play an important role in ensuring social and technological stability (equity and functionality) on the local level during the transition process. At the same time their public owners also push them towards more flexibility and change. One of their key roles is connecting technologies and actors on different levels and across sectors. UUC also play a decisive role for the resilience of the socio-technical energy system in transition (further elaboration in section 6.3). Hence, the empirical findings contribute to a more nuanced picture on incumbents' agency beyond the study of national champions and also exemplify the particular actor type "urban utility company" to an international, non-German speaking audience. Additionally, the findings help to overcome the common dichotomy of positive challengers and negative incumbents in transition studies by showing the diversity of roles incumbents can play during an energy transition process. In this context, the conceptual findings on the six analytical categories provide a systematic basis for a more neutral and fine-grained analysis of incumbents. They allude to commonalities of public incumbents in (other) network industries and with their linkage to the TEF framework they facilitate the systematic cross-sectoral analysis, mentioned above. Finally, these findings do not only contribute to cross-sectoral empirical analysis but also open doors for improved theory building and more informed discussions on incumbents in network industries.

Role of agency With this more neutral and nuanced approach to study incumbents as well as by providing empirical findings on the diversity of incumbents' roles for the energy transition, the dissertation contributes to an improved understanding and a strengthened analytical weight of the role of agency in transitions studies. It also kicks off a discussion on assessing the contribution of actors to the transition progress. For the progress of a transition, particularly in its mature phase, every contribution in the desired (more sustainable) direction counts, regardless whether it comes from a challenger, incumbent or somebody different. Related to the lack of systematic analysis of agency, transition studies did not yet provide concepts or tools to assess this contribution of actors to the transition process. The presented frameworks help to pay more attention to the effects of agency on the system and can build a basis to develop an evaluation framework for actors' contributions to sustainability transition.

Predominant assumptions Finally, empirical findings from the analysis of UUC provide an interesting example of urban infrastructure self-governance. On the one hand, this alludes to polycentric governance, which plays an important role for the resilience of a socio-technical system and will be elaborated at the end of the following section. On the other hand, these findings challenge the predominant capitalist paradigm in transition studies. Transition scholars do not (yet) openly question the paradigm of neo-liberalism, economic growth or the dominance of market-based solutions – in European infrastructure sectors. In this context, the study of UUC, especially for the case of Switzerland, shows different solutions and paradigms in local infrastructure management. Public service orientation, public ownership, democratic control and local monopolies (in the case of Switzerland) are only a few examples. With their roots in public administration and their infrastructure network basis, UUC did not operate profit-oriented for a long time. They did not need to grow or to specialise, since they were in charge to manage the entire urban system and find systemic solutions. And although they adapt to the market-based and profit-oriented regime, which is pushed by the EU, UUC still provide interesting examples of alternative mind-sets, beliefs, solutions and approaches, which fundamentally challenge the neo-liberalist paradigm. From the more in-depth study of the diversity of incumbents in infrastructure sectors, transition studies thus could start a more informed discussion on the fundamental underpinnings - the landscape - of sustainability transitions.

6.3 Contribution of the findings for the improved understanding of actor- and system-level dynamics of mature sustainability transitions

The subsequent and last section of the discussion summarises and synthesises the conceptual contribution of the dissertation's individual modules (presented in sections 2.3.1 to 2.3.4 and sections 5.1.2, 5.2.2, 5.3.2 and 5.4.2) and links them back to the conceptual fundamentals (section 1.2) to show their explanatory value and integrated contribution for the overall research aim of this dissertation:

Research aim of this dissertation is to understand key aspects (structures and processes) of mature sustainability transitions in the energy sector from both the system and the actor perspective.

6.3.1 System configuration – Resilience range in transitions

Module 1 and module 2 focused on the analysis of system functionality for socio-technical energy systems in mature transitions. Based on the resilience concept, they presented a conceptualisation of system functionality, which results from the balance of diversity and connectivity on multiple scales of the socio-technical system and allows for a balance of stability and flexibility on multiple scales of the system. Stability and flexibility are considered key system abilities, diversity and connectivity are considered key system characteristics. The overall system is conceptualised as a nested system of systems, which has a social and technological sphere on each level (compare layers in Figure 6-21).

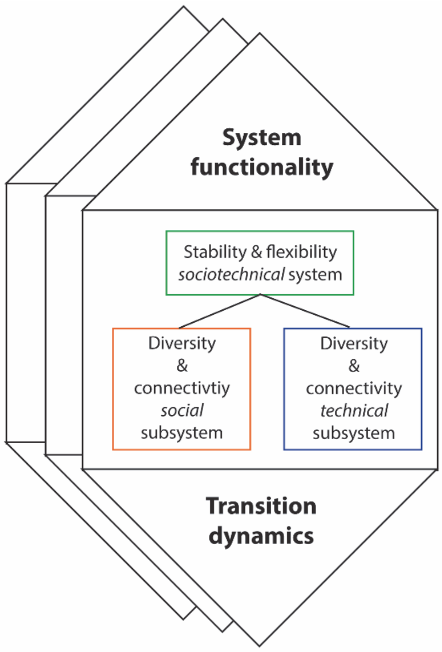

Figure 6-21: System characteristics and abilities for system functionality - allowing for transition dynamics (author's own representation)

In order for the overall system to maintain its functionality while fostering transition dynamics in the mature phase of its sustainability transition, its system characteristics need to be balanced and aligned among the spheres (social and technological) and the scales (e.g. organisation, region, nation). The relation of diversity and connectivity to the functionality and transition dynamics of the system can be conceptualised as an ideal-type "**resilience in transitions-range**" within which the system is resilient during the ongoing transition (see Figure 6-22).

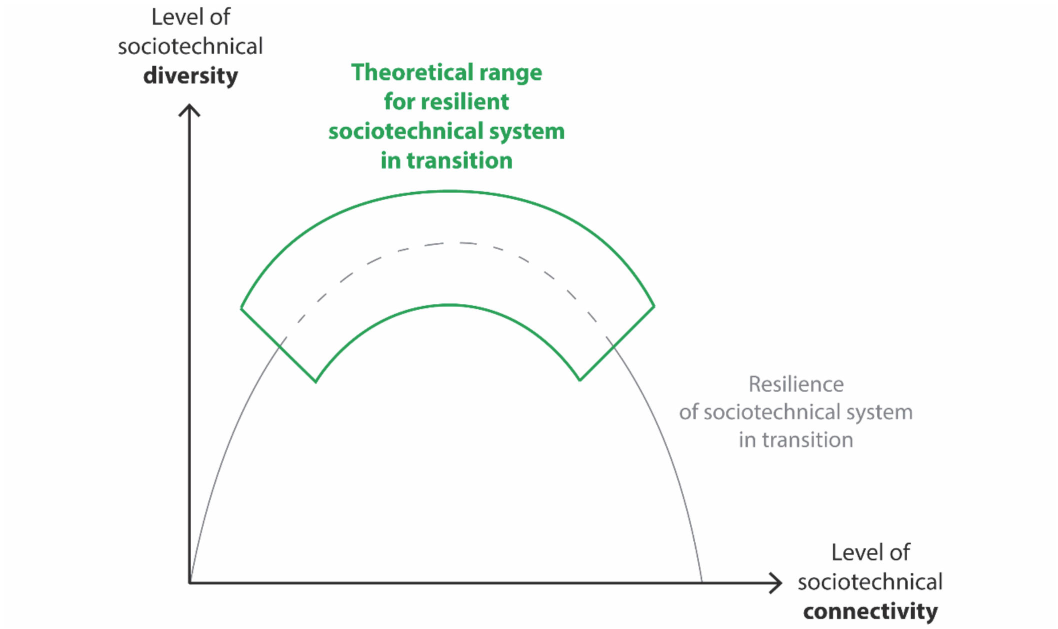

Figure 6-22: Theoretical range of resilience for socio-technical energy system in transition (author's own representation)

Below this range (too low diversity and/or too low connectivity) but also above this range (too high diversity and/or too high connectivity) the system is not resilient. Its functionality is endangered and it might collapse if a shock may occur. At the same time it also does not allow for transition dynamics. Too low diversity and connectivity do not allow for the development of alternatives in the system, too high diversity and connectivity do not allow the system to function efficiently to actually perform the transition. Moreover, diversity and connectivity values *both* need to stay within this range. For example, a high diversity of energy production technologies can only operate in a secure manner if the technologies are connected, either to the overall system (e.g. the grid which is highly connected) or among themselves on a local level (e.g. on the household or quartier level). Additionally, the qualitative differences of the technologies can be balanced through their connection to other technologies (e.g. connection of base-load and peak-load technologies or technologies using different resource bases, storable or not).

The empirical findings from the explorative application of the indicator set to regional socio-technical energy systems (see section 5.2.1) provided first qualitative indications regarding the "**necessary levels of diversity and connectivity**" which hypothetically mark the lower and the upper end of this "resilience in transitions – range". From what we have seen in the empirical analysis, the levels of diversity and connectivity do not stay constant but vary over the course of a sustainability transition. In the individual phases, different aspects therefore become more important than others.

In the **pre-development phase**, the social system needs to allow for modules to emerge so that pioneers or change agents can form their networks – the overall connectivity of the social system should therefore not be too high. These modules should have a medium level of diversity including diverse actors with different backgrounds and approaches. These modules must not be driven by politicians only but also include industry actors, research and ideally also representatives of the wider society (e.g. NGOs or associations). The actors, however, need to have enough in common to be able to effectively work together (debates on principles would hinder these pioneer networks) (compare also results from module 3 in section 5.3.1). Similar for the technological system, in order for technological innovations to evolve successfully, the overall connectivity of the technological system should not be too high. Modularity is important, since the technological system needs to function – without the innovations and also if they are tested in the system (e.g. a new storage unit, which might suddenly fail and feed-in electricity suddenly). At the same time high levels of disparity and variety are decisive to find and test a broad range of alternatives as well as to find those, who fulfil the goals and function best. Their balance can however remain at low levels in this early phase, to avoid potential large system failures.

In the **acceleration and take-off phase**, technological connectivity should remain at medium levels. On the large scale, connectivity needs to decrease to allow for the new technological solutions to be tested and included in the existing system. Especially centrality needs to decrease, e.g. the centrality in the electricity grid, to allow for the inclusion of decentralised technologies without endangering the overall grid stability. These changes also require socio-technical innovations for the management of connectivity (e.g. smart grids and demand-side management, which allow to balance the increasing diversity via the support of local connectivity). In the technological system, the local connectivity needs to increase while the large scale connectivity should decrease. Diversity remains stable, respectively decreases, since certain technologies are selected and their share increases (variety decreases but balance increases). Similarly, for the social system: the centrality of traditional actors needs to decrease (also via changed regulation) so that new actors with new competences can enter the governance system to (help) implement the new solutions (e.g. demand management requires a lot of ICT knowhow and new cognitive paradigms for grid steering). Ideally, these new actors collaborate with traditional actors, to integrate the new management approaches and knowhow in the existing system to ensure its functionality. Social diversity remains stable regarding the variety, however the balance of the actors managing and developing sustainable technologies should increase in the overall system.

Finally, for the **stabilisation phase**, the empirical evidence of this study is not yet rich enough, since the regions under study just entered the stabilisation phase. However, it seems to be important, that the technological connectivity on the local and the national level are developed in parallel: local connectivity allows to balance technological diversity on the local level, large scale connectivity (e.g. through transmission grids) might still be needed to balance the local modules and provide a backup-function. The diversity in the technological system should be balanced on medium levels, to allow for an efficient and robust functioning of the system, while still providing the structural basis to remain adaptive (e.g. through redundancy and alternative solutions). For the social system, local connectivity should remain also on medium levels: decentralised peer-to-peer trading or auto-consumption modules still would need central steering agencies to function efficiently as well as they need entities, which manage their embeddedness in the larger context (e.g. connection to the distribution grid). Most importantly, regulation needs to change to accompany and support the stabilisation of new governance forms.

In conclusion, the relation of **diversity and connectivity to resilience** is not linear – it is not to be considered as the more diversity and connectivity the more resilience but as a complex balance, which builds the structural basis for the system to manage stability and flexibility forces on the different scales of the system (the large scale might need to be stable to allow for flexibility on the local level and vice versa). Finally, the resilience concept proposed here is also not to be considered as contrary to transition dynamics – it is not to be considered as the more resilience the less transition dynamics, but if the system manages to always remain in the "resilience range", it has enough diversity and connectivity to function smoothly and change itself towards more sustainability at the same time – which is especially important in the mature phase of a sustainability transition.

6.3.2 Determinants of agency – Actor-level and system-level framework

Module 3 and module 4 focused on determinants and key drivers of systemic transitions. Their results are summarised in a joint framework for the analysis of actor-level and system-level influence factors on agency as important determinants of transition dynamics (see Figure 6-23). Transition dynamics are influenced by both individual's and organisational agency. **Organisational agency** is conceptualised as a result of and dependent on individual's agency. **Individual's agency**, however, is not necessarily embedded in an organisational context and therefore to be understood as not directly dependent of organisational agency. Consequently, actors are both individuals as well as organisations. Organisations are perceived as "aggregate actors" who behave in a certain way, even though their actual agency is conducted by individuals. Individual's and organisational agency cause multi-scalar short-term and long-term systemic effects, which change the socio-technical system and result in transition dynamics, which then are again perceived by individual actors and influence their agency. Transition dynamics are thus complex, interrelated processes, for which agency is a key driver.

Both, individual and organisational agency are shaped by different determinants, which can be grouped in three levels: **systemic, organisational and individual determinants** (see Figure 6-23). Systemic determinants of agency are institutions (e.g. regulation, norms or values, such as the public services, liberalisation or federalism), the physical-technical system (e.g. grid infrastructure, plants, technologies) and the governance system (e.g. the actor network relations, roles and responsibilities of actors). Organisational determinants are cooperative goals (market performance vs. public services quality), cooperative strategies (e.g. lobbyism on the local level or investment in renewables abroad), cooperative culture (e.g. administrative and entrepreneurial mind-set) and cooperative structure (e.g. multi-utility). Individual determinants are goals (e.g. act for climate change), strategies (e.g. search for strategical allies), perceptions (e.g. positive or negative evaluation of policy change) and learning processes. Individual determinants influence individual's agency directly through the actor, whose characteristics they are. Similarly, organisational determinants influence organisational agency directly through the characteristics of the organisation. Individual determinants also influence organisational agency indirectly, since organisational agency is performed by individuals (see Figure 6-23).

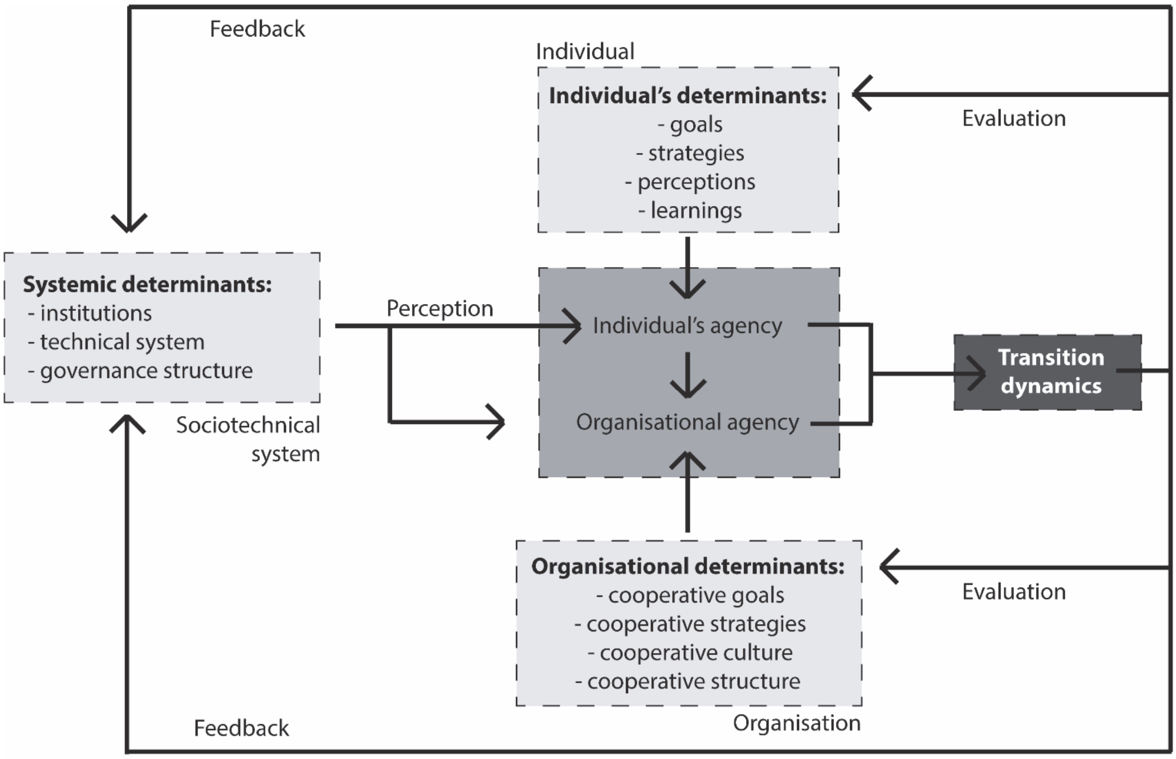

Figure 6-23: Concept of individual and organisational agency as driver for transition dynamics (author's own representation)

The influence of individual's and organisational agency can be positive or negative for transition dynamics. Certain actors might invent technologies, design narratives or create social innovations, which support transition endeavours and are influencing the transition dynamics positively. Others might influence the dynamics negatively – also through technology development, lobbyism or investment in non-sustainable solutions. The proposed framework for actor-level and system-level determinants of agency can be applied to all kinds of actors, whether they are considered as traditional "regime" actors or as innovators acting in a "niche". It is therefore not related to certain structuration levels. It is also important to emphasise that the framework allows to focus on individual's agency or organisational agency for a specific question without ignoring the other level. If for example a study focuses on organisational agency, the framework nonetheless encourages to consider individual agency and their determinants to understand the background and details of organisational agency. And vice versa, if a study works on individual's agency, their potential organisational background should be considered to explain at least parts of their behaviour. In conclusion, this framework serves as a research heuristic for the systematic study of agency, considering explicitly its embeddedness in the individual's, organisational and the systemic context.

6.3.3 Mature sustainability transition – goals, strategies, abilities and characteristics

To link these individual conceptual contributions back to the fundamentals, presented in section 1.2, and embed them even more specifically into the context of mature sustainability, it is important to recall the challenges, which Markard (2018) presented: system functionality, system integration and system reconfiguration are seen as the main challenges for mature sustainability transitions. Based on the results of this dissertation and inspired by the recent discussion that mature sustainability transitions do not only need a scaling-up of more sustainable solutions, but likewise a scaling-down or phasing out of unsustainable solutions (Loorbach, 2014), these challenges can be conceptualised as follows: Besides transition dynamics, maintenance of system functionality is the main aim of mature sustainability transitions. The system integration (of sustainable solutions) and the re-configuration of the existing (partly unsustainable) system structures are key strategies for successful mature sustainability transitions. Stability and flexibility are considered as the necessary system abilities, which support the strategies if they are balanced throughout the entire course of the transition. Finally, the key system charactersitics - social and technological diversity and connectivity - build the necessary structural basis to support the system abilities (see Table 6-9).

Table 6-9: Mature sustainability transition concept (based on Markard, 2018)

Mature sustainability transition	
Goals	Maintain functionality **&** support transition dynamics
Strategies	System integration of new solutions **&** system re-configuration of old solutions
Abilities	Stability **&** flexibility
Characteristics	Social **&** technological diversity **&** connectivity

In order for the system to successfully run through a mature sustainability transition, it needs to keep up socio-technical functionality and transition dynamics, which it can achieve trough the re-configuration of "old" system structures and the integration of "new" – more sustainable – system structures (see Figure 6-24).

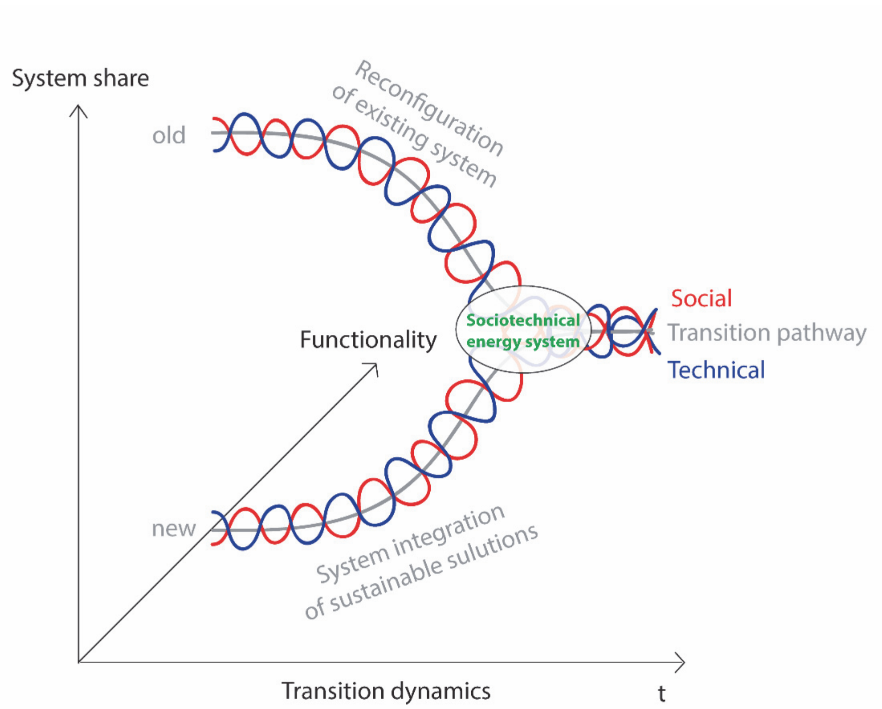

Figure 6-24: Goals and strategies for mature sustainability transitions (author's own representation)

To analyse and understand the system structure and the transition dynamics of a system in a mature sustainability transition, the two analytical concepts presented above – the "resilience range" and the "actor-level and system-level framework" can be linked to the conceptualisation of mature sustainability transition goals and strategies (see Figure 6-25). This integration allows to analyse key structures and dynamics of mature sustainability transitions in the energy sector from both, the system and the actor perspective. The system functionality is reflected in the system characteristics and abilities. The transition dynamics are driven by the individual and organisational agency. The system characteristics and abilities also support transition dynamics and agency supports the system characteristics and abilities.

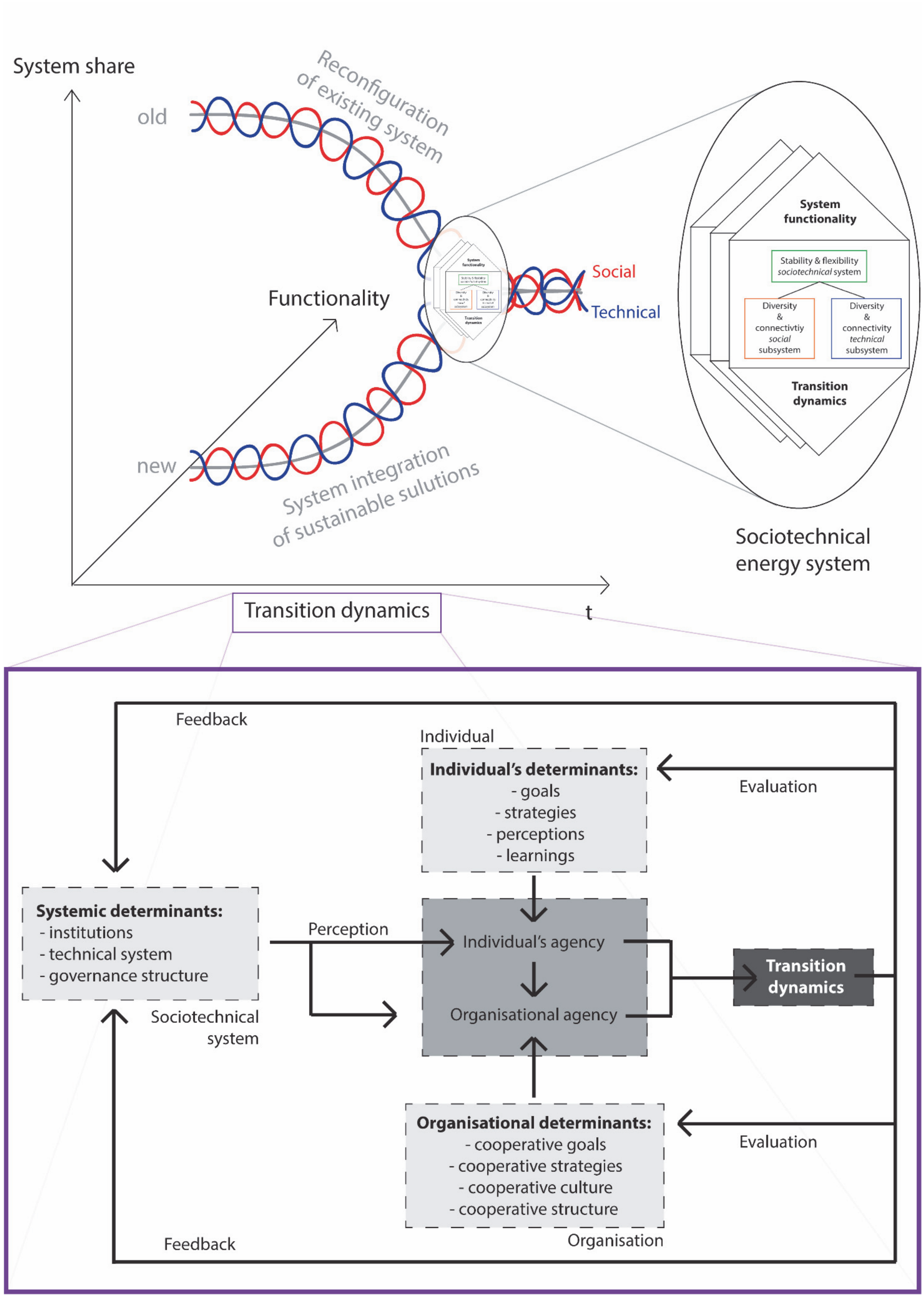

Figure 6-25: Integrated framework on structures and dynamics of systems in mature sustainability transitions (author's own representation)

Reflection: The role of urban utility companies' agency for diversity, connectivity, stability and flexibility

Finally, after having presented the overall framework and key conceptual contribution of this thesis, the discussion concludes by an explorative reflection on how the agency of urban utility companies (UUC) supports system characteristics and abilities for functionality and transition dynamics. This exemplary and non-exhaustive reflection represents an outlook on possible ways for future theory building in the context of mature sustainability transitions. It is based on the rich empirical basis from module 4 and especially on the results of two expert workshops (see section A.4.6).

UUC play an important role for the diversity and connectivity of the (local) social and technological subsystems in the energy transition:

For **social diversity** they e.g. make sure that all citizens of the urban system have access to energy supply, they care for other public services, which allow the social functionality of the system. It is the daily business of UUC to manage the social diversity of an urban system. On the one hand, their customers represent the social diversity of the urban system: from private households in different milieus to small and middle-sized companies in different sectors as well as large industries or public entities e.g. schools. They all have different expectations and needs for their energy supply (while some consumers want to actively contribute to the energy transition as prosumers, other households or businesses just want the lowest energy prices possible, or certain customers are more dependent as others to 100% supply security – a hospital or a highly specialised factory might be very sensitive and vulnerable to any kind of interruption). On the other hand, the social diversity of the urban system is also reflected in the diversity of expectations of their owner – the city. Their owner encounters them with different targets (e.g. in different political parties: the left-wing and green party who are pro change vs. the more conservative parties) and different means (e.g. different ministries: the financial or the environmental ministry, who set different rules). UUC are therefore used to work and cope with this diversity and are therefore able to maintain it on the long-term.

For **technological diversity**, UUC always managed different energy sources at the same time as well as different networks to supply electricity and heat to the city (the electricity grid, the gas grid or district heating networks). It is their key task to find the best technological solutions for the different city districts and consumer needs in their urban area (e.g. heat pumps for individual homes or district heating for entire districts. In the context of this task, but also due to their often progressive owner strategy, they invest in pilot projects for energy efficiency, renewable energy sources and systemic solutions (such as participative PV power projects, district heating with power-to-X solutions, new storage technologies and pilots of local smart grids). In so doing, UUC contribute to technology diversification. Compared to large electricity producers, who might specialise in particular solutions and search for markets internationally, the urban utility is in charge of a local system for which it needs to employ a diversity of technological solutions and services, adapted to the local context. An urban utility company therefore is a technology all-rounder and incorporates a broad body of locally specific knowledge and competences in the firm.

Finally, for **social connectivity**, the UUC are the interface between the technological energy system and the local society. They can link actors to technology (e.g. in participative financing models of renewables, supporting energy cooperatives or peer-to-peer trading pilots). They also have an important coordination function in the local energy system. As grid operator but still also as producer and supplier, they have contact to all local actors and coordinate them for a smooth functioning of the local energy system. Moreover, they also connect and balance the consumer needs on the one side and the owner goals and expectations on the other side. Finally, their customer is at the same time indirectly also their owner, the citizen. And so, they have a tradition of maximising the "profit" for their owner not financially – because the owner as consumer would be the one to pay – but with a more holistic understanding of reducing the overall economic costs, supporting local value creation, offering public services to the city and finally providing the basis for a good standard of living in "their" urban system.

Regarding **technological connectivity**, the UUC manage the different infrastructure networks of the city and can combine them in sector coupling and grid convergence (storage with power-to-x, using the telecommunication grids for smart grid solutions or to push for the electrification of the private transport by offering car sharing options and charging infrastructure). Since the urban utility still also have their own, often local energy production and manage the increasing share of prosumers in their grids at the same time, they can link central and decentral energy production for managing the local grid stability and supply security (virtual power plants, CHP, district heating). However, latest here, the EU regulation – separating the grid management (regulated monopoly of the city) from the energy production and supply (in competition) – causes difficulties. For the prosumer management, for example, they are not the only ones who can offer these services (e.g. demand side management) so that they lack knowledge, which they would need to stabilise their grid. Here, the liberalisation and the energy transition regulation causes difficulties, e.g. the grid operator does not have the full knowledge he would need for smart grid steering (to incorporate even more decentralised and diverse energy production / and consumption)

UUC are key players to ensure **local stability and flexibility** during the transition process.

For technological **stability**, they e.g. balance local volatilities – also among different types of energy sources in their role as DSO and ensure supply security. They can support decentral prosumer-management or more explicitly demand-side management and link it to their grid operation task, which additionally supports the grid stability. Third-party aggregators, indeed can also take on this task, they however lack the connection to the distribution grid and so the overall system management would have higher transaction costs (the urban utility company in their role as DSO would need to supervise an auction process, in turn, the aggregators would need to establish the contact to the prosumers, which the DSO already has). Finally, due to their tradition as infrastructure operators and based on their public ownership, they have a long-term vision for investments and therefore also support future stability of the technological system.

For **social stability**, UUC for example ensure the local public services (affordability and accessibility to energy supply) and allow for local direct democratic control over the critical energy infrastructures. More explicitly, they guarantee the link of the citizens and their political representatives to the energy infrastructures. UUC can also contribute to local financial stability, since their multi-utility structure allows them to balance losses in particular domains. However, the increasing investment needs in the energy domain is challenging, since the energy sector traditionally provided the financial sources for this balancing. For many UUC, the gas supply still provides these financial sources, however, especially urban societies become more critical about this fossil source, too. The financial sources for investments in more sustainable energy supply become more and more disputed. Finally, UUC certainly balance the diverse expectations of different stakeholders and support local cooperation and trust among the different actors of the urban society.

At the same time, their public owners push them towards change, investments in new technologies and approaches to support the energy system's flexibility.

Regarding the technological **flexibility**, they are operating a local system, where they can adapt infrastructures more easily, just because the system is smaller. Most UUC are still also multi-energy providers, which can combine different technologies, e.g. for local storage solutions. Their owners also urge them to invest in local pilots, like geo-thermal heat or e-mobility infrastructure, which decisively support the adaptive capacity of the local energy system. Finally, UUC always need to find optimal solutions for very different settings in their urban system (from historical to home-owner's districts). This task results in a very broad set of corporate knowhow and problem solving mentality, which can support future flexibility.

In terms of **social flexibility**, their public ownership exposes them very directly to any kind of societal changes and they learned to adapt to these changes (long-term normative changes but also short-term political changes) while still ensuring the system stability. This direct exposure to societal dynamics also makes them less resistant to transitions, as e.g. specialised private actors who would just look for a different market. Their public ownership and the respective financial backing through which they are less profit-focused than private companies also allows the UUC to cooperate with new entrants and help innovations into the system.

However, the UUCs' traditional task and mandate was system stability and so their competences and current behaviour has a clear tendency towards stability. Flexibility was only seen as necessary variable for system functionality. Nonetheless, the reflection above shows, that they would have the resources and competences to support flexibility also more explicitly in the context of the energy transition. During the expert workshops, their role for flexibility was dicussed very controversially, however, the participants agreed on their role of "supporting" other actors in increasing the flexibility of the local system.

For the overall system, the national energy sector, they also take over the important role of a sub-system manager, working on the specific resilience of "their" urban system. UUC reflect the federal governance structure of the energy system in Germany and Switzerland, which creates stability on the national system-level. They are key players in a so called polycentric governance system which the resilience scholars consider as key structural characteristic of resilient and thus functional and transitioning systems. This first explorative reflection already shows, that the UUC play an important role for the system functionality in mature sustainability transitions and can also support transition dynamics on the urban level.

Chapter 7 Conclusion and practice implications

The thesis closes by summarising key findings on a general level (section 7.1) and reflecting on limitations and avenues for further research to show the potential for future development in research (section 7.2**Erreur ! Source du renvoi introuvable.**) Finally, it puts a particular emphasis on the practitioners' perspective (section 7.3). Section 7.3.1 summarises the key insights from a practitioner's perspective. Section 7.3.2 adresses target-group-specific recommendations to show the potential for future development in practice.

7.1 Summary

The current transition of the energy sector in Germany, Switzerland and Austria can be considered as a mature sustainability transition process. For over 20 years, policymakers, entrepreneurs and activists have been engaging in a fundamental change of the energy system towards more sustainability, more renewables and less energy consumption. Nowadays, the transition reached the regime level and causes major changes on multiple scales as well as complex, non-linear dynamics for both, the social and the technological sphere of the energy system. At the same time the energy system can be considered as a critical infrastructure system, which is of existential importance for the society. The maintenance of its social and technological functionality while undergoing change is thus inevitable. In this context, the agency of key actors becomes more and more important, especially of traditional actors, incumbents, which are responsible for system stability.

This dissertation tackled the main research aim to understand actor- and system-level structures and dynamics of mature sustainability transitions in socio-technical energy systems.

For the better understanding of system functionality, it drew from resilience literature, based on which it conceptualised resilience of socio-technical energy systems in transition as result of system characteristics diversity and connectivity, which support the key system abilities for resilience: robustness (stability), adaptive capacity and transformability (flexibility). The dissertation presented an indicator set to analyse and measure diversity and connectivity for both, the social and the technological subsystem of energy systems. It applied this indicator set to three energy regions in transition and discussed different methods for the empirical analysis. For the better understanding of key drivers for transition dynamics, the dissertation analysed and (re)conceptualised agency embedded in its systemic context in a sustainability transition, by combining transitions literature with additional theoretical considerations. For the individual level, it conceptualised the HES framework for socio-technical systems and discussed its connection to the MLP. For the organisational level, the dissertation empirically explored the determinants of urban utility companies' agency in Switzerland and Germany. Based on the empirical insights and theoretical considerations from public corporate governance and network industries literature, it proposed general analytical categories for public incumbents in network industries and linked them to the TEF, to make them accessible for transition studies. Finally, the dissertation linked the developed concepts back to the conceptual fundamentals of transition studies (see section 1.2) and presented an integrated framework for analysing system structures and transition dynamics in mature sustainability transitions, considering the actor- and the system-level as well as the social and the technological sphere.

This dissertation was structured in four modules, whereby module 1 and 2 focussed on system functionality and the conceptualisation of resilience, module 3 and 4 focussed on the analysis of determinants and the conceptualisation of agency in mature sustainability transitions. Methodically, this dissertation was implemented, employing an iterative theory building approach, which develops new theoretical considerations, based on empirical insights and pre-existing theory. The empirical analyses were conducted, based on a mixed methods approach, which allowed for rich empirical evidence and triangulation. Main data sources, used in this dissertation were scholarly literature, regional structural data and documents as well as transcripts from several rounds of semi-structured expert interviews and expert workshops, which stemmed from three cases: energy regions in Austria and Germany, a network of change agents in Germany and urban utility companies in Germany and Switzerland. The main analytical methods, employed in this dissertation, were qualitative literature analysis, document analysis and structuring qualitative content analysis.

In sum, this dissertation provided theoretical conceptualisations and empirical findings for a deeper and more complex understanding of system- and actor-level structures and dynamics in mature sustainability transitions. On the system-level, it provided a resilience conceptualisation for energy systems, focussing on dynamic aspects and showed the importance of social dynamics in the context of the energy transition. It also challenged existing concepts in energy resilience studies, such as rapidity and system identity and contributes to the further scholarly discussions and theory building process on resilience in socio-technical energy systems. On the actor-level, the dissertation provides a solid basis for the systematic study of actor- and system-level determinants and feedbacks of agency on the system. It also contributes to a better understanding of higher structuration levels in socio-technical energy systems, which are of great relevance for mature sustainability transitions. The dissertation moreover provided a nuanced empirical and theoretical picture of incumbents, using the example of urban utility companies. This example challenged predominant economic paradigms in transition studies and provides and interesting example for urban infrastructure-self-governance, which plays a crucial role for the resilience of energy systems. Finally, the dissertation contributes an analytical framework for socio-technical energy systems in mature sustainability transitions, by summarising and locating the developed concepts for the analysis of system functionality and transition dynamics in the overall conceptual frame. This integrated framework facilitates empirical analysis on the mature phase of sustainability transitions in the energy sector, it supports cross-case comparisons and contributes to further theory building on mature sustainability transitions.

7.2 Limitations and further research

The subsequent section provides a reflexive overview on i) content and ii) method limitations of this dissertation and iii) related avenues for further research. For more detailed discussions on the individual modules' limitations see also the publications in part B.

7.2.1 Limitations

Content Although the indicators for resilience of socio-technical resilience provide a very valuable tool for systematic analysis, the thesis did not yet provide a comprehensive theory on the related causalities among diversity, connectivity and the level of resilience or the progress of the transition. Indeed, I proposed a hypothetical range of resilience, however, the lacking quantification did not allow to define quantified levels of diversity and connectivity needed for resilience during different phases of the transition. This is also related to the approach of developing the same indicators for the social and the technological subsystem. Although they allow for comparison and foster a greater system understanding, they require data of equal characteristics for both subsystems. In this context, the intended quantification of the indicators turned out to be very difficult for both subsystems and was finally not possible. It is moreover also difficult in a qualitative way, since the interpretation of the results for the indicators is very context-dependent (spatial and temporal) and cannot replace an in-depth, qualitative analysis process. For example, whether sector coupling is always a sign for a holistic and successful energy transition implementation strongly depends on the local context: an electrification of the public transport is only reasonable if the electricity production is C02-neutral.

From a more general point of view, the proposed indicator set does not explicitly comprise inertia and path-dependencies in the system under study. The indicators only reveal the structural changes over time. It remains the researcher's responsibility to further investigate the "why" behind these structural changes in a qualitative manner. A mixed methods approach is thus inevitable to apply the indicators. Due to the great data need for the analysis, the empirical application of the indicator set was only possible for two, respectively three case study areas, which were all located in federal European countries with mature sustainability transitions. The selected empirical evidence might compromise on the generalisability of the results. This is also related to the fact, that the understanding of system functionality and transition progress itself are subject of social construction. They might differ substantially in different cultural backgrounds and might also change over the course of a transition.

The same limitations hold true for module 3 and 4. Although the conceptual contribution was based on pre-existing and established frameworks, the empirical evidence was based on singular cases (change agents and urban utility companies). An application to more and different kinds of actors would have been additionally valuable, was however not feasible in the scope of this dissertation. The dissertation investigated determinants of individual's and organisational agency, it did however not further investigate their interrelation and potential interdependencies or their importance in the different transition phases. This dissertation was very much engaged in a balanced analysis of actors-level and system-level dynamics, informal institutions (e.g. routines, discourses, power structures or mind-sets) were not yet explicitly analysed. The proposed indicator set and frameworks, however, conceptualise them as part of the social system (diversity and connectivity can also be applied to institutions) or part of the systemic determinants of agency. Finally, this dissertation conceptualised energy transition progress in terms of GWh of renewable energy sources, other measure like economic costs or the social distribution of costs and benefits could be made more explicit.

Methods The research methods applied in this dissertation are mainly qualitative, the reflection on their limitations is thus based on the quality criteria for qualitative research, proposed by Lincoln and Guba (1985): trustworthiness, credibility, dependability, transferability and confirmability (see also Miles and Huberman, 1994; Flick, 2009).

- To ensure the **trustworthiness and credibility** of the results, the theory building process was supported by scholarly discussions as well as the analysis of concrete empirical cases. For the empirical analysis, the documents used were all checked for their credibility (e.g. peer-reviewed publications and trustworthy reports) and the interview transcripts were anonymised to allow a maximum of freedom for the interviewees to answer directly and honestly. However, the energy sector is constantly changing, and the results are therefore highly context dependent. An objective truth cannot be achieved, the methodological design however tried to compensate for this through large samples of interviewees to achieve at least intersubjective truth.

- For the **transferability or generalisability** of the results, the theory building was based on pre-existing frameworks as well as the comparison of cases (module 2) and the explicit scholarly discussion on generalisability (module 4). This however does not prevent potential biases, which are related to the selected empirical evidence. The interview partners for module 4, for example, were selected for to their rich insider knowledge and experience with urban utility companies. Despite the broad variety of backgrounds, they might nonetheless have an above-average positive attitude towards urban utility companies, which could bias the results. Regarding the empirical analysis, the mixed methods approach tried to support the generalisability of the findings through richer empirical evidence and triangulation. Especially module 3 however lacks an explicit validation step, which can compromise the generalisability of the findings.

- Regarding the **confirmability** of the results, all sources and results of the theory building process are documented in the related publication. The documentation tries to allow for as much transparency as possible. However, in theory building processes, it is difficult, if not impossible, to document every step. For the empirical analysis, full transparency was given on sources and analytical steps, which are either directly documented in the publications or additionally made available in the appendix of the thesis. The anonymisation, which helped for trustworthiness of the results however compromises on the confirmability, since the transcripts cannot be published. Transcripts and records are nonetheless stored and can be re-evaluated in case of doubt.

- Regarding the **dependability** of the results from the theory building process, countless rounds of scholarly discussion and iterations on the deduction of findings were conducted. Module 1 and 4 comprised explicit validation steps with practitioners, to balance the scientific bias and work on the applicability of the concepts. Transparency on data sources and analysis processes try to cope with this problem. However, the individual researcher bias can never be excluded. No researcher is fully neutral and as I mentioned as the beginning, my personal normative background definitively causes my positive attitude towards renewable energies as well as local and democratic governance structures.

7.2.2 Further research

The application of the developed indicator set for resilience in socio-technical systems to other case study regions, which are e.g. not located in a federal energy governance system or not located in Europe where pre-existing regimes and network structures shape the transition path, would be very insightful. Energy systems, which are not as dependent on the network infrastructure as the European energy systems might add other indicators or different indicator expressions, which are important for their system functionality. A transdisciplinary approach with a close collaboration of researchers and practitioners could provide very fruitful results for both sides, since practice could profit from a new assessment and system design perspective and research could profit from the rich system knowledge, especially if data are not always available and for the investigation of the social subsystem, where only trust among actors opens the doors for qualitative research.

In this dissertation, the indicator-based analysis of diversity and connectivity of energy systems was mainly focussed on the system configuration (physical infrastructure and actors) and did not particularly analyse the regime configuration. It would however be very fruitful, to transfer the indicators also to the “institutional configuration” and analyse more specifically, how it is interlinked and feedbacks to the technological and the actor system. Especially in the context of network industries, where formal regulations play an important role, a combined analysis of physical system, actor system and regulatory system configuration could uncover interesting insights on drivers and barriers in mature sustainability transitions (where pre-existing regulations are dominant). For the scholarly endeavours to improve resilience concepts for socio-technical systems, a continued discussion on the interdependency of system characteristics (diversity and connectivity) and abilities (robustness, adaptive capacity and transformability), between the subsystems and the general system but also during the transition phases would be of great value, too. The explicit link of the indicators to the panarchy concept could facilitate the study of positive and negative feedbacks among different system-levels. The further analysis of thresholds, tackling the question “at which level of connectivity does resilience again decrease?” would be very enriching for the theory development on resilience in socio-technical systems, but also for practical system management.

Likewise, the discussion on the role of agency for system resilience builds an interesting field for further research. As the example of the urban utility companies already showed, it would be very enriching to assess the role of different actor types´ agency for connectivity, diversity, stability and flexibility of the system. In addition, the logics of actor relations (e.g. power relations, coalition building, the role of narratives etc.), which are already widely discussed in transitions literature could be transferred to resilience literature, to work on a better understanding of agency for system resilience and also contribute to a conceptualisation of social resilience, which is still at the beginning. These conceptual contributions could result from empirical studies, which employ the indicators on the actor-level. Future research on incumbents in socio-technical systems in transitions should definitively have a closer look on incumbents below the national champion level, further work on the “neutralisation” of the picture of incumbents and aim for a better understanding of them. As mentioned before, if a mature sustainability transition should become successful and allow for a more sustainable regime to stabilise on a large scale, incumbents are perhaps the most important players. Transition studies should switch the focus from the initial phase of a transition, innovations and their dynamics to the more mature phases of transitions.

More research is also needed on urban utility companies, which are a particular phenomenon of federal energy governance systems and largely unknown on an international level. For example, a comparison of mono-utility companies and multi-utility companies regarding their contribution to system resilience and their role for the transition would be an interesting avenue for further research and could provide policymakers with interesting insights in energy system governance. In this context, a comparison with the Scandinavian countries (mainly centralised states with e federal energy system) or North America could also help to develop a more multifaceted picture on an international level. Within the Urban utility companies provide many interesting alternative approaches besides the logics neo-liberalism, economies of scales, externalisation of costs and non-systemic procedures. From their case, future research could reveal new or revised solutions for infrastructure governance and transition scholars could start a discussion on the economic paradigm needed for successful in sustainability transitions. Regarding the governance of sustainability transitions, it would be moreover interesting to have a closer look at differences among federal and central states in their design, progress and difficulties in sustainability transitions and analyse if there are differences if a central state has a federal energy system or vice versa.

7.3 A practitioner’s perspective

Although this dissertation mainly dealt with theory building and aimed for the improvement of general dynamics in mature sustainability transition processes, it was also strongly engaged in empirical analyses and aimed for in-depth insights, which are useful for the practical reality and actual design of mature sustainability transitions. The final section of this dissertation is therefore dedicated to the practitioner’s perspective and provides a reflection on the practical implications of the thesis’ findings (section 7.3.1) as well as target-group-specific recommendations (section 7.3.2). It was purposefully called “practice implications” and not “policy implications” to emphasise that the design and successful implementation of mature sustainability transitions involve a vast diversity of actors: policymakers, administration, entrepreneurs as well as society representatives, such as traditionally associations, educators or activists.

7.3.1 Key insights from a practitioner’s perspective and related practice implications

The reflections are structured in five paragraphs on key findings and related practice implications: i) empirical findings on diversity and connectivity, which improve the understanding of resilience in energy regions in transitions, ii) methods for analysing the resilience of a socio-technical system in transition, iii) insights from resilience theory for the actual transition design, iv) empirical findings on change agents and urban utility companies in the energy transition, which improve the understanding of the actor’s role for transition, and finally, v) a concluding discussion of fundamental values in mature sustainability transition processes.

Empirical findings on diversity and connectivity The empirical findings of module 2 showed the trend that in the early phase of the transition, energy systems have a rather low diversity in the technological subsystem (former energy production systems were focussed on only a few centralised production technologies) and rather high level of diversity in a niche of the social system (a small network of diverse actors is involved). Over the course of the transition, the technological diversity decisively increases (investment in new technologies), whereas the diversity in the social system remains stable. More actors get involved, but not necessary very different actors. Similarly, the technological connectivity in the electricity system is very high at the beginning - in the heat system it varies (for district heating and gas high, for oil low). The social connectivity is high on the niche level, since the small actor network is in direct and very intense exchange, often with a central actor or organisation. Over the course of the transition, the connectivity in the technological system remains stable: for the heat system there are diverging trends (more connectivity through district heating and Power2X but also island solutions with solar or ambiance heat) for the electricity system, connectivity decreases (more modularity and decentralisation). In the social subsystem, connectivity remains high in the small actor network, however decreases for the overall system since more and more less central actors get involved. At the moment, where the transition enters the regime and stagnates, the technological subsystem is highly divers and medium connected, however the social subsystem is not diverse enough and too connected. In order for the system to reach the mature phase of a transition and remain resilient at the same time, the social diversity needs to be increased and social connectivity should decrease, too. In short, more diverse actors should be included in the energy governance system, with more divers mind-sets, capabilities and responsibilities. The social system should not only include pioneers and frontrunners but also powerful incumbents and “ordinary” people, e.g. households, house-owners, tenants. More diverse business models, narratives and regulations are needed, as well as the willingness to tolerate diverging opinions. Traditional actors, not only policymakers but also energy producers and grid operators play a critical role here. They can link and translate the innovative solutions to the regime level and should be incentivised and pushed for doing so. Similarly, for the technological side. If the transition reaches the regime level, technological diversity is high, however connectivity does not fit to the changed system structure and endangers the resilience of the system. In practice, the (too high) connectivity of the grid should be reduced and allow to mirror the decentralised diversity of new production technologies. At the same time the connectivity among technologies (for electricity and heat production) should be increased, to compensate for volatilities and allow for flexibility. Smart city approaches to link public transport and electricity production or brokering technologies, such as the usage the gas grid for energy storage are only a few examples, how this problem could be tackled. In conclusion, the empirical findings of this dissertation draw the attention to key resilience factors (diversity and connectivity) and can build an interesting new perspective for regional planning, policy making but also for investment strategies in the energy sector.

Methods for analysing resilience The indicator set allows to assess the resilience of an energy system in transition. For this, it first draws the attention to the diversity of technological infrastructure (e.g. available technologies, their share and qualitative difference) and the social governance system (which types of actors are involved, how many of them, how diverse are they in their resources, abilities and mind-sets). Second, it assesses the connectivity of the technological infrastructure (connectedness within a technology but also among technologies, centrality of certain technologies, the possibility to build modules) and the social sphere (collaborations among actors, dominance of actors, formation of sub-groups). The thesis findings presented the energy flow analysis as well as the social network analysis as two methods, which allow to assess the technological and social structure of the system. Both methods are directly applicable in practice and do not require expensive software. They require however in-depth system knowledge and a rich data set as bases for the analysis. During the analysis of this dissertation, data availability was one of the major difficulties. For a long time, the energy system was very stable and system knowledge was manageable and only relevant to a few people. With the increasing complexity and the aim to transform such a complex system, profound and holistic system knowledge and related data sets are crucial. Digitalisation can decisively support the establishment of such a knowledge base and should be used more proactively.

Insights from resilience theory The dissertation’s findings from resilience theory can inform the transition design in practice: the notion of functionality, equal consideration of social and technological aspects, dynamisation, and finally the notions of specific and general resilience. Resilience theory emphasises system functionality and points to its importance throughout the entire transition process. Transition design in practice should always keep the functionality notion in mind. For the technological subsystem, this is already the case, however the equal consideration of technological and social aspects shows, that social functionality is important, too. This dissertation alluded to the fact, that social functionality of an energy system is relative and dependent on the actors’ definitions of it. For the practical design of a transition process this implies, that also social aspects need to be considered for the planning process (e.g. discussions on basic values and whether they should be kept or changed and in which way). With the stronger consideration of social aspects, resilience theory also changes the focus from a reactive system design (ability to withstand shocks) to a proactive system design (endure a fundamental transition). This mind-set should shape transition design processes in practice: the system’s robustness is important, its adaptive capacity and transformability however are crucial to “survive” the transition. Concretely, actors as well as technologies need to learn constantly to become more flexible and develop new capabilities. This specific resilience of subsystems (actors, organisations but also individual power plants) supports the general resilience of the system. In transition design for the energy sector, more attention should be payed to cross-scale interferences and feedbacks, which can endanger the general resilience of the system (e.g. subsidising powerful actors can increase the path-dependency and lock-in in in certain business models and technologies, which are in fact outdated).

Empirical findings on change agents and urban utility companies The results from the empirical analysis of change agents and urban utility companies showed the importance of diversity and connectivity, too. The change agents network consisted of like-minded but very diverse and well-connected doers. However, the high share of conservative and locally rooted mind-sets was surprising. The mixture of being locally rooted and conservative but nonetheless curious, open for change and concerned about future generations seemed very fruitful for transition endeavours. The change agents were able to link new solutions to the existing system, since they could access different abilities and resources in their network. This implies for the practical design of transitions, that one should on the one hand find and connect these particular actors, however also always push for an open and lose network structure, to avoid the danger of a lock-in. On the other hand, a focus on the local level facilitates progress and the development of individual innovative solutions, which than can act as role models for others. This also means, that regional transition design should aim for connectivity to other regions in transition to allows for knowledge and best-practice exchange. Similarly, for the urban utility companies. They are also highly diverse in their portfolio and connect technologies and actors in their urban system (see reflection section 6.3). Moreover, the thesis showed, that are more differences among urban utility companies within one country, than between two countries. Involving urban utility companies in the transition design process means to deal with them as individual cases and knowing about their particularities. A comparison among federal states with a long tradition of urban utility companies can decisively improve their understanding. In conclusion, the thesis pointed out, that it is absolutely critical, to understand actor- and system-level factors, which influence certain actors. This allows for a deep understanding of their agency and facilitates to involve them in the transition design process (e.g. to understand the differences between a new energy provider, a large traditional producer and a municipal energy utility company helps to communicate and interact efficiently with them). The dissertation provided two frameworks, which can be used in practice, to analyse certain actors and their behaviour in the transition process. Such a framework-based analysis allows to compare findings for several actors and finally facilitates generalisability and a deepened overall understanding of the role of agency in transition processes (e.g. how their production assets, the job profiles in the firm or their political mandate explain their behaviour).

Discussion of fundamental values Finally, the study of urban utility companies showed that they provide alternative solutions to the liberalised and scale-effects based economic regime, which is pushed by the EU. Moreover, they play a major role in the decentralised and digitalised technology regime, which is currently unfolding in more and more European countries. Even more so if they still operate in a bundled mode (network operation and energy production and distribution in the same company), as in Switzerland. Thus, they challenge the existing regime with local, integrated solutions and show the mismatch of regulations for economic liberalisation and the development of renewables in the digital age. For the practical transition design, urban utility companies should be re-considered as a tool to allow for local and direct democratic control on the transition process, for integrated technological solutions on the city scale and regional value creation. However, one should not forget, that they are product of a federal energy governance structure and cannot by "imposed" in any other system. An energy system needs to allow for subsidiary management, bottom-up dynamics and a certain level of independency for cities in order to allow for the establishment of urban utility companies. At the same time, one should not overlook that urban utility companies are also a product of a (continuous) societal discussion and can be changed according to current societal values (e.g. different job requirements, more entrepreneurship etc.). To actively "use" urban utility companies for the design of a democratic energy transition does not mean to protect them as they are, but keep their democratic footing and start a discussion on the fundamental values during the transition process. Their future roles and responsibilities should be actively rethought as well as their value should be made visible on the European level on order for other countries to see advantages and challenges of a local infrastructure self-governance system. Finally, it is the society, who decides whether urban

Overview on practice implications

- Develop a system, which allows for flexibility and dynamics, but remains stable in its key functions. Base regional planning and decision-making on diversity and connectivity indicators.
- Aim for a systemic perspective, considering social and technical aspects equally as well as the interrelations between the resilience of subsystems and the overall system.
- Consider social aspects and take into account their relative nature by fostering discussions among diverse actors about key values and concepts how the energy system transition "should be".
- Employ scientific methods for system analysis, such as energy flow analysis and social network analysis, which support the in-depth and holistic system knowledge. Create a rich knowledge base on the system in transition, to support informed decisions and allow for the involvement of more diverse actors.
- Have a closer look at actor- and system-level factors, which influence the behaviour of key (incumbent) actors for the transition, to better understand them and be able to involve them more effectively in the transition process.
- Search for and involve conservative actors which are open for change and connect them.
- Consider urban utility companies as institutions, which allow for direct democratic control on the energy transition process. Search for the exchange among federal countries to improve the understanding of urban utility companies, find new solutions for their redesign and make it visible on the European level.
- Actively re-discuss how the fundamental societal values can be mirrored in the governance system and call attention to the societies influence on the design of public companies.

utility companies will become rusty dinosaurs or a redesigned phoenix from the ashes which helps the successful implementation of the mature sustainability transition in a federal energy system.

7.3.2 Target-group-specific recommendations

Regional developers and urban planners, policy makers on different federal levels, urban utility companies' managers but also new entrants to the energy sector are considered as potential target groups of this dissertation.

Urban utility companies' managers Urban utility companies are key players in a decentralised renewable energy system, however, liberalisation dynamics and economies of scale challenge their business models. They should actively collaborate with other UUC, on the national but mainly also on the international level. Together with other DSOs, they should find their voice on the European level to communicate their contributions and roles for system functionality but also the transition progress. UUC need to overcome their "in-house" and "do-it-yourself-logic" and actively look for partners to push the idea of local and democratic energy system management. For doing so, they need to get rid of their dusty self-image, become aware of their new roles and responsibilities and communicate that the local energy management can actually be "cool" and innovative. UUC are local, diverse, democratic and large economic forces in their region as well as social entrepreneurs. Only if they change their self-image, they will be able to "tell the story" – especially to an international audience so that others could learn from them. Finally, UUC should also actively work on their relationship to "their" municipality, try to understand the policymakers' concerns and explain the tensions and backgrounds of the energy sector to their owners. In so doing, they can sustain the owners' backing and maintain their entrepreneurial freedom at the same time.

Municipal policymakers and administrative specialists Municipalities – as owners and key stakeholders of UUC – of course need to support collaboration and change of image in UUC. They should prevent any major privatisation of their UUC and rather consider regional aggregation among UUC to keep the direct democratic control over their critical infrastructure. Weizsäcker et al. (2005) provide very insightful reflections and concrete case studies on the limits and conditions for privatisation in critical infrastructure industries. They conclude that privatisation is only successful and not cost-increasing for society, if it is accompanied by strong regulation, which makes the business unattractive for private actors. Municipalities should aim at a close collaboration with their UUC, define clear owner strategies and goals, which are ideally not conflictual. The owner goals should moreover be generic enough that the UUC still has enough room for corporate manoeuvre and can operate efficiently. Municipalities must not control every single step but work on their relationship of trust to "their UUC" via good communication. Finally, municipalities as shareholders are at the same time also stakeholders and differ in this regard decisively from private shareholders: shareholder value is stakeholder-value. So municipalities should insist on fair working conditions and participation rights of the UUC employees, since these employers are their citizens. And, similar as for the UUC, also municipalities should more proactively communicate their contribution and role to the energy transition process and the overall energy system functionality, so that national and European policymakers become more aware of it. For a good international overview on re-munipalisation of public services see Kishimoto and Petitjean, 2017.

Regional developers and urban planners Planners should aim for diverse energy sources and modular structures in the regional and urban energy system planning. They should not overstretch efficiency and large scale structures but aim for nested systems thinking, e.g. in mini-grids and modular solutions combining different sources. Moreover, planners should rethink the usage of existing infrastructures as for example the grids and how the modular solutions can be linked to it, to reduce economic costs, increase the share of renewables and ensure supply security. They also would need to collaborate not only with their local UUC but also with their counterparts from other regions and actively "lobby" for these local modularity on the national level so that regulation would be changed accordingly. Planners need to consider the social side of infrastructures more actively. They should not design infrastructure systems in such a way that they operate efficiently from a systems perspective but also from the actor's perspective. How people use energy and why, in how far they are flexible in their demand as well as able and willing to invest in new energies needs to become integral part of the planner's knowledge base. If so, they can actively support system design for more renewables and help to overcome "not in my backyard" tendencies, which are mostly based on fears and lacking system knowledge, which the planners could provide. In conclusion, active exchange of experts and the public is needed to design diverse, flexible and smartly connected local energy systems.

New entrants to the energy sector New entrants to the energy sector play an important role for diversity and can provide the new solutions which are needed for the successful social and technological transition. However, they are often not able to successfully enter the existing "regime" and might fail. For them it is thus important to connect to the UUC and the municipalities on the local level. Here they might even have personal contact and can convince the UUC or the municipality to test their innovation on a larger scale. For doing so, the new entrants would need to work on their understanding of UUC and the traditional way of functioning of the energy sector, to be able to successfully communicate and "translate" their innovation. This potential local collaboration and implementation might not provide immediate exponential growth for a start-up and might be challenging at the beginning, but on the long run, such local collaborations can become successful pilots which provide international attention and reputation.

National policymakers and administrative specialists National political representatives and administration experts should allow and facilitate local and diverse solutions to support the energy transition progress as well as the system functionality. They should let the regions take more responsibility regarding the organisation of a decentralised energy system. In this context, digitalisation and smart systems are key issues. National policymakers should be well aware that data security and accessibility will become a public service in the near future, especially in the context of smart decentralised energy system management but also in the context of smart city projects. They should think data infrastructure also as a critical infrastructure and design policies and regulation accordingly. (Local) public ownership should be considered as an important tool to ensure public service in the data domain, too, even if the management might be aggregated and private. Here, as well as in the other domains, the main task of national policymaking is nowadays the link of the regional to the European level, which supports the functioning of a multi-level governance structure. This faultless functioning of the social system is highly relevant in the energy sector and critical from a resilience perspective. In Switzerland, national policymaking would need to focus more on the increase of domestic renewable energies and the respective market design, the development of support schemes and regulatory change. In this context, local social acceptance is key and the national level could support local endeavours e.g. by developing new compensation schemes which go beyond traditional subsidies and pay attention to the local circumstances. Switzerland particularly would need to rethink its heavy licensing procedure for new renewable energy installations and especially the fact that not only local people but interest groups in the entire country have a major veto right against renewable energy projects. In Germany, national policy making should rethink large grid extension projects and focus on local, modular smart grid solutions. And of course, the coal phase-out should not even be a question anymore. In both countries, this would require more courage to break traditional institutions and to go against established power relations of large centralised TSOs and energy companies. Finally, national policymakers in both countries would need to focus also on the reconfiguration and deconstruction of existing infrastructure - not only on the development of shiny new solutions. Who is responsible and who pays for this system reconfiguration? “The respective energy companies” is a too easy answer. Energy was and still is a societal issue. Nuclear power plants were constructed from tax payers’ money and they will be dismantled from tax payers’ money. We should rather discuss in beforehand how to plan and finance deconstruction.

European policymakers and administrative specialists This fundamental change of power relations and the respective reallocation of responsibilities would need to be supported by the European level. The EU would need to give more responsibilities to DSOs as well as the regional and urban level of energy related administration and governance. This “power shift” is deeply rooted in the subsidiary tradition of the EU, where as much as possible should be done on the lowest governance level as possible. However, over the last decades, EU policymakers seemingly forgot about the construction principle of subsidiarity and tended to centralise governance structures – not only in the energy sector. The EU level though should provide clear guidelines and support local and diverse solutions as long as they fulfil the overall goal. In this context, the EU policymakers should also rethink their liberalisation directives and verify where they actually hinder energy transition progress (e.g. is unbundling needed for local mini-grids? Can decentral structures at all be managed with market-based approaches, tending to economies of scales and centralisation?). Moreover, European policy making should consider mobility as a decisive part of the energy transition and global warming mitigation endeavours. European policymakers pushed for the liberalisation and integration of the European aviation and railway sector as well as the road network. Accordingly, they need to foster transition not only in energy production but in major consumption domains, too.

Finally, this thesis clearly showed that the regional and urban level is the relevant entity for the implementation of the energy transition but also for the management of system functionality in an increasingly decentralised system. However, these regional entities are embedded in a national and European context, which is highly relevant, too. Ideally, the superordinate levels provide coherent goals and rules for the transition and support the connectivity of the different submodules. The regional level develops diverse solutions for the context-specific implementation of these goals. On the regional level, people can take responsibility more easily and can act with direct feedbacks. This multi-level interplay is very complex. However, if it is managed successfully as a “panarchy” which balances these bottom-up and top-down dynamics, it builds the fundament of a resilient system. In order for this panarchy to work, a discussion and agreement on future roles of the different actors and a re-allocation of responsibilities and mandates in the energy governance is inevitable. National and European policymakers but also researchers could facilitate and convene this exchange, including utility companies and grid operators from the national and regional scale alike.

Chapter 8 References

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PUBLICATIONS

List of Publications

Resilience of socio-technical energy systems in transition

Publication 1 Binder, Claudia R., Susan Mühlemeier, and Romano Wyss (2017) "An indicator-based approach for analyzing the resilience of transitions for energy regions. Part I: Theoretical and conceptual considerations" *Energies* Vol. 10 No. 1, p. 36.

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Publication 4 Mühlemeier, Susan, Romano Wyss, and Claudia R. Binder (2017) "Und Aktion! – Konzeptualisierung der Rolle individuellen Akteurshandelns in sozio-technischen Transitionen am Beispiel der regionalen Energiewende im bayerischen Allgäu" *Zeitschrift für Energiewirtschaft* Vol. 41 No. 3, pp. 187-202.

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All authors contributed equally to this publication. The doctoral candidate contributed to theoretical conceptualisation, empirical analysis and writing of the publication.

energies

MDPI

Article

An Indicator-Based Approach for Analyzing the Resilience of Transitions for Energy Regions. Part I: Theoretical and Conceptual Considerations

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Abstract: The transition of our current energy system from a fossil-based system to a system based on renewables is likely to be one of the most complex and long-term societal transitions in history. The need for a fundamental system transformation raises the question of how to measure the continuing progress and the resilience of this process over time. This paper aims at developing the conceptualization and operationalization of resilience for energy systems in transition with regard to both social and technical aspects. Based on the resilience concept in social-ecological systems literature, we propose to conceptualize resilience for energy systems building on two core attributes of resilience, namely diversity and connectivity. We present an indicator set to operationalize these key attributes in social and technical systems using: (i) definitions and measurements for three fundamental diversity properties—variety, balance and disparity—and (ii) basic connectivity properties from the social network analysis literature—path length, centrality and modularity. Finally, we reflect on possibilities for an application of these indicators in the social and technical system's spheres and discuss the added value of the approach for energy transition research.

Keywords: resilience; energy transition; socio-technical systems; social-ecological systems; diversity; connectivity

1. Introduction

The envisaged transition of the energy system towards greater sustainability is one of the major challenges of the 21st century [1]. A number of countries have set specific transition goals, and have invested heavily in both technology development and infrastructure measures [2–10]. From an analytical perspective, energy transition processes can be understood as a succession of both intended disruptive changes and incremental adaptation processes along a specific change path [11]. Throughout the change process, humans have to anticipate, to adapt to, and to learn from and within fundamentally new situations, while taking into account the technical possibilities at disposition [12,13]. According to Grin et al. [14] "[transition processes] are interwoven with economic sectors (mobility, housing, agriculture) and in fact deeply rooted in our societal structures, routines and culture." The transition of the energy system towards renewable energies and higher energy efficiency is a complex, and long-term societal change. This implies that the transition of the energy system has to be analyzed in an integrative way, taking into account the co-evolution of technological and societal factors [15].

In the energy transition literature, decentralized energy systems are increasingly seen as being key for achieving a low-carbon, renewable energy system [16]. As such the role of the regional level has increasingly gained importance as has already been acknowledged by the European Union [17]. For the remainder of the paper, we understand regions as territorial entities approximately the size of nomenclature of territorial units for statistics (NUTS)-3 as defined by the European Union [18]. Several scholars have analyzed the relevant factors for an energy transition at regional level. Main points that have been discussed are the role of guiding visions and foresight, the characteristics of the actors and social arenas involved in the transition process, the way institutionalization takes place, and the development of the energy and material flows over time [19–27]. A handful of scholars have developed models for analyzing and simulating transition processes [28–30]. These studies identified, amongst others, the following issues: (i) Guiding visions are essential for initiating the transition [20–22,31–33]; (ii) There is a significant delay between the initial vision until some physical changes can be observed [19,23]; and (iii) the engagement of communal and regional stakeholders is key to establishing a new governance structure through connecting actors in collaborative networks and regional action arenas [34].

What has often not been explicitly integrated in these analyses is the fact that for a transition to be successful, a faultless functioning of the energy system along the transition path is paramount [35]. In other words, the system has to remain resilient to external and internal shocks and unplanned disruptions throughout the transition process [34,36,37]. For this to be achieved, both the technical properties of the systems in transition as well as the connection to the social sphere have to be considered along the different phases of the transition pathway (Figure 1). While social actors are important to drive the transition, a faultless functioning of the technical energy production and distribution systems is important both from an economic and political point of view to ensure public support, and prevent unwanted disruptions of the transition process [38].

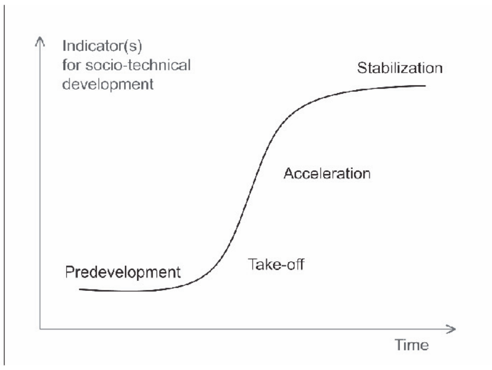

Figure 1. The four transition phases of socio-technical transitions (based on [11]).

When conceptually defining the resilience of the energy transition we have to understand what an energy transition implies and which aspects of the social and technical subsystems change in which way along the transition pathway. Envisioning the co-evolution between the social and the technical subsystems, one should be able to observe emerging institutions and new players, e.g., new businesses such as energy producers or suppliers of raw materials and the related changes in the governance structure it goes in hand with. In addition, potential new funding mechanisms which would support and foster the transition have to be taken into account [19,23,39–43]. When looking at the technical aspects of the system, we expect the energy transition to bring about (i) development and utilization of new technologies; (ii) increasing share of new (renewable) technologies in mix of energy generation;

and (iii) become flexible as to deal with fluctuation in the loads and supply volatility [23,28,44–46]. Whereas the changes to be obtained seem to be clearly defined, there is lack of knowledge regarding the resilience during the transition process itself or there is the need for "building the resilience of a new direction" [47].

To our knowledge, no studies to date have explicitly analyzed and operationalized the factors that affect the resilience of an energy system along a transition pathway, both from a social and a technological perspective. In this paper we address this issue from a theoretical and conceptual point of view. We aim at: (i) Conceptualizing the role of resilience with regard to both social and technical aspects of energy transitions; (ii) Developing a set of indicators to analyze the resilience of the energy system throughout the transition process; and (iii) giving first insights into how these indicators might relate to transition processes.

We organize the paper along the following sections. We start off with a theory-driven conceptualization of how to understand resilience for energy systems in transition in section two. We then propose an operationalization of the resilience of energy systems based on a set of six indicators for both diversity and connectivity in section three. In section four we discuss the possible application of the resilience indicators in energy systems, before we conclude with general insights and further research ideas in section five.

2. Conceptualizing Resilience of Systems in Transition

Resilience can be described as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" [48]. In the same line of thought, [49] describes resilience of a system as the capacity of the system and its components to withstand shocks (stability) as well as to adjust to changing external conditions (adaptive capacity), based on the flexibility of the system's configuration. Systems themselves can be understood as an ensemble of qualitatively diverse system components and their interlinkages, e.g., by means of flow of energy, or information. Based on this system understanding, resilience can be defined as a function of the diversity of system components and the connectivity patterns between the components [50,51].

In the tradition of systems thinking in a social-ecological systems (SES) understanding, research following the seminal work by [52,53] in the field of ecology has pointed to both static and dynamic elements of resilience, allowing a system to stay in a dynamic equilibrium state where system elements are in a sustainable relation to one another, not endangering the long-term stability of the system [54,55]. A key concept in SES resilience is the adaptive cycle [53,55,56]. The core idea behind the adaptive cycle is that as ecological and social systems are forced to adapt to internal and external change, on different scales and over different spaces of time, the fundamental characteristics of the system changes in terms of both diversity and connectivity.

In comparison to the SES literature, resilience thinking has only sporadically been used as an explanatory concept in socio-technical (STS) studies. Aside from studies with a strong technical orientation [44,57,58], the only scholars who have tried to link a comprehensive resilience concept to socio-technical issues to our knowledge are [59,60]. The authors stress the commonalities between SES and STS as complex adaptive systems, and base their call for an application of resilience as a guiding research concept to STS on the argument that, very much as in SES, STS research should be able to give informed policy recommendations in how to support the progress towards more sustainable societies, and therefore must also give answers "over who governs, whose system framings count, and whose sustainability gets prioritized" [60].

For the remainder of the paper, we build on this understanding of resilience in STS by combining the SES resilience concept with a STS systems understanding [55,60–62], which is based on the idea that socio-technical transformation processes go hand in hand with a co-development of the social and technical system [63,64]. Within this understanding, ecological aspects are indirectly accounted for via the resource-base that underlies the respective technologies. We consider a transition resilient if the resulting system is resilient along the whole transition process, in analogy to the phases of the adaptive cycle [56]. Thus, during a resilient energy transition the systems will pass through stable and adaptive stages, characterized by differing configurations of both the social and the technical components of the energy system, but will never lose its overall resilience.

3. Operationalizing Resilience of Energy Systems in Transition

Based on the resilience understanding presented above, we propose to operationalize the resilience of energy systems in transition building on two core attributes of resilience, namely diversity and connectivity [50,51]. While the measure of diversity is linked to the structural attributes of the system, connectivity is process oriented and related to the interaction between the system components [65–67]. Following [56], these two system characteristics co-determine a system's structural stability and adaptive capacity in the face of continuously changing external conditions, as well as in the face of disruptive shocks. According to Holling (1973) "Stability, . . . , is the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns to an equilibrium state and with the least fluctuation, the more stable it is".

This implies that there is a need for a minimal level of both component-based diversity and interaction-based connectivity so that resilience of the system be attained, while the levels of diversity and connectivity will vary along the transition pathway in order for the system to maintain its adaptive capacity [68].

Operationalization of social sphere: social arenas

With respect to the analysis of the social system, one possibility to tackle the great number of actors and their complex interaction patterns is to work with the concept of "social arenas" [20,32]. Social arenas are defined as "societal subsystems or spheres, characterized by their rationality and codes depending on their function" (translated from [20]). Commonly these arenas are differentiated through their specific structure and their functional characteristics, distinguishing, e.g., between the political, the entrepreneurial or the private household arena. For the transition to be resilient and to ensure the functionality of the system, actors of different arenas have to be included and they have to collaborate with each other [37]. Thereby, we look at social connectivity as the exchange patterns between actors from different social arenas, while we consider diversity as the functional qualitative difference between arenas.

Operationalization of the technical sphere: technologies

With respect to the technical system, we distinguish between different groups of (renewable) energy production technologies. Kost et al. [69] have applied a differentiation in production technology groups with respect to their (relative) locality. This is more precise than only studying the energy sources and it is less detailed than analyzing each specific technology. For the determination of diversity, we suggest to consider different forms of technologies, such as hydropower (small and big plants), photovoltaic (rooftop and open field), solar thermal energy, biomass heating, and combined heat power production (CHP). With regard to connectivity, we base our operationalization on the transmission infrastructure that links the various production entities amongst each other, and to the consumers. In the following subsections, we suggest six metrics for measuring diversity and connectivity, accounting for both the social and the technical components of the energy system.

3.1. Diversity

According to [70] the definitions and measurements of diversity are similar across disciplines and system contexts. Diversity can be conceptualized by three fundamental properties: Variety, balance and disparity (Table 1). Each of these properties has been found to be necessary but insufficient to conceptualize diversity [71,72]. Scholars have still, not found a fourth property which is relevant for diversity [70].

Table 1. Suggested measures for operationalizing diversity in socio-technical energy systems (based on [70]).

Diversity Indicator	Definition	Social System	Technical System
Variety	Category count N	Number of types of social arenas present in the regional energy governance structure Role for resilience: Higher adaptability and stability through integration of different views and perspectives	Number of groups of technologies present in the local energy production system Role for resilience: Integration of different technologies, basis for flexibility and adaptability
Balance	Shannon evenness $S = -\sum_i \frac{p_i \ln(p_i)}{\ln N}$ Shannon Weaver (includes variety) $S = -\sum_i p_i \ln(p_i)$	Number of actors per social arena in comparison to overall number of actors Role for resilience: Indicator for stability, efficiency, flexibility	Share of technology groups in overall energy production Role for resilience: Shows how much the region relies on one energy technology group (energy portfolio)
Disparity	$D_i = f\ (d_{ij})$ $f(d_{ij})$: function of distance in disparity space between categories i and j	Qualitative differentiation between arenas Role for resilience: Determines stability, transaction costs and flexibility	Qualitative differentiation between technologies Role for resilience: Diverse technologies—basis for adaptability to uncertain external shocks

3.1.1. Variety

Variety is "the number of categories (we use the term type) into which system elements are apportioned" [70]. According to [70], "all else being equal, the higher the variety, the greater the diversity". It is quantified by the "category count" (N; Table 1).

Social: In the social system, variety relates to the question of how many types of social arenas are prevalent in the governance structure of the regional energy system (e.g., politics, industry, research, society or media). Role for resilience: From a resilience perspective increasing variety of social arenas leads to an increasing amount of perspectives and viewpoints present in the regional energy discourse. This can lead to an increasing adaptive capacity but potentially less stability, which might be supportive for systemic change. A low variety of social arenas can imply less diverse perspectives and viewpoints but potentially higher stability. A too low variety on a long run, however, might also lead to the destabilization of the systems, as relevant actor groups (arenas) might be excluded.

Technical: In the technical system, variety refers to the amount of different types of renewable energy technologies present in the region (e.g., photovoltaic, solar heat, hydropower, combined heat and power, [60]). Role for resilience: A large variety of technologies might destabilize and increase the costs of the energy system, as, e.g., technologies within different load types (base load and peak load) have to be aligned and integrated into the system [45,46,73,74]. This lowers the actual stability but can increase the adaptive capacity: a high variety of technology groups also represents a window of opportunity where new technologies emerge and potentially lead to a system change if they can be integrated into the existing structure. At the stabilization point of the transition, the best suited technologies establish themselves. A low variety within the technical system contributes to stability but lowers the potential adaptive capacity of the energy system, which might be needed to react to external shocks.

3.1.2. Balance

Balance relates to the patterns of allocation of the elements across the different categories. Stirling [70] proposes several indicators for measuring the balance. The most popular and easiest to use is the Shannon index. The Shannon evenness index [60] is the one explicitly used to measure the balance (Table 1, Equation (1)):

Shannon Evenness-Pielou $$S = -\sum_i \frac{p_i \ln(p_i)}{lnN} \quad (1)$$

where *ln* the natural logarithm and p_i the proportion of system category *i* [60]; *N*: number of types of arenas or energy technology groups.

Kharrazi et al. [75] suggested applying the Shannon-Weaver index which combines the variety and balance (Table 1, Equation (2)):

Shannon-Weaver $$S = -\sum_i p_i \ln(p_i) \quad (2)$$

where *ln* the natural logarithm and p_i the proportion of system comprises category *i* [70,75].

In both cases: The higher the value of the Shannon index is, the more even the balance is. According to [70] "all else being equal, the more even is the balance, the greater the diversity".

Social: In the social system balance relates to the question of how many actors are active in each type of social arena compared to the overall number of actors in the regional energy governance system. Role for resilience: From a resilience perspective, a high balance is related to a more even distribution of the viewpoints within the regional governance structure and provides stability to the system. This might, however, lead to decreasing efficiency as suggested by [51]. An uneven distribution of viewpoints might lead to a domination by one party and potentially foster a transition, but also lead to a neglect of significant aspects for the stabilization of each transition step.

Technical: In the technical system balance refers to the share of each technology group in the overall energy production [70]. Role for resilience: From a resilience perspective, a high balance implies a more even distribution of technologies might provide a lower stability (different load types must be handled etc.), and potentially a higher degree of flexibility and adaptability, depending, however, on the type of technology. A low balance means that energy generation is driven by mostly a specific technology group. This potentially leads to a higher stability of the system but at the same time to a lower degree of flexibility and potential for adaptability.

3.1.3. Disparity

Disparity relates to "the manner and the degree in which the elements may be distinguished" [64] (p. 709). We suggest to calculate a multi-attributive disparity [70,71,76] (Table 1, Equation (3)). Thereby disparity (D_i) is a function of the different attributes characterizing either the arenas or the technology groups [60,70]:

$$D_i = f\ (d_{ij}) \quad (3)$$

$f(d_{ij})$: function of distance in disparity space between categories *i* and *j*.

With the analysis of the multi-attributive disparity we can account for different attributes of the social and technical systems. According to [64] (p. 709) "all else being equal, the more disparate are the presented elements, the greater the diversity".

Social: In the social system disparity relates to the question how different from each other the arenas are. Possible attributes for the disparity analysis are (i) time horizon of different actors (short-term for entrepreneurs vs. medium-term for politicians) [31]; (ii) their modes of action (communication, coordination); (iii) their structure, and functionality (legislation for politicians, investments for entrepreneurs) [20]; (iv) and their spatial reference (regional for politicians, cross-regional for entrepreneurs, local for private households) [31]. Role for resilience: From a resilience perspective the higher the disparity among the arenas, the higher is the adaptive capacity of the social system because different and diverse types of knowledge and viewpoints can be integrated into the regional energy discourse. A high disparity, thus, contributes to avoiding "short-sightedness" within the social system and creates new options and strategy spaces. Low disparity implies that the knowledge base and viewpoints of the arenas involved are similar. This lowers the transaction costs, makes the system more efficient and potentially stabilizes it, however, potentially reducing its adaptive capacity.

Technical: For the technical system attributes for analyzing the disparity of the different energy production technologies can be: (i) Type and availability or scarcity of energy carrier; (ii) CO_2 emissions; (iii) Dependency on weather (sun or wind); (iv) Production costs; (iv) Surface consumption per kWh; and (v) efficiency of each technology group [69,77–82]. Role for resilience: From a resilience perspective disparity is the system's structural basis to "choose" between qualitatively diverse alternatives. High disparity provides a broad portfolio of options for a system to develop and is a crucial factor in terms of preparedness to especially unforeseen shocks. Low disparity means that the technology "portfolio" to choose from is rather limited, having, e.g., similar dependencies on environmental conditions or similar environmental impacts. Low disparity also implies a low flexibility and adaptive capacity. It can also imply a high redundancy, making the system more stable.

3.2. Connectivity

We build upon basic concepts from network analysis in order to operationalize connectivity in the technological and social sphere. Based on the social network analysis literature [83,84], as well as the application of network metrics to energy systems [57], we identify three main aspects of connectivity, namely path length, centrality and modularity.

3.2.1. Average Path Length

The average path length describes how many intermediate steps must be taken to establish a connection between any two components of a system (Table 2). A short average path-length allows a system to be more easily steered, and for information to circulate faster [84].

Table 2. Suggested measures for operationalizing connectivity in socio-technical energy systems.

Connectivity Indicator	Definition	Social System	Technical System
Average Path Length	Average path length $l_G = i > jl(i,j)n(n)(n-1)^2$ [85] with average path length in the network being the arithmetical mean of all the distances. $l_G = \frac{1}{n(n-1)} \sum_{i \neq j} d_{ij}$ [85]	Number of steps it takes to reach other actors from other arenas along the shortest path. Role for resilience: A shorter path length facilitates the sharing of knowledge and experience.	Length of the transmission lines between production and consumption sites. Role for resilience: A shorter path length speeds up the propagation of harmful supply perturbations.
Degree Centrality	Degree Centrality $C_D(n_i) = d(n_i) = \sum x_{ij} = \sum x_{ji}$ [84] The degree centrality of a node is calculated by summing up the connections that a node has to other components in the network. One can distinguish between in- and out-degree centrality. The Average Degree, which is an indicator of the overall density of the network, can be defined as: $\overline{d} = \frac{\sum_{i=1}^{g} d(n_i)}{g}$ [84]	Number of connections of actors within one arena to actors in other arenas in comparison to overall possible number of connections. Role for resilience: A higher centrality reflects a higher coordination power.	Number of connections to other producers or/and consumers in the distribution network. Role for resilience: High degree centrality, Nodes represent Intervention points.
Modularity	Modularity Index $Q = \sum_i (e_{ii} - a_i)^2$ [86] where e_{ii} is the fraction of edges in the network between any two nodes in the module i, and a_i the total fraction of links originating from it and connecting nodes belonging to different ones.	Measure of the tendency of actors from different arenas to form subgroups which are detached from the rest of the network. Role for resilience: Higher modularity increases the creation of new ideas within partially secluded subgroups.	Measure of autonomy of certain parts of the distribution network Role for resilience: Higher modularity allows an autonomous functioning of parts of the system (islanding).

Social: Applied to the social part of the system, the average path length can be interpreted as the relative social distance between actors from different social arenas. It can be measured by looking at whether actors are in direct contact with one another, and if not, how many mediating steps lay between them [87,88]. A shorter average path length between actors from different arenas allows for a faster propagation of information between the social arenas. This is important to have an exchange on different views of how to further develop the energy system with respect to transition goals, as well as to coordinate network activities in an efficient way [85,89]. Role for resilience: direct communication channels between actors from different arenas related to low average path length strengthens resilience by allowing for effective short-term collaborative action in the face of imminent shocks. Furthermore, efficient sharing of knowledge and experience across different arenas due to direct links between actors also allows for a higher adaptive capacity of the system in the longer run [83,88].

Technical: Average path-length in the technical system can be understood as the average length of the transmission lines between different nodes (production & consumer). While longer path lengths imply a higher loss of energy given a stable loss per km of wire, the propagation "speed" of supply perturbation will most likely be lower in systems with higher path lengths, i.e., with more potential intervention points (nodes) for a given grid size. Role for resilience: Higher-path length (more nodes between different parts of the system) results in a slowing-down of the propagation of harmful supply perturbations. Ash and Newth [90] suggested that longer path lengths can be a stabilizing factor increasing resilience in technical systems that are prone to cascading effects, such as energy distribution networks.

3.2.2. Degree Centrality

Degree centrality describes the relative position of a network component (actors, electricity production sites etc.) with respect to the other components of the system [91,92]. It is calculated as the number of direct links that exist between a network component and its network environment [83,93]. When looking at the system as a whole, average degree describes the overall centralization of the network, in other words the concentration of network ties linked to individual actors or system components, as the sum of the individual degree centrality measures in relation to the overall number of possible ties. Components with an over-average centrality in a system can be described as hubs, which are central for the functioning of a networked system due to their role as connecting entities (brokers), building bridges between otherwise unconnected actors and/or technical components of the system [90].

Social: Degree centrality measures can be applied to measure the importance of actors within the social arenas with respect to their capacity to be in direct contact with other actors both within as well as across arena boundaries. The higher degree centrality is, the higher the coordination power of actors within the system, e.g., with regard to planning and implementing changes to the production and distribution capacities of the regional energy system. High degree centrality supports actors in making their concerns heard. Due to their central position in the network, central actors can actively steer governance processes, and take influence on others. On the downside, if central actors are exposed to too many obligations, they may also be constrained in taking specific, especially unpopular, action [94,95]. Role for resilience: in the face of system-wide shocks, the initiation and coordination of collaborative action by central actors, who can directly communicate with many other actors across the various arenas allows for a swift implementation of specific adaptation measures. Central actors can be important to steer collective action in social systems, by coordinating activities across arena boundaries. Central actors can also have the power to slow down or even prevent a system to adapt to changing circumstances if they follow certain vested interests [88]. Central actors can also act as knowledge brokers across arena boundaries, giving them high power in what information they distribute, for example concerning financial or technical issues [96].

Technical: Within the technical system, degree centrality measures can be applied to estimate the role technology groups (e.g., solar, wind, etc.) have with respect to both the overall output they generate, as well as to the number of pro-/consumers they are linked to. If centrality is high, the production or distribution sites of the individual technology groups can be seen as local hubs of the system, which are critical for the system's stability and should be protected, especially in scale-free networks [90]. As centrality partially correlates with modularity, high-centrality nodes bridging between (production-) modules have an above average importance for the stability of the system as a whole [84,85,97,98]. Role for resilience: central nodes represent intervention points to allow for a swift (re-)stabilization of the system's functioning in presence of external or internal shocks, but high overall degree centrality can also have a destabilizing effect on (energy) network if these hubs are removed or destabilized. Ash and Newth [90] proposed that interconnection of hubs (nodes with high centrality measures) allow for a quick distribution and hence absorption of disturbances (p. 681), thus propagating inter-hub connectivity. Other authors have come up with contrary views, stressing the danger of (involuntary) hub-removals [99].

3.2.3. Modularity

Network modules describe parts of the network that share above-average interaction intensity (when compared to the system as a whole) and that are partially detached from other parts of the network [100,101]. Modularity measures can either be applied to predetermined entities (such as social arenas) and be utilized to distinguish between in-group versus out-group connection, or can be applied to investigate overall network structures [102].

Social: Modularity measures can be applied to measure the interaction intensity within social arenas versus the interaction intensity between social arenas (see [87] for an application in the tourism sector). If the modularity index is high, this means that many subgroups exist, which may be detrimental to overall cooperation in the system. Low modularity measures indicate a homogenous distribution of connections within the network, with actors from various arenas sharing similar numbers of connections and a high potential for exchange of information across arena boundaries. Role for resilience: High modularity can lead to an intense sharing of new ideas within partially secluded subgroups, resulting in higher (local) innovation, and therefore higher overall adaptive capacity of the system [94,95]. At the same time, high modularity can impede the flow of information between actors that are not part of the same subgroup. If subgroups form across arena boundaries, the variety of information shared is higher when compared to subgroups that are formed of actors from the same arena. This is important when it comes to support regional (social) innovation processes [96], which can lead to higher long-term resilience of the system by supporting both resistance and adaptive capacity.

Technical: In the technical system, modularity measures describe the presence of autonomous production or distribution modules within the overall network, which can sustain energy distribution independently over a certain period of time. An autonomous functioning of certain parts of the system allows a blocking-off of harmful effects by islanding parts of the network [103]. Role for resilience: [104] suggest that the resilience of a system increases, if the overall modularity or/and the clustering of a system increases. They relate this to concepts of edge resilience and node resilience (see [98] p. 116). Shocks spread less quickly in modularized networks, and can be "blocked" at the entrance node to the module. Linked to this, Roege et al. [57] postulate that—given a certain modular structure—system components (modules) can function autonomously, if the essential functional aspects are covered within the module itself. This is important in order to be able to detach parts of the network in the case of (localized) perturbations, allowing for an overall stabilization of the functioning of unaffected parts of the network, and thereby increasing the resilience of the network as a whole.

4. Discussion

In the previous sections, we conceptualized resilience for energy systems as STS in transition, taking into account both the social and the technical aspects. We operationalized the resilience of socio-technical systems in transition based on the key attributes diversity and connectivity and derived a set of indicators related to diversity and to connectivity patterns of the system. In the following we engage in a discussion on: (1) Possible effects of different degrees of diversity and connectivity on the resilience of transitions; (2) Implications of measuring the resilience of transitions for energy systems; and (3) Future research needs.

4.1. Effects of Different Degrees of Diversity and Connectivity on the Resilience of Transitions

To understand how the selected indicators, relate to the resilience of a transition, we have to combine the levels of each indicator presented above first at the level of attribute (i.e., diversity and connectivity), second at the level of the system (social and technical), and third at the integrated level, i.e., social-technical system. It must be considered that there is no linear relationship between the indicators (and the levels) and the resilience of the transition. This means, as presented above, the resilience of the system increases if there is a higher modularity, but obviously if the system is too modular the resilience might decrease again, suggesting rather an u-curve than a linear relationship [51]. Thus, in the following we illustrate theoretically for four cases how different extreme values of diversity and connectivity might mirror different states of the resilience of a transition. The empirical analysis of two energy regions using these indicators follows in part two of this work: An indicator-based approach for analyzing the resilience of transitions for energy regions. Part II: Empirical applications.

Regarding diversity the necessity of looking at the three indicators in an integrative way is best stated by [100] (p. 1627) "... the most serious difficulty with conventional variety-balance indices concerns the neglect of the crucial property of disparity . . . .This can yield manifest perverse results . . . ". We consider the same to be true if we aggregate the three indicators. Thereby, a key question is how the weight of the three different indicators is defined. Furthermore, as shown by [105] the same value of the aggregate indicator can be obtained with different values of the three indicators, however, having a completely different outcome. In addition, for example, in the beginning of the transition, there might be a high variety of arenas, whereas their balance comes only at a later stage.

The same is true for connectivity. While connectivity measures are inherently interrelated with one another, the distinction between the three indicators helps to understand the underlying drivers and barriers of cooperation and collaboration in the social sphere, which helps to build stability and adaptive capacity along the transient pathway by means of steering current and future development, and enabling innovation. In the technical sphere, the three connectivity measures allow to assess the structural resilience of the system with regard to both external shocks, and internal disruptions. This helps decision-makers to plan further adjustments in the energy infrastructure to drive the transition towards higher sustainability.

We consider that what is true for diversity and connectivity is also true for the combination of these two attributes. That is, the resilience of a transition cannot be studied by only considering diversity or connectivity or by only analyzing the technical or social systems independent from each other. In the following we illustrate in the form of fictive scenarios four possible constellations of diversity and connectivity components and discuss their implications for transitions.

Case A (Diversity high, connectivity high):

The *regional energy governance system* is composed of a high variety of types of actors, which are well distributed across the social arenas and which are very different from one another (e.g., politics, artists, businesses). The actors are organized in distinct modules, which have a well-defined and well-elaborated communication structure composed of direct communication paths, with low average path lengths. There is a clearly defined central actor ensuring that the system is able to react to potential crisis situations while still maintaining its governance stability. In the *technical system*, there is a diverse amount of different technology groups, which are different from each other and which occur in the same share. This provides for a large and balanced technology portfolio. The different technologies are so well connected to each other that despite the large portfolio, the efficiency of the energy system is not negatively touched upon. The central organization (e.g., energy region manager) also supports an efficient combination of the different energy technologies. In such a constellation, it is very likely that an energy transition might be successful and fully supported by the social system and well embedded into the current technical energy system. This would be an ideal-typical case of a resilient transition.

Case B (Diversity low, connectivity low):

The *regional energy governance system* is composed only of 1 or 2 very similar arenas (e.g., city and community representatives) who have a segmented view of the social system within the energy transition. The measures taken are shortsighted and do not consider all the actors involved, thus, hampering the social acceptability of the transitions process itself. The low degree of centrality (e.g., no central managing actor) leads to a lack of central steering power by individual actors in the social system which allows for uncontrolled growth of individual technical initiatives. In the *technical system*, the technology portfolio consists of a few technology types, e.g., solar and nuclear, which are not well balanced themselves. The high amount of, e.g., solar energy producers, who are not well integrated into the grid, resulting in long average transmission paths, makes the system difficult to be steered. This constellation is likely to cause severe technical, economic, and governance inefficiencies and the energy transition is likely to fail. One empirical case that can partly be related to this constellation is the case of the ökoEnergieland in Austria [19]. The transition process towards withdrawal from fossil fuels was mainly initiated by two visionary leaders, the town's engineer and the mayor of the town of Güssing. One key innovation in the region was the development of the first combined heat-power plant, installed in the town of Güssing. This plant provided a large share of the renewable energy used in the region. In the further development of the transition one could observe increases in the diversity of actors and technologies, however, a dominance of the two founders and the combined heat-power technology prevailed and even though they were establishments of several businesses in the region the connectivity with other relevant players in the region was rather low mimicked in the populations lack of awareness and interest concerning energy-related issues [33]. However, a high share of renewables in the energy portfolio was reached (amounting up to 52% in 2010 [19]). This low diversity and connectivity finally, among other factors, led to a bankruptcy of the region in 2011 and 2016 [106–108].

Case C (Diversity high, connectivity low):

The *regional energy governance system* is composed of a high variety of types of actors, which are well distributed across the social arenas and are different from one another (e.g., politics, artists, businesses). However, the actors are not well organized and have not established a clear communication structure. Thus, communication takes a long time, is inefficient and often does not reach the correct addressee. There are several central actors causing high transaction costs and low reactivity within the system. In the *technical system*, there is a diverse amount of technology groups with a very similar overall share. This provides a large and balanced technology portfolio. As the different technologies are not well connected to each other, the transmission pathways are long, causing high inefficiencies within the energy system. As there is no explicit central organization, i.e., there are no central actors with steering capacity coordinating the development of and coordination between the large amount of technologies prevalent in the region. In such a constellation, there are two forces that could affect the transition. On the one hand diversity measures indicate an optimal starting point for further developments toward the transition goal. On the other hand, as the system components are not well connected and high inefficiencies prevail, it is not clear whether the energy transition would fail or would reach a stabilization point, if connectivity is further enhanced. Case C, thus, could indicate an intermediate stage within the transition of the regional energy system. A case that has some aspects of this constellation, is the energy transformation in the energy region Weiz-Gleisdorf (see also Part II: Empirical applications). This case shows high diversity in the social and technical systems, a high connectivity in the social system, but a rather low connectivity in the technical system. The share of renewable energies in the regions was around 26% in 2010 [33].

Case D (Diversity low, connectivity high):

The *regional energy governance system* is composed only of 1 or 2 very similar arenas (e.g., city and community representatives), who have a segmented view of the social system within the energy transition. The measures taken are shortsighted and do not consider all the actors involved, thus hindering the social acceptability of the transitions process itself. There is nevertheless a high degree of centrality and the actors are organized in modules. This and very efficient communication ways ensure that the system can react, even though only partly, to external demands. In the *technical system* the portfolio consists of a few technology types, e.g., solar and nuclear, which are not well balanced themselves. The high amount of, e.g., solar energy producers or large wind energy producers is well integrated into the grid, resulting in short average path lengths, and there is well established modular system in place, so that the energy technologies which are present are easy to handle and to steer in case of external perturbations. This constellation is likely to lead to a partially stable transition as on the one hand the available technologies are well managed but, on the other hand, relevant technologies might not be considered and thus not integrated into the transition. The low integration of the different arenas leads to low acceptability and potentially low inclusion of relevant actors hindering a complete transition. An example for this type of transition could be the transitions in the northern part of Germany, where the regions rely mostly on wind energy as the sources of renewable energy. These four examples showed that when studying the resilience of the transition of an energy system it is essential to include both the aspects of diversity and connectivity, as well as the social and technical systems. If we would neglect one or the other we would run into the problem of taking wrong decisions and making wrong policy recommendations.

4.2. Implication for Measuring Resilience along the Transition Path

When reflecting on the role of diversity and connectivity for resilience, following the logic of the adaptive cycle [56] the overall level of diversity is likely to decrease over the course of a transition, while the overall level of connectivity might increase. Our case A above shows for the energy system that even a high diversity can lead to a high resilience if the connectivity of the system is set-up in an optimal way.

In the technical system, the balance and disparity are likely to decrease along the transition path, due to economies of scale, while variety is likely to stabilize at a certain point (number of mature technologies). With regard to connectivity, the centrality will likely increase both in the social and technical systems, because a smaller number of actors and production sites will provide the same level of service, while the (qualitative) differentiation between the units increases over time. The average path length is likely to stabilize at a level that allows efficient processes, while allowing for a certain structural flexibility.

4.3. Future Research

Further research should focus on two main aspects. First, a further differentiation with the concepts of diversity and connectivity is needed, regarding the question, whether and how an integrated set of indicators should be built and how their different levels can be interpreted with respect to the resilience of the transition process. Second, the indicators have to be tested empirically to ensure their applicability, interpretability and usability for policy development. We propose an empirical application of the indicators to an Austrian case study region in An Indicator-Based Approach for Analyzing the Resilience of Transitions for Energy Regions. Part II: Empirical Application (also part of the present Special Issue).

5. Conclusions

In this paper, we conceptualize and operationalize the resilience of socio-technical energy systems in transition. We take up a resilience understanding from social-ecological systems (SES) research and apply it to regional energy systems. We derive a set of six indicators related to diversity and connectivity, which characterize the resilience of a regional energy system. Diversity can be measured by variety, balance and disparity of the system, whereas connectivity can be measured by average path length, degree centrality and modularity. These indicators provide metrics for analyzing the resilience of energy transitions across regions. They allow for an empirical investigation into the different structural aspects of energy systems in transition, and their evolution over time.

For analyzing the resilience of the transition at a certain stage of the transitions it is important to look at the six indicators simultaneously. The four theoretical examples presented show that only when studying the six indicators concomitantly we can achieve a meaningful interpretation of the results. The precise way of how the diversity and connectivity measures relate to each other in practice is subject to further empirical analysis.

Regarding the role of diversity and connectivity along the transition path, our theoretical analyses suggest that diversity is likely to decrease along the transition path, while connectivity is likely to increase. Thereby the development of each of the indicators relating to diversity and connectivity might vary from each other.

Further research will have to determine the explanatory power of our indicators for the analysis of resilience in energy transitions in general, and provide insights on how regional characteristics and political regulations, affect the real-world values of the diversity and connectivity measures. This will allow us to derive contextual policy-recommendations for a resilient management of regional energy transitions in the future.

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All authors contributed equally to this publication. The doctoral candidate contributed to theoretical conceptualisation, empirical analysis and writing of the publication.

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MDPI

Article

An Indicator-Based Approach for Analysing the Resilience of Transitions for Energy Regions. Part II: Empirical Application to the Case of Weiz-Gleisdorf, Austria

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Abstract: In this paper, we apply an indicator-based approach to measure the resilience of energy regions in transition to a case study region in Austria. The indicator-based approach allows to determine the resilience of the transition of regional energy systems towards higher shares of renewables and potentially overall higher sustainability. The indicators are based on two core aspects of resilience, diversity and connectivity. Diversity is thereby operationalized by variety, disparity and balance, whereas connectivity is operationalized by average path length, degree centrality and modularity. In order to get a full picture of the resilience of the energy system at stake throughout time, we apply the measures to four distinct moments, situated in the pre-development, take-off, acceleration and stabilization phase of the transition. By contextually and theoretically embedding the insights in the broader transitions context and empirically applying the indicators to a specific case, we derive insights on (1) how to interpret the results in a regional context and (2) how to further develop the indicator-based approach for future applications.

Keywords: resilience; transition; energy; energy region; Austria; indicators

1. Introduction

Local and regional energy systems are important entities in the current energy transition towards a low-carbon, renewable energy system [1,2]. At a regional level, in Austria for example, 106 "climate and energy model regions" including 1113 municipalities with 2.5 million inhabitants have been created and initiatives such as climate communities (Klimabündisgemeinden) or e-5 communities (e-5 Gemeinden) have developed since the 1990s [3,4]. In Germany, similar initiatives such as the 100% renewable energy regions (100ee-Regionen) have emerged on a regional scale, with similar initiatives at city and community level [5–7]. Some of these regions have been quite successful in the energy transition, building new institutional structures and increasing the share of renewable energy sources in the regional energy supply, while being able to export energy to other regions [8–13]. In many cases, however, a few years after the initial enthusiasm, a hiatus emerged as the expected outcomes in energy self-sufficiency were not reached within the time they were envisioned [14–16].

Empirically, several authors have analysed the relevant factors for an energy transition at a regional level to be successful. As such, they have investigated the role of guiding visions and foresight, the number and characteristics of actors and arenas involved in the transition process, the course of the institutionalization process, or the development of the energy and material flows over time [8,9,17–19]. A number of studies have developed models for analysing and simulating transition processes towards sustainability [20–22]. However, even though there is empirical evidence that the success of a transition depends, amongst others, on the transition pathway itself [23], none of the studies has explicitly analysed the resilience of a regional energy system in a transition process.

Resilience as a core concept of social-ecological and socio-technical systems research has gained substantial attention in the last two decades, both from a scientific and from a policy-oriented point of view (see [24] for a comprehensive review). In the socio-ecological systems literature, resilience is traditionally understood as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks" [25]. Out of the analysis of critical infrastructures, a specific literature strand on energy resilience has emerged, dealing, that is, with the resilience of the power grid to external shock [26–28]. Further applications are in urban infrastructure planning and in risk and disaster management [29]. Out of these studies, a number of frameworks to conceptualise critical infrastructure resilience and energy system resilience have emerged and various measures and indicator sets have been proposed to understand and measure the resilience of the technical energy infrastructure [30–33]. Though helpful for the reflection on the technical aspects of the socio-technical properties of an energy system in transition, energy resilience remains a predominantly static concept, which a focus on restoring functionality of a given energy system after a critical shock. It also lacks a true integration of social aspects, such as social structures and relations. Where social aspects are taken into consideration, the social subsystem is mostly treated subordinate to the technical subsystem and mostly analysed with respect to the resilience of the technical system.

Most of the resilience literature remains conservative in the sense that it presupposes stable system states and advocates for a management approach of complex social-ecological and socio-technical systems (see e.g., [34]). We build upon an alternative understanding of resilience following in "[that resilience is] less characterized by systemic properties and rather operates on the context [level] of the system" (p. 4). In other words, it is important for the system to maintain its basic functionality, even as key actors, processes and functions change over time [35]. Inspired by the four stages of the adaptive cycle (exploitation, conservation, collapse and reorganization), a procedural understanding of resilience can be seen as the capacity of a system to navigate all phases of the adaptive cycle, while still providing the basic services of what [36] call "the net social utility."

Reference [1] have theoretically derived an analytical approach to assess the resilience of regional energy systems in transitions. They base their approach on two core-attributes of resilience, namely diversity and connectivity. Building on the indicator set developed in Reference [1], we aim in this follow-up paper to apply indicators to a specific case-study region in Austria and reflect on the possibilities, added values and potential pitfalls of empirically measuring the resilience of a regional energy transition. We do this along the following four guiding research questions, relating to the application of the indicators and their interpretation:

- How can we apply the approach proposed by [1] to allow to empirically measure the resilience of a regional energy system in transition, with regard to both the social and technical aspects?
- Where can the studied regional system be situated with respect to the four ideal-cases presented in Reference [1] and what can we learn with respect to the (potential) success of the transition process?
- Does the approach allow for a resilience assessment that is transferable to other regions and other contextual settings?
- What are the policy implications of using this indicator set to analyse an energy region in transition?

In order to tackle these questions, we build on empirical material from a case-study area in Austria. We apply the indicators developed in Reference [1] and measure the core aspects defining the resilience of the system throughout the transition process. We then compare the results with qualitative insights from another case study area in Germany. We conclude with some general insights and specific recommendations regarding the application of a resilience framework in the context of (energy) transitions.

2. The Resilience of Regional Energy Transitions

The current shift of the energy supply structure from a mainly fossil fuel based system to one built on renewable energy sources takes place on different geographical scales, that is, on a global, national, regional and local level. The regional scale has been emphasised by policy-makers and experts alike to be especially suited for bottom-up initiatives and policy-interventions due to (1) the spatial and social proximity of actors, (2) the regionally accessible resources and (3) the positive regional economic effects of renewable energy development [37,38].

Transitions are usually driven by specific actors within a systemic context, who for ideological, economic or technical reasons are convinced that change processes are required and push for systemic change [39]. Novel ideas, disruptive technology developments and innovative ways of doing business normally develop in "niches," which offer engaged actors the possibility of trial-and-error experimentation without being fully integrated into the mainstream system. By means of up-scaling and proliferation, the practices and actors can potentially link up to the mainstream systems and the actors of the so-called system regime (see e.g., [40]). Whereas this view originated in the context of technological innovations, the idea has been taken up in the area of sustainability science linking it to processes of transition towards more durable and responsible ways of organizing society, doing business and using resources (see [31,32]).

The transitions of socio-technical systems, systems in which technologies, their social use and governance structure are conceptualised as deeply interlinked and developing in a co-evolutionary way, can be subdivided into four distinct archetypal phases: the pre-development, the take-off, the acceleration and the stabilization phase (see [41]). In the pre-development phase, the transition process starts to get under way and values, ideas and ways of doing business begin to change, at least for certain actors and actor groups that actively push for change (the actors of the niche, see [39]). On a system's level, the pre-development phase is characterized by a dynamic equilibrium and the status quo does not change (yet). The take-off phase is when visible changes in the system's structure and functioning appear on wider scales not only in the niche but also on the regime level. During the acceleration phase, collective learning processes fundamentally change the system's functioning, new technologies are broadly adopted and social practices are adapted accordingly. During the stabilization phase, the speed of social change decreases and a new dynamic equilibrium is reached.

2.1. Measuring Resilience along the Transition Pathway

Reference [1] propose six metrics for measuring diversity and connectivity, accounting for both the social and the technical components of the energy system (Table 1). Diversity and connectivity are assessed separately for both the technical and the social subsystems.

Table 1. Indicators for the social subsystem (based on [1]).

Diversity	Connectivity
Variety—Number of social arenas present in the regional energy governance structure.	Average Path Length—Number of steps it takes to reach other actors from other arenas along the shortest path in order to coordinate activities.
Balance—Number of actors per social arena in comparison to overall number of actors involved in the regional energy governance structure.	Degree Centrality—Number of connections of actors within one arena to actors in other arenas in comparison to overall possible number of connections.
Disparity—Qualitative differentiation between arenas (e.g., organisational structure, key actors, time horizon or spatial reference).	Modularity—Measure of the tendency of actors from different arenas to form functionally distinct subgroups, which show stronger connectivity with the subgroup than with the rest of the network or are (partially) detached from the rest of the network.

2.1.1. Social Sub-System

With respect to the analysis of the social subsystem we rely on the concept of "social arenas" [17,37]. Social arenas are defined as "societal subsystems or spheres, characterized by their rationality and codes depending on their function" (translated by the authors from [17]). Commonly these arenas can be identified by their specific structure, that is, network or market-based and the functional characteristics of their central agent groups, such as politicians, entrepreneurs or private households. In the context analysed, we selected the following social arenas based on the specific characteristics of the sector and the case-study areas: industry, associations, research, politics and media. In order for the system to be resilient at all points along the transition pathway, the actors from the different arenas have to collaborate with each other to ensure the functionality of the system and drive the system′s development towards sustainability (see [42]). Thereby, social connectivity is characterized by the exchange patterns between actors from different social arenas. We can distinguish here between formal and informal exchange patterns [43,44]. Formal connectivity can encompass shared business ownership, contractual collaboration arrangements, outsourcing and joint venture activities, membership in industry organizations, or similar. Informal connectivity includes information exchange on a personal and voluntary basis, between business partners or not, which helps build social capital but is not directly linked to formal collaboration agreements (e.g., [45,46]). For a formalization of the respective concepts in mathematical form we refer to [1].

2.1.2. Technical Sub-System

With respect to the analysis of the technical subsystem, we distinguish between different groups of (renewable) energy production technologies (technology groups). The differentiation in production technology groups with respect to their locality has been applied by [47], as it is more precise than only studying the energy sources and it is less detailed than analysing each specific technology. In the analysed regional context, the most important technology groups in renewable energy production are hydropower (small and big plants), biogas, combined heat power production (CHP), photovoltaic (rooftop and open field) and solar heat. In order for the transition to be resilient, the technical subsystem needs to be changed carefully so that the energy provisioning functions are not endangered. The changing structure of the regional electricity grid and gas network as well as the evolution of local district heating networks, which are highly relevant to allow for a faultless integration of higher shares of renewables, have to be taken into account. The metrics for measuring diversity and connectivity in the technical subsystem based on [1] are given in Table 2. For a formalization of the respective concepts in mathematical form we refer to [1].

Table 2. Indicators for the technical subsystem (based on [1]).

Diversity	Connectivity
Variety—Number of groups of technologies present in the regional energy production system	Average Path Length—Length of the transmission lines between production and consumption sites
Balance—Share of the individual technology group in regional energy production	Degree Centrality—Number of connections to other producers or/and consumers in the regional distribution network
Disparity—Qualitative differentiation between technologies (e.g., energy conversion efficiency, resource used, production costs or weather dependency)	Modularity—Measure of autonomy of certain parts of the distribution network that function independently from the main network

3. Data and Methods

We exemplify our operationalization with results from an analysis of the socio-technical transition in the Energy Region Weiz-Gleisdorf (EWG) in Austria (Figure 1). The EWG is a "climate and energy model region" located in Styria, Austria and encompasses 18 communes with a growing population of around 42,000 inhabitants [48]. EWG has a long tradition in technology development for renewables, especially solar heat and photovoltaics [49]. In 1996, the regional communes founded an energy region association in order to coordinate and foster the regional energy transition endeavours towards higher shares of renewables and energy efficiency innovations. Since 2007 EWG is also an EU LEADER region and since 2011 a "smart region" [50].

Figure 1. Map of Energy Region Weiz-Gleisdorf's (EWG's) location in Austria (red circle). Source: [51].

We draw on qualitative and quantitative data from [8,9,20] and on our own investigations in the area in November 2016. We present results for the years from 1990 up to 2016. This period of time was according to important events in the social subsystem, which emerged in the interviews conducted for this study.

For the determination of the constitution of the system and the establishment of the system models, we chose the years 1996, 2011 and 2016. 2011 and 2016 were the years when the interviews were conducted. We chose to include only one additional period in retrospective, due to the difficulty to assess different point in time in the past and potential biases regarding the evaluation of past events (e.g., the rosy effect, seeing the past more positive than the present [52]). 1996 was chosen since it was considered as an important milestone in the energy transition due, amongst others, to the formal foundation of the energy region structure and the institutions that went hand in hand (secretariat, association) [8,9]). For consistency of the analysis, we selected the same years for the technical subsystem (1996, 2011, 2016) but also integrated figures reaching back to 1990 in order to fully assess the predevelopment phase. This allowed us to investigate in the development before and between the dates in the social subsystem.

3.1. Data Collection

For the social subsystem, we built on secondary data from interview transcripts in 2011 [8,9,20]. Additionally, we collected primary data in the region in 2016. Interviews were conducted with the most important actors in the regional energy governance system, who are able to oversee the whole transition process (13 interviews in 2011, 9 interviews in 2016). The 1990 to 2011 evolution of the system configuration was discussed in both cases. While the interviews were held following a semi-structured design in both years, a mental model approach complemented the interviews in 2016 [53–56]. The mental models were elaborated by using concept maps as graphical representations of individual perceptions of reality [57]. Hereby, the interviewees were asked to draw their mental models of the social subsystem of the energy sector in the region, focussing on (1) who were the most important actors in the region with respect to the energy transition, (2) how central were these actors with respect to the other actors in the system and (3) how closely did they collaborate with other actors in order to drive the transition process? The mental models were replicated for the years 1996, 2011 and 2016.

To gather data for the technical subsystem, we used the publicly available energy balance sheet for the federal state of Styria [58]. A comprehensive data set was only available on the level of the federal state of Styria and not on the regional level of EWG. From the structure of the regional and the state-wide energy system, we assumed that the characteristics of the energy system on the two levels was sufficiently close in order to allow for deductions from the state to the regional level. This assumption has been supported by two interviews with energy experts in the region, a representative of the biggest urban utilities company in the region and a representative of the regional energy grid operator. Additionally, we considered data on the regional level from [8,9,20] and evaluations of further regional experts. However, data for photovoltaics, biomass and solar heat where only available from 2010 onwards. No quantitative data was available for the evolution of the electricity grid and heat network over time. Thus, we rely on qualitative evaluations from regional grid operators, which we collected in semi-structured expert interviews. This approach allowed to complement the former dataset not only by information on the current situation but also by a graphical representation of the perceived configuration of the social subsystem in the past and its changes over time.

3.2. Analytical Methods

Following the approach lined out in Reference [1] we conducted an indicator-based analysis of the two central resilience aspects diversity and connectivity separately for the social and technical subsystems. We concentrated on the actors and technical installations which are linked to the renewable energy sector, who either taking over an active or passive role in driving the transition of the energy system towards higher levels of sustainability (actors) or are indispensable in bridging production and consumption of renewable energy (technical subsector).

In the social subsystem, we analysed the diversity based on the interview transcripts from [8,9] according to the structured qualitative content analysis [59,60] by coding the transcripts in MAXQDA (http://www.maxda.de). We investigated the variety of the social subsystem by revealing the social arenas, which the interviewees perceived as important for the regional energy transition in 1996, 2011 and 2016. Regarding the balance, we analysed the most important actors mentioned by the interviewees and assigned them to their corresponding social arenas—thereby, multiple assignments where possible, for example, politicians who were association members and were in addition working in industry. Regarding disparity, we described the qualitative differences amongst the social arenas based on the criteria proposed by [1,61].

We operationalized the connectivity indicators in the social subsystem based our analysis of the interview transcripts. This touches the revealed qualitative descriptions of the connectivity measures put forward in Reference [1]. Additionally, we aggregated the individual concept maps of the interviewees to work the shared perception(s) of the social subsystem's configuration in 1996, 2011 and 2016. Thereby, we followed the Cognitive Mapping Approach for Analysing Actors' Systems of Practices (CMASOP) by [54] to analyse the mental models of the regional actors from a systems perspective. The CMASOP proposes 4 steps: conducting qualitative interviews, coding the interview transcripts, deriving individual cognitive maps and merging of the individual maps to a common "social cognitive map" [54]. For the average path length, we derived mentioned relations between actors of different social arenas—whether they were direct or indirect (which causes a higher path length). In addition to the revealed proximity between the actors, we also interpreted the perceived proximity from the conceptual maps. In order to analytically grasp centralities, we derived notions of central actors from the interviews—as representatives of their social arena—and analysed the concept maps regarding the central position of one arena and as well as a relatively higher share of relations to other arenas. Finally, to measure modularity in the social sphere, we looked for stronger relations between actors from particular social arenas in contrast to the average intensity of relations in the regional context.

In the technical subsystem, we analysed the diversity by studying the renewable energy production technologies from 1991 to 2015 in the state of Styria. Following [1], we started off by defining how many technology groups existed at each point (variety) in time and how much they differed from each other (disparity). For the latter, we described the qualitative differences amongst the involved technology groups, based on the criteria, proposed by [1]. We calculated the balance as the share of each renewable technology group in the overall energy production over time. We calculated both, the Shannon Weaver $S = -\sum_i pi \times \ln(pi)$ and the Shannon Eveness $S = -\sum_i pi \times \ln(pi) \cdot \ln N$ indices.

We applied the connectivity indicators in the technical subsystem qualitatively for both electricity and heat. Regarding the average path-length in the electricity grid, we analysed the evolution of the electricity grid′s length on the lower tension levels which are relevant to the region (level four and below). For the heat supply, we analysed the evolution of the gas net as well as the district heating systems and the number of households connected to the gas net or district heating systems. Regarding degree-centrality, we analysed the electricity grid structure regarding its adjustment to the increasing number of decentralised production sites using renewable energies—for heat, we interpreted the changes in the gas net and district heating networks. Finally, we also analysed the grid structures with respect to module formation within the electricity grid and the heat networks and interpreted the results for the modularity indicator. Table 3 summarizes the measures that have been applied for every indicator.

Table 3. Measures for the indicators in the social and technical subsystems.

Measure / Subsystem	Diversity			Connectivity		
	Variety	Balance	Disparity	Average Path Length	Degree Centrality	Modularity
Social Subsystem	Count of social arenas	Number of key-members per arena	Qualitative difference between arenas	Perceived distance between actors from different arenas	Perceived centrality of actors from different arenas	Relative strength of relation between actors from diff. arenas
Data Source	Interview data	Interview data	Interview data	Interview data & CMASOP	Interview data & CMASOP	Interview data & CMASOP
Technical Subsystem	Count of technology groups	Share of technology group for electricity and heat production	Qualitative difference between technology groups	Length of electricity grid (<level 4) and length of district heating networks	Grid structure (gas and electricity) with respect to production sites	Independent distribution networks within the electricity or district heating systems
Data Source	Energy balance sheet	Own calculations	Expert estimations	Interview data	Interview data	Interview data

4. Results

In the following section, we present our results for the six indicators [1] for both, the technical and the social subsystem—structured according to the four predefined transition phases. As mentioned earlier, we have restricted ourselves to actors in the social subsystem that are in one way or the other engaged in the transition towards higher shares of renewables in the energy system and the infrastructure(s) that are linked to the proliferation of renewable energy. This in order to guarantee for a highest possible consistency, allowing for reproducibility with other actors and a broader set of (incumbent) technologies in the future once data availability issues are resolved.

4.1. Predevelopment Phase (1990–1996)

4.1.1. Social Subsystem

Diversity: In the early phase of the regional transition, we identified medium variety levels, since actors from four arenas were involved in the social subsystem: politics, associations, industry and research. The balance was high, since every arena was represented by only 1–2 actors and no arena was perceived to be dominant. The politics arena was represented by two mayors of the two big municipalities in the region, the industry by a municipal utility and a regional construction firm, research by two regional research centres and the association arena by an association for the promotion of renewables. Finally, the disparity among the arena was also high (see Table 4), since the arenas clearly differed in their coordination form (hierarchy in politics, networks in associations and research and market for industry), main function (energy and energy-related products from industry, rules and funding from politics, knowledge and technology from research and networks and funding from association) as well as in their time-horizon (short-term for politics, mid-term for industry and mid- to long-term for research and associations). The overall diversity of the social subsystem in the predevelopment phase can be considered as medium to high.

Table 4. Disparity attributes of arenas involved in the social subsystem in EWG (adapted from [61]).

Social Arena / Characteristics	Industry	Associations	Research	Politics	Media
Core Actors	Energy producers, cooperatives, construction and production firms	Regional energy associations, LEADER groups, Industry associations	Regional innovation centre, Universities, research institutions, Research departments in firms	Municipalities, the provinces, the EU	Regional newspaper
Coordination of Actors	Market	Network	Network	Hierarchy	Market
Main Goals within the Arenas	Investing in renewables, providing energy and energy-related products	Coordinate and represent regional actors, provide funding, integrate external actors	Developing and testing of new technologies, introducing new knowledge in the region	Regulating, subsidizing, investing in energy plants/research projects	Informing the public, opinion building on political decisions and observed behaviour in industry
Time Horizon for Activities	Medium-term	Long-term	Medium-term	Short-term	Short-term
Spatial Reference of Actors	Local–international	Local–regional	Regional -national	Local—international	Local–regional

Connectivity: The path length among the actors engaged in renewable energy production in the early phase of the regional energy transition was perceived as very short. All actors knew each other personally. The two mayors (politics arena) were perceived as the centre of the social subsystem, connecting all other actors. At the same time, the classical energy providers and urban utility companies were not yet taking part in the transition. As a consequence, the politics arena had the highest centrality, which resulted in a high overall centrality in the governance system of the transition. At that time, no modules were detectable within the social subsystem. Over all, the connectivity in the social subsystem was high.

4.1.2. Technical Subsystem

Diversity: In the predevelopment phase in Styria only one renewable energy source existed for electricity production, that is, hydropower. The amount of electricity produced with hydropower however slightly increased from 2680 TWh/year to 3250 TWh/year from 1990 to 1996. Variety was 1, balance 0 and no disparity can be calculated, due to the presence of only one technology group. Overall, the diversity regarding energy production from renewable sources was low.

Connectivity: The regional electricity system in the predevelopment phase was characterized by decentralized production in combination with a centralized electricity grid and lower tension levels (up to level 3) were predominant. This system configuration leads to high average path-lengths, based on the fact that there are no large centralised production sites in the region. Additionally, the centrality of the grid was high, since the production and consumption entities were only connected through central transformer units and the regional grid is embedded in the highly centralised national grid. Finally, there was low, respectively no modularity in the grid, since there was no possibility to decouple autarkic parts of the grid which directly connected production and consumptions units on the lowest voltage level. The overall connectivity of the electricity grid can be considered to be situated at medium levels. For heat, the application of the indicators is more difficult since grid- and off-grid technologies existed (wood and oil burning), while there was no overarching grid in place in order to connect them. In the early phase of the transition, the path length was high in the gas net and low for the off-grid technologies. The centrality was high for gas and low for the off-grid technologies, whereas the modularity was low for gas and high for the off-grid technologies. Overall, the connectivity in the technical subsystem can be seen as medium to low.

4.2. Take-off Phase (1996–2001)

4.2.1. Social Subsystem

Diversity: In the take-off phase, the variety rose slightly, since the media arena was also perceived as important part of the social subsystem. Regarding the balance, the number of actors in the politics arena increased significantly due to the foundation of the energy region association which unified all 18 municipalities in the region. Moreover, more and more actors in industry and research became active in renewable energies. Investments were made and research collaborations were built, also beyond the regional level. Thus, the politics and associations arenas were perceived as less dominant and the overall balance declined to medium levels. With the appearance of the media arena, the disparity further rose. Media activities are coordinated through the market (like industry) and delivers information and facilitates opinion building, however, it has a very short-term focus. The overall diversity in the social subsystem can be considered as medium to high.

Connectivity: The path length in the social subsystem was perceived to remain at low levels, however, with the foundation of the regional energy agency and the larger engagement of industry and research, more (less central) actors were involved so that the path-length increased. Accordingly, the centrality declined to a medium level. As in the previous phase, the politics arena was perceived to be the most central. Actors from the political arena (including communal administration) were key in connecting actors from other arenas, together with the energy association. Additionally, direct connections among industry and research emerged. Finally, the modularity also slightly increased towards a medium level—due to bilateral projects among research and industry and the institutionalisation of the politics arena in the energy association. Overall, the connectivity in the social subsystem slightly decreased and can be considered to be at a medium to high level. At the same time, the existing collaborations became more formalised and stable with the foundation of the energy region association.

Figure 2 gives an overview of the aggregated mental models that were derived from the interviews in the region. The inner square delimits the regional energy system as perceived by the actors. The ovals depict actor groups belonging to specific arenas. The distance between the ovals equals the perceived proximity of the actor groups in terms of their collaboration in the field of renewable energy, as seen by the interviewees.

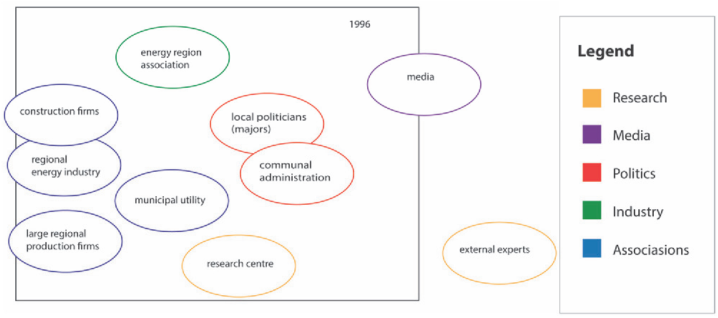

Figure 2. Aggregation of individual conceptual maps of the social subsystem in 1996 (authors′ own elaboration).

4.2.2. Technical Subsystem

Diversity: In the take-off phase, we start seeing a slight increase in the production of renewable energies. As wind power started to be produced, variety increased to 2. As the share of wind to overall electricity production out of new renewables was low (0.9%), both balance indicators are at around 0.01. At the same time disparity was high, with two technologies very different from each other present in the region. The overall diversity was low to medium.

Connectivity: The connectivity of the electricity sector remained without any large changes during the take-off phase. In the expert interviews, central actors in the sector clarified that the rising share of decentral production sites based on renewables was greatly absorbed by the buffering capacity of the grid. In the heat sector, the installation of biomass heat and CHP plants—which are embedded in district heating networks—began to rise. Correspondingly, grid-based heat technology became more and more relevant in the region. As a consequence, rising path-lengths, decreasing centrality and increasing modularity can be observed, as insular heating solutions (mainly based on firing oil) are being replaced by biomass-fired district heating solutions. Overall, the level of connectivity of the technical subsystem can be situated at low to medium levels.

4.3. Acceleration Phase (2001–2011)

4.3.1. Social Subsystem

Diversity: In the social subsystem, variety and disparity decreased slightly, since media was no longer mentioned as important arena for the social subsystem. The balance decreased as well: The number of actors in the politics and association arena increased slightly but in the industry arena many new actors were mentioned—especially distribution grid operators and regional utilities and larger production firms which were located in the region. Thus, the industry sector was perceived as dominating the social subsystem. Nevertheless, there were some qualitative changes in the other arenas: in politics, the other municipalities were perceived as becoming more active, in the association arena the foundation of the LEADER region association was an important factor to generate money and networks beyond the region. Additionally, there was the foundation of a new research centre which also attracted partners from outside the region. The overall diversity remained at medium to high levels as the social subsystem was perceived as fast moving and very dedicated to the progress of the transition.

Connectivity: The trend of the increasing path length continued, since more actors were involved, which only had bilateral contact to particular actors from the core network (e.g., industry actors to politicians, research actors or the LEADER group). Nevertheless, the core network from the predevelopment phase remained closely linked (Figure 3). And although the industry arena was still perceived to be dominating and central, with the LEADER group, the association arena became again more central in linking actors from politics to research and industry. Thus, the centrality can be considered as medium. The modularity increased to a medium level, since several collaborations among the arenas where established around projects like the planning and implementation of new district heating areas, new housing areas or the representation of the region at the national exhibition. The overall connectivity in the social subsystem can thus be situated at a medium level.

4.3.2. Technical Subsystem

Diversity: During the years 2001–2011, we can observe a rapid increase in the electricity produced by renewables. A high range of technologies was deployed in the region, ranging from photovoltaic, electricity out of geothermal power production all the way to waste related technologies. The total amount of electricity produced in Styria from renewable energy sources increased from 2978 TWh/year in 2001 to 4264 TWh in 2011. The variety increased to 9 distinct technologies. The Shannon Weaver index, which describes the balance by including the variety measures in the calculation, surged from 0.01 up to 0.8 during that period. However, the Shannon Eveness index, increased only up to 0.35 (see

Figure 4). Furthermore, also the disparity increased as very different energy technology groups were included in the production of electricity and heat. Overall diversity attained high levels.

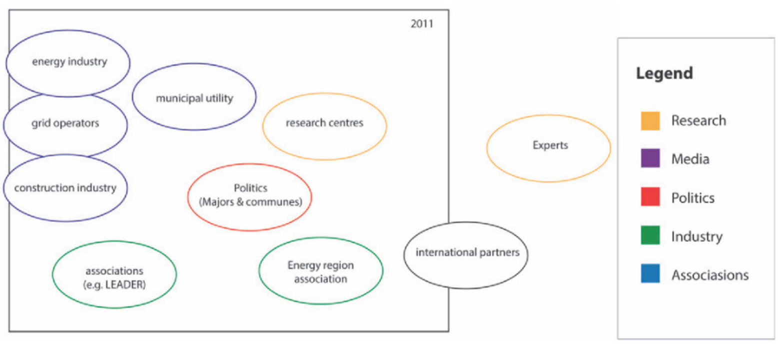

Figure 3. Aggregation of individual conceptual maps on the social subsystem in 2011 (authors' own elaboration).

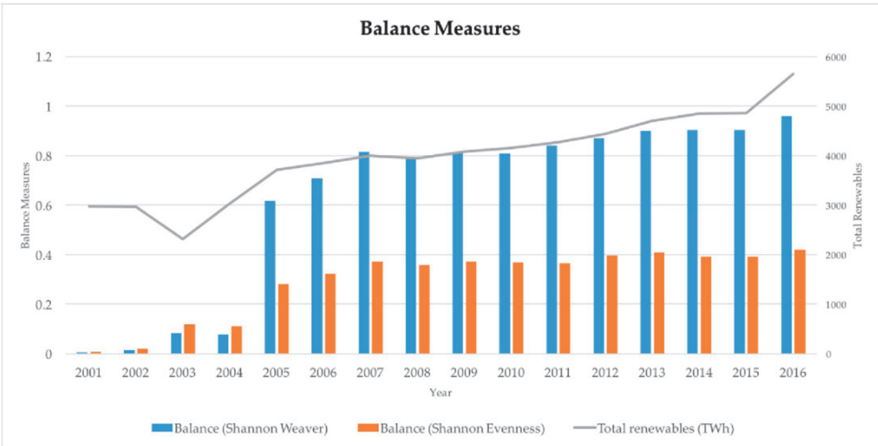

Figure 4. Development of the balance indicators for electricity production out of renewables over time (until 2005 only real values and not normed values were available). Data source: [58]).

Connectivity: There were no substantial changes in the electricity grid, however, the experts mentioned in the interviews that the regional grid operators began to mesh the grid on the medium voltage levels from around 2006 onwards, which means that they added additional non-linear connections which allow to supply a consumption unit through several distribution entities. With this development, the overall path length rose, the centrality decreased and the modularity remained low, since there was no specific opportunity to form modules in the grid. In the heat sector, the installation of biomass heat plants and CHP plants in district heating networks continued, so that the connectivity in the heat sector increased slightly. Overall, the connectivity of the technical system rose to medium levels.

4.4. Stabilisation (2011–2016)

4.4.1. Social Subsystem

Diversity: The variety remained unchanged in comparison to the previous phase, so does the balance. The industry and the politics arena also remain the two arenas which together comprise the most actors. The disparity of the arenas is constantly high. In the industry arena, new entrants were mentioned in the area of mobility. In the association arena, the merger of the energy region and the tourism region association were perceived as major changes to the composition of the governance system. Additionally, it is interesting to see that the disparity within the industry sector is higher than in any other arena. The arena is not only built up of utilities, operators of the energy distribution systems (DSOs) or electrical engineering firms but also includes regional construction firms, large production firms as well as actors in the tourism sector, which are present in the region and engaged with energy transition issues. The overall diversity remained medium to high.

Connectivity: The average path length remained medium. The densely connected core network of actors remained in place. So were some more loose connections to more peripheral actors, especially those located in industry. The centrality of actors from the politics and industry arena remained high, whereas the perceived centrality of the energy region association declined. Regarding modularity, most of the modules were built around projects and therewith characterized by a clearly defined timeline. New modules were only mentioned around mobility projects. However, some interviewees criticised that the members of the initial actor network remained closely linked with one another while connections to other actors—especially from industry—were rare and remained loose. Moreover, the interviewed actors noted critically that the links to the broader society and especially to non-energy related interest groups in the region, were underdeveloped, so that the main core of actors in the social subsystem were perceived to represent almost a module for themselves. Overall, connectivity in the social subsystem remained at medium levels.

4.4.2. Technical Subsystem

Diversity: The total share of renewables in electricity production reached 52.1% in 2016 (Statistics Austria)*:* As shown in Figure 4, after 2011 the total amount of electricity produced from renewables stayed almost constant. The variety in technology groups increased by 1 to 10. While the Shannon Eveness index remained almost constant, the Shannon weaver index increased slightly as one more technology contributed to the overall renewable share. Table 5 provides an overview over the disparity of the five most important technology groups employed in the region in 2016 (all data refers to the year 2016). Overall diversity of the technical subsystem is high.

Table 5. Disparity attributes of energy production technologies employed in EWG (adapted from [1]).

Disparity Attribute \ Technology	Hydropower	Biogas	CHP	Photovoltaic	Solar Heat
Energy Conversion Efficiency (η) [9]	0.85	-	0.85	0.08–0.16	0.5–0.7
Resource Base	Water	Biomass	Biomass	Sunlight	Sunlight
Direct CO_2 Emissions	No	Yes	Yes	No	No
Land Consumption [62]	Low	High	High	Medium	Medium
Dependency on Weather Events	Medium	Medium	Medium	High	High
Costs (cent/kWh) [47,63–66]	15.6–17.8	13.5–21.5	12.2	7.8–14.2	22

Connectivity: There was no major change in the electricity grid from the acceleration to the stabilization phase, with overall connectivity stabilizing at medium levels. The experts mentioned that meshing was considered as an ongoing maintenance task, which further decreased the centrality and increased the path-length. However, the experts stressed that if the legal framework would allow to build regional modules which could partly be uncoupled from the grid while connecting the regional production and consumption units directly, there might be a major change in electricity grid. This would cause rising path lengths and rising modularity while the centrality would decrease and result in a medium connectivity. In addition, the experts evaluated the technical development of power-to-gas/heat/cold/fuel as an important factor to rise the connectivity. Thus, there would be the possibility to use the gas net, extend it and connect other production technologies to it. Moreover, it would allow for regional storage—especially in combination with battery storage—which leads to a higher potential for modularity. For the time being, connectivity measures remained at medium levels.

4.5. Overview of the Results

When summing up the development in both the social and technical subsystems, the following levels of diversity and connectivity can be reported at the current stage of the transition:

Diversity in the social subsystem: the diversity in the social subsystem of EWG evolved from being very high, to medium levels. While variety and disparity remained at medium and high levels throughout the transition processes, respectively, measures for balance went from high at the beginning of the transition to low towards the stabilization phase.

Connectivity in the social subsystem: with regard to connectivity, the social subsystem of EWG went from being highly centralized and loosely linked to being of medium centralization, long(er) path-ways between the actors and higher modularity within the network as actors from new arenas engaged in the transition and new actors joined the different arenas.

Figure 5 gives an overview of the development of the diversity and connectivity measures in the social subsystem along the transition pathway.

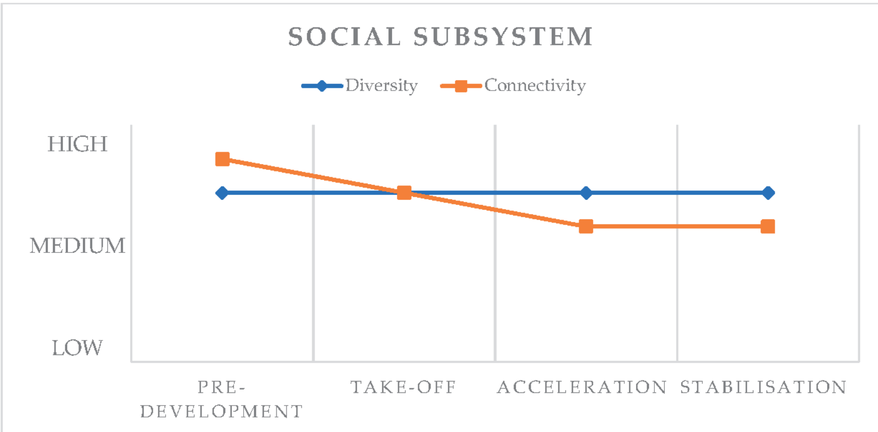

Figure 5. Development of diversity and connectivity measures in the social subsystem.

Diversity in the technical subsystem: the diversity in the technical subsystem in EWG went from being dominated by one technology (hydropower) to showing a big diversity when it comes to the renewable energy technology employed in the region. While balance was low and disparity high at the beginning of the transition (take-off phase), as the transition process advanced, both stabilized at medium to high levels.

Connectivity in the technical subsystem: the connectivity in the technical subsystem of EWG was characterized by high centralization and high average path-lengths (in the sense of transmission distances between production and consumption) at the beginning of the transition, with no modularity built in the system. As the transition proceeded, average path-lengths remained at a high level, whereas the centralization of the system was undermined by meshing activities and the emergence of prosumer structures. Modularity stabilized at low levels.

Figure 6 gives an overview of the development of the diversity and connectivity measures in the technical subsystem along the transition pathway.

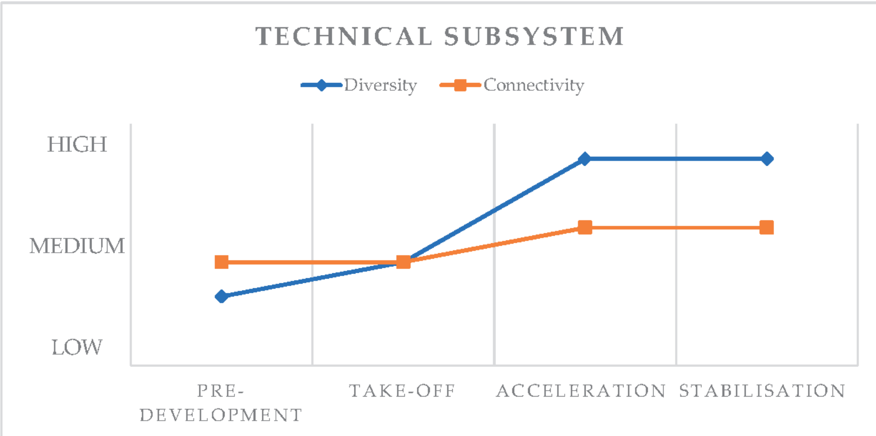

Figure 6. Development of diversity and connectivity measures in the technical subsystem.

5. Discussion

In this paper, we have taken up the indicator-set proposed by [1] and applied these indicators to the EWG region in Austria for the 1990–2016 period, which represents the timespan from the very first initiatives towards renewable energy production in the region, to a situation of stabilisation and can be seen as potentially being a temporally intermediate state before the next push towards higher shares in renewables in the future (2016 being the last year with reliable data).

In Reference [1] four ideal-typical situations were derived from a theoretical point of view, combining extreme values in terms of diversity and connectivity in the both the social and technical subsystems. A situation with both high diversity and high connectivity was seen to be beneficial for the progress of an (energy) transition with regard to both the support for the transition in the social sphere and the embedding of new technologies into the current technical energy system. Mixed constellations with high diversity/low connectivity and low diversity/high connectivity, respectively, were associated with incomplete transition processes, where two scenarios are likely:

- High diversity, low connectivity: intermediate state of a transition.
- Low diversity, high connectivity: situation of lock-in, where the lack of integration of central arenas leads to a blocking of the transition.

Finally, a situation with low diversity and low connectivity is likely to lead to technical, economic and social governance inefficiencies and is associated with a failing transition.

If we look at the development of the diversity and connectivity indicators over time in the EWG region, we find that the development in the social and technical subsystems have been running in the opposite direction. While connectivity and diversity have been high in the social subsystem at the beginning of the transition process, equivalent to high resilience following [1], connectivity and diversity were low in the technical subsystem, undermining the resilience of the technical subsystem. In other words, while actors from very divers social arenas collaborated intensely at the beginning of the transition process, the technical system was not yet in a state that would have allowed the system to withstand major external shocks, for example in terms of declining prices for renewable energy. Over the course of time, with more people engaged in the energy transitions and the core of idealistic pioneers cutting back on their engagement, diversity and connectivity of the social subsystem decreased. Concomitantly, diversity and connectivity in the technical system increased substantially over the years, with a high potential for a further substantial increase of system connectivity with changing regulations under way, that would allow for regional prosumer networks in the electricity system to form.

The current system state can be seen to be at an intermediate state, close to situation sketched out as case C in Reference [1], with a system-state characterised by medium to high diversity and medium connectivity levels in both the social and the technical subsystem. Such a system configuration provides an optimal starting-point for a further development towards a fully renewable energy system due to the high diversity of production technologies and actors from various social arenas involved in the transition. At the same time, the sub-optimal connectivity, both with regard to the integration of big industrial players on the social side as well as the (partially) underdeveloped connectivity on the technical side, raises questions whether or not a full transition of the system can be achieved. On the social side, big industry players should be actively approached by local actors to contribute to the energy transition and collaborate more intensely by for example by actively engaging in the further development of local district heating systems which could be fed with excess heat from industrial processes and water treatment. On the technical side, the medium level of connectivity is mainly due to lagging development of district heating infrastructure, on the one side and a ban on captive prosumer communities from a regulatory perspective, on the other side. This could be overcome with appropriate policy adjustments.

References [67,68] present results for a similar region in Germany, based on a comparable theoretical framework and applying the same set of indicators proposed by [1]. The Allgäu region investigated in these two studies is characterized by high diversity and medium connectivity levels, both in the social and the technical subsystems. While connectivity and diversity were measured only for one specific moment in time, the analysis of supplementary interview data was—just as in EWG—a major source of information and indispensable in order to understand the drivers and rationales behind the transition process. In the Allgäu we observed that the progress of the transition came more or less to a halt after a very dynamic period from 1990–2010, due to both political decisions on the state level and an unattractive market environment with falling prices for (renewable) energy. Interview partners pointed to the fact that an increase in connectivity within the social subsystem, involving additional actors, for example, from the tourism sector and adding complementary management organisations (e.g., in other cities), would help broaden the support for energy transition issues in the region. Additionally, the analysis showed that to achieve higher levels of resilience, the connectivity of the technological subsystem should be enhanced for example by network and technology convergence (power-to-heat) or the development of regional storage capacities.

In line with the situation in EWG, the resilience of the energy transition in the Allgäu region can be seen as being rather high but being fundamentally challenged by the broader political system it is embedded in. While the support for energy transition processes remains high in Austria on all government levels, the decision taken by the state government in Bavaria has had substantial repercussions for the implementation of specific measures and especially for the further development of wind power, in the region.

Overall, the application of the indicator set developed in Reference [1] can help provide policy-makers with indications how the system in transition is set up, what main factors in both the social and technical subsystem affect the resilience of the system in a positive or negative way and which potential problems (e.g., due to lock-in and path-dependencies) have to be tackled in order to strengthen the resilience of the system. However, one has to consider that indicators can only depict a part of the system and that for interpreting them the whole system should be taken into account. Thus, the context and boundary conditions might significantly affect the development of the transition of an energy system even though the diversity and connectivity indicators are similar. In addition to these refinements, we propose to integrate redundancy measures in the specification of overall resilience, following, that is, [28]. Redundancy measures allow to complement the diversity measures by adding a functional perspective, that is, the possibility of an actor, or a technology group, to take over the function of another entity.

Table 6 provides an overview and summarizes the core insights from the analysis and reflection of the results with regard to the social and the technical subsystem in EWG.

Table 6. Key insights from the analysis of the technical and social subsystem in EWG.

Subsystem / Issue	Social Subsystem	Technical Subsystem
State of Resilience in EWG (Source of Information)	Medium-to-high diversity, medium connectivity (based on interview data and mental models)	High diversity, medium connectivity (based on quantitative and qualitative data from energy balance sheet and interviews)
Strength of Approach	Place-specific understanding of social system, based on perception of regional actors, illustration of proximities by means of mental models	Integration of both electricity and heat system, combination of quantitative and qualitative data
Weakness of Approach	Strongly varying balance measures whether we use the Shannon-Eveness or the Shannon-Weaver indicator	Problems to get data on technical system configuration on a regional level, coverage of district heating networks
Methodological Challenges for the Future	Get quantified and longitudinal data for time-series analysis	Integrate prosumer networks, collect quantitative data on a regional level

Limitations and Further Research

In the present study, we could show the development of the regional energy system over time and reflect on its resilience. Nevertheless, data availability and diverging quality of data remains one major limitation in the context of this study. For the technical subsystem, we could only get reliable data for the electricity system on the state level but not on the regional level, since the states are still the administrative units in the technical subsystem, which collect all the relevant data. Regarding the data for connectivity in the technical subsystem, grid data was only available on the national scale and only for the most recent years. Hence, a longitudinal investigation based on primary data was not possible and we had to resort to expert knowledge from the interviews.

Unlike for the technical subsystem, the region was a straight-forward unit of analysis for data collection regarding the social subsystem. Accordingly, we could grasp a good understanding of the transition in the social subsystem using different qualitative research methods. Nevertheless, a more quantified and comprehensive analysis (e.g., conducting a full sample network analysis in combination with a structured media analysis) would allow for an even deeper understanding of the evolution of interaction patterns between social agents. In addition, decision-making processes at supra-regional level could be taken into account in order to get supplementary information on the further (financial) support of the transition process towards a fully renewable regional energy system.

While previous work suggests that both the diversity and connectivity of a system can change and has to change over time, allowing for the system to adapt to external changes, there is up to now no established literature on what levels of both diversity and connectivity are ideal in order to maximize the resilience of the system throughout the transition.

In other words, while the ideal-typical levels of diversity and connectivity described in the four cases in Reference [1] apply in general, they might not apply to every moment along the transition pathway, with strong levels of diversity and connectivity potentially leading to a strong degree of stabilization of the system that is not desirable, for example, in the take-off and acceleration phase.

Further empirical research will have to inform the resilience community when high and low levels of diversity and connectivity, respectively, are desirable in the social and the technical subsystems along the transition to a fully renewable regional energy system.

Regarding the individual indicators and the calculations we could carry out, a notable difference could be detected between the Shannon weaver and Shannon evenness indicator. A sensitivity analysis showed that the Shannon weaver index is highly sensitive to how the technologies are defined. If we instead of explicitly using the technology groups suggested in the results section use other secondary electricity sources (e.g., waste, leaching liquid, incineration) as one additional technology group in our calculations, the Shannon Weaver index decreases from 0.96 to 0.79 in the year 2016. The Shannon Eveness index, however is much more robust regarding the technology definition, the effect being however reverse. Here the index increased from 0.39 in to 0.46. Thus, in future studies the balance indicator needs to be selected carefully, depending on the interest of the study and the results need to be reflected accordingly.

6. Conclusions

In this paper, we have applied the indicator set developed in Reference [1] to the EWG region in south-eastern Austria. The empirical application of the theoretically derived indicators allows to measure the resilience of a socio-technological transition, in this case the transition of the regional energy sector towards a system based on renewable energy sources. The six indicators allow to operationalize the key resilience aspects which are diversity and connectivity in both the social and the technical subsystems.

The region shows medium to high levels of diversity and medium levels of connectivity in the social and technical subsystems. This corresponds to a situation where the transition towards renewable energy sources is well underway but the structure of both the social and technical subsystems might not be fully appropriate (yet) to drive the system towards a fully renewable system state.

In practice, the approach proposed by Binder and colleagues in Reference [1] provides a solid basis for the analysis of the energy transition in EWG. The measures for diversity and connectivity could be successfully applied to both the technical and the social subsystems and allowed to retrace the system's composition along the transition path-way. Some difficulties occurred in getting all the required data on a regional level, which was especially the case for some of the indicators in the technical subsystem. Based on our empirical work in the EWG region, an indicator-based approach to measure the resilience of a sustainability transition is a promising and important tool for future policy planning when the goal is to work on a shift of an existing (unsustainable) system status to a more sustainable one in the energy context.

For a further refinement of the indicators, especially with respect to the technical subsystem, we propose integrating redundancy measures. Further research would need to specifically take this factor into account, since the characteristic of diverse actor-groups or technologies being able to functionally supplement each other may become relevant for the resilience of the overall system in times of crises of shocks. Redundancy measures would ideally complement diversity measures by taking into account not only the characteristics but also the functionality of the system components in both the technical and the social subsystems.

Finally, for further investigation of the resilience of socio-technical systems in transition, it would be important to have a closer look at the key-actors' characteristics and abilities which allow for the transition to proceed while supporting the system's resilience at the same time. This would apply for the individual actor level but also for the organisation level and could lead to a reflection on which roles to attribute to which actors in the different arenas but also at the different phases of the transition to ensure the resilience of the system undergoing the transition.

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Doctoral candidate’s contribution

The doctoral candidate is the main author of the publication. Theoretical conceptualisation, empirical analysis and writing of the publication was done by the doctoral candidate. Co-authors contributed to the design of the publication and provided reviews.

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"It's an Endurance Race"

An Indicator-Based Resilience Analysis of the Energy Transition in the Allgäu Region, Bavaria

The Allgäu region in the state of Bavaria is one of the pioneering regions in the energy transition in Germany. To analyse the resilience of the transition process itself, we developed an indicator set for diversity and connectivity, two key elements to characterise the resilience of a system in transition.

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"It's an Endurance Race". An Indicator-Based Resilience Analysis of the Energy Transition in the Allgäu Region, Bavaria
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Abstract
The energy transition currently taking place in Germany is recognised as being one of the most ambitious socio-technical transitions at the present time. Scholars have so far mostly studied the resilience of the current or future state of the energy system. They have neglected to analyse the resilience of the transition process itself. We present an interdisciplinary way of analysing the resilience of the energy transition operationalised as a socio-technical transition, using an indicator set for diversity and connectivity. For the case of the Allgäu region in the state of Bavaria, we measured these indicators in a semi-quantitative way, and found that the diversity indicators point to a resilient transition process. The connectivity indicators, however, show that the region is in a state such that the transition could stagnate. For the future of this transition process, connectivity should thus be increased, for example, by involving the tourism sector in the actor network. Our research confirms the need for an interdisciplinary analysis of the resilience of an energy transition.

Keywords
Allgäu, connectivity, diversity, energy region, indicators, resilience, socio-technical system, transition

The energy transition we are currently experiencing is likely to be one of the most challenging transitions of our time (Leipprand et al. 2016). According to Grin et al. (2010, p. 197), transition processes "are interwoven with economic sectors (mobility, housing, agriculture) and in fact deeply rooted in our societal structures, routines and culture". Furthermore, energy transition processes can be seen as a succession of both, intended disruptive changes and incremental adaptation processes (Rotmans et al. 2001). Throughout the transition process, humans have to anticipate, to adapt to, and to learn from and within fundamentally new situations, while considering and adapting the technical possibilities they have. Thus, there is a need to study the transition process by considering both, the social and the technical perspectives concomitantly (Büscher and Schippl 2013, 2017, Rohracher 2001, Verbong and Geels 2007, 2010).

Several scholars have reflected on the resilience of the energy transition (Brand and Gleich 2015, Gössling-Reisemann et al. 2013, Hodbod and Adger 2014, Roege et al. 2014, Stührmann et al. 2012). Taking the seminal definition of Walker et al. (2004, p. 6), which describes resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change, to still retain essentially the same function, structure, identity, and feedbacks", Strunz (2014) suggests that the energy transition can be thought of as a shift between two regimes, the fossil-nuclear energy regime and the renewable energy-based regime. He proposes that for achieving the transition three things need to happen: first, the resilience of the current regime must decrease while building a >

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TABLE 1: Assessing diversity and connectivity as two key elements, which characterise a system's resilience. The two tables show suggested measures for operationalising diversity (table 1a, based on Binder et al. 2017, Stirling 2007) and connectivity (table 1b, based on Binder et al. 2017, Freeman 1978, Weimann 1982).

TABLE 1A

INDICATOR	DEFINITION
variety	number of categories in which the system elements can be divided
balance	distribution patterns of the elements across the different categories
disparity	the way and the degree in which the elements can be distinguished

TABLE 1B

INDICATOR	DEFINITION
average path length	number of steps needed to connect two nodes to each other on shortest path
degree centrality	relative position of each node in the network with respect to the other nodes
modularity	parts of a network with over-proportional interaction intensity compared to the system

vision of a new regime; second, a shift towards the new regime has to become visible; third, the new regime has to become resilient itself. His view on, and definition of resilience thereby follows the "stability model" presented by Böschen et al. (2017, in this issue)[1]. However, he misses out in conceptualising the resilience of the transition process itself – that is, "the resilience of the new direction" (Olsson et al. 2014) or "the resilience of the transition" (Binder et al. 2017, Schilling et al. forthcoming).

Our contribution addresses exactly this issue. Adopting the "transformation model" offered by Boeschen et al. (2017, in this issue)[2], we look at the energy transition from a socio-technical perspective, present an indicator set to study the resilience of the transition itself, show for the case of the Allgäu how this indicator set can be applied, and discuss the implications of analysing the resilience of a transition. Accordingly, the article is structured as follows: after an overview of the indicators used, we continue with describing the case and the methods applied to elicit the indicators. Subsequently, we summarise and discuss the results. Finally, we conclude with a reflection on the added value and limitations of our approach for policy and research.

Conceptual Approach and Indicator Set

We conceptualise the energy transition to be resilient if the system under study is resilient along the whole transition path (Gunderson 2001, Mühlemeier et al. forthcoming). This implies that the energy system is likely to pass through more and less stable phases during the transition process itself, while not losing its overall function including the faultless functioning of the social and technical parts of the system (for example, avoiding threats for societal peace or large dangerous blackouts).

To assess the resilience of the transition process, we apply the indicator set developed by Binder et al. (2017). The indicator set (table 1a and b) is based on measures of connectivity and diversity as two key elements to characterise the resilience of a system in transition. Based on system sciences, we selected these two key elements to analyse both the system's individual components (diversity) and the systemic relationship between these components (connectivity). From an analysis, we can draw conclusions about the system's characteristics which are essential for resilience during a transition (e.g., stability, flexibility or adaptability). Both diversity and connectivity can be applied to the social and the technological subsystems, allowing us to study the energy system transition as one integral socio-technical system (STS) transition (for details see Binder et al. 2017, for a detailed overview on the operationalisation of the indicators as well as the indicators' role for resilience see table 1 and 2 in the *electronic appendix*[3]).

Case-Study: The Allgäu Region in the State of Bavaria

The Allgäu region is a rural, partly alpine area, located in the southwest of Bavaria, Germany. It encompasses four districts (Lindau, Ost-, Ober- and Unterallgäu) and three cities (Memmingen, Kaufbeuren and Kempten). The Allgäu region is one of the pioneering regions in the energy transition in Germany. Currently, 39 percent of the total electricity demand are produced based on renewable resources – with the district Ostallgäu being the front-runner producing 109 percent of the electricity demand from renewables (StMWi 2017a, 2016). Historically, the large forest areas and the alpine rivers were used for energy production (Bayerisches Landesamt für Statistik 2015b). This long tradition in decentralised energy production from renewables has not only provided the necessary infrastructure but also the technological knowledge for the recent energy transition. Today, the high wind speeds on the top of the hills and the large quantity of biomass produced in agriculture are additionally used for electricity and heat production from renewables (StMWi 2017b, Bayerisches Landesamt für Statistik 2015a).

The Allgäu region is a pioneer not only in terms of the technological aspects of the energy transition, but also in terms of the evolution of social structures and the governance system which

1 Following Böschen et al. (2017, p. 222, in this issue), a "stability model" is based on a structural understanding of resilience and focuses on means of maintaining an entity's stability.

2 Following Böschen et al. (2017, p. 222, in this issue), a "transformation model" is based on a process-oriented understanding of resilience. Such a model focuses on an entity and its co-stabilisation within the surrounding context.

3 The supplementary *electronic appendix* is available at *www.oekom.de/supplementary-files*.

go along with the technological changes. Its focal institution is a local energy agency (eza! Energie- und Umweltzentrum Allgäu), founded already in 1996, which coordinates the regional energy transition endeavours, supports the communes in establishing energy transition and climate change policies, advises citizens for energy efficiency measures, and manages a large network of local firms in the domain of energetic renovation and energy services. Additionally, the early support of traditionally powerful actors like municipal utilities, waste management firms and large production firms, forest owners as well as politicians from all parties and regional banks, helped decisively to institutionalise the regional energy transition and form a highly connected network of regionally well embedded actors (see also Mühlemeier and Knöpfle 2016, Mühlemeier et al. 2017).

Data Collection and Analysis Methods

This explorative case-study analysis is based on a mixed methods approach (Flick et al. 2004) employing both quantitative and qualitative methods. We divided the social subsystem into social arenas (Binder et al. 2017, based on Späth et al. 2007). The technological subsystem was divided into technology groups (Binder et al. 2017, Kost et al. 2013). With these subdivisions, we defined comparable research entities for both the technological and the social subsystems (for more details see table 1 and 2 in the *electronic appendix*[3]).

For the social subsystem, we based our analysis on semi-structured interviews which we conducted in 2014/2015 in the Allgäu region. The interviewees were selected according to the snowball >

EXHIBIT *SURVIVING THE FUTURE – RESILIENCE & DESIGN* (2016)

EXOPATCH

"WHAT CAN WE DO WHEN NATURE'S RESILIENCE POTENTIAL IS DWINDLING DUE TO OUR INTERFERENCE WITH ECOLOGICAL PROCESSES? CAN WE MAKE USE OF TECHNOLOGY TO CORRECT AN IMBALANCE IN NATURE?"

Geo-engineering, asteroid mining, the Mars mission: is a renaissance of speculative design arising? The top secret ExoPatch project was presented to the global public for the very first time at the exhibition. ExoPatch is a solar sail in the orbit of the Earth and the Sun, shielding the arctic from the sun during the summer months. This enables the melting of the arctic ice mass to be slowed down and grants a time advantage to humanity for sorting out a more climate-friendly future life on Earth, while nature can resorb carbon and methane molecules. Dystopia or viable future scenario?

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TABLE 2: Empirical results for diversity indicators (table 1a) and their implications for resilience of the transition in the Allgäu region's energy system. Figures quoted from regional energy flow analysis calculated on the basis of data for 2011. (PV: photovoltaics; CHP: combined heat and power)

	VARIETY	BALANCE	DISPARITY
social subsystem	***high*** 6 arenas involved: politics, associations, industry, energy industry, research and media	***medium*** ■ most actors and organisations are in associations' arena ■ less but equally distributed in politics, industry and energy industry ■ least in research and media	***high*** ■ different organisation types (market-based, hierarchical, network-based) ■ logics of action (product-oriented in competition, regulation-oriented in coalition, information resp. lobbying-oriented merely in cooperation) ■ time horizons (short-term – long-term)
implications for resilience of transition	***positive*** plurality of viewpoints and broad societal acceptance of transition	***positive*** if one arena drops out, the transition is still supported by other arenas with a balanced amount of actors	***positive*** plurality of action logics, aims and time horizons provide a broad basis for change, with actors complementing each other with different competences ***negative*** can cause tensions and unbridgeable differences which hinder the transition
technological subsystem	***high*** ■ *electricity:* hydro power, PV, wind power, CHP ■ *heat:* biomass heat, solar heat, heat pumps, CHP	***low in total*** 64% of the electricity demand / 95% of the heat demand is based on imports ***medium for renewables*** ■ *electricity:* 14% PV, 13% hydropower, 8% biomass, 1% wind ■ *heat:* 11% imported wood, 2% waste heat, 2% biomass, 1% solar heat/heat pumps	***high*** ■ different resource bases (wind, water, sun, biomass) ■ weather dependency and storage ability (PV/ wind = high, water/biomass = lower) ■ different efficiency (wind/hydropower/CHP higher, PV low) ■ different load types (peak = PV, hydro/CHP = base load)
implications for resilience of transition	***positive*** shortages or shocks for one technology group can be balanced out, which facilitates the transition towards more renewables	***rather positive*** ■ *electricity:* transition is in progress, ■ no dominating technology, so shocks will not lead to a standstill ***rather negative*** ■ *heat:* transition not yet started or stuck; high dependency on imports	***positive*** ■ complementarity ensures stability, reduces vulnerability in case of technology specific shocks, e.g., less sunny or windless days ■ storage capacity could enhance the resilience through balancing the volatility of PV and wind power

sampling method (Flick 2009, p. 168) asking for "the most important pioneers in the regional energy transition". The recorded interviews were transcribed and analysed according to the structured content analysis (Mayring 1991) using the software *MAXQDA*[4]. From the transcripts we identified actors and organisations, which the interviewees mentioned as important for the regional energy transition, as well as the interrelations amongst them. The representations and analyses of the revealed network were performed using the software package *VISONE*.[5] We analysed the actor network as one-mode network where actors and organisations were treated equally (Wasserman and Faust 1994, p. 36). Although this qualitative network analysis does not fully represent the local actor network – since it is based on the actors' perceptions at one point, it nevertheless allows for intersubjective validity without having employed a full sample method (for more details see Mühlemeier et al. forthcoming)

For the analysis of the technological subsystem, we used the data of a regional energy flow analysis (Baccini and Bader 1996, Hinterberger 2016). The energy flow analysis covered all energy flows for production, distribution and consumption of heat and electricity in the Allgäu region in 2011. The data was generated from publicly available sources. For the electricity production, the data was collected from the *Renewable Energy Sources Act's (Erneuerbare-Energien-Gesetz, EEG)* register of the transition and distribution grid operators, the energy atlas Bavaria (StMWi 2017a) and individual plant operators.[6] We estimated the share of power plants that were not promoted in the *EEG* scheme, using expert interviews with the local energy agency eza!. The heat production data was generated from the energy atlas (StMWi 2016), a report from the energy agency eza! (Böhm et al. 2015) and data from plant operators. For visualisation and analysis, we used the software *STAN 2.5*.[7] Regarding the electricity grid and heat grid structure in the region, no comprehensive data was available so that we only could qualitatively evaluate the current situation. We based our evaluation on expert interviews with transmission and distribution grid operators.

4 *www.maxqda.de*
5 *www.visone.info*
6 For detailed references see Mühlemeier et al. forthcoming.
7 *http://stan2web.net*

TABLE 3: Empirical results for connectivity indicators (table 1 b) and their implications for resilience of the transition in the Allgäu region's energy system.

	AVERAGE PATH LENGTH	DEGREE CENTRALITY	MODULARITY
social subsystem	***medium*** 2,9 among all actors, which means every actor is connected via three others; actors are relatively close to each other but information flows are not always direct	***medium*** ■ regional energy agency (association arena) has higher degree centrality (10%) ■ subsequently, most central actors are a politician, an association leader and two industry actors	***medium*** seven modules, every module consists of actors and organisations from different arenas
implications for resilience of transition	***positive*** Actors are well reachable and information can flow rather easily; nevertheless, there is enough distance which might avoid tensions. Transition process might progress less quick but more constantly	***rather positive*** A clear central actor facilitates the management of the transition endeavours; a medium centrality, nonetheless, allows for alternative movements, ideas and solutions in the network; however, not all arenas are represented among the central actors.	***positive*** Modules across the arenas allow for alternative ideas and distributed steering capacity in the network; this is supportive for transition, as long as the modules remain connected among themselves.
technological subsystem	***high/low*** *electricity:* ■ ***low:*** short average path length on high voltage level ■ ***high:*** long average path length on low voltage level *heat:* ■ ***high/low:*** gas grid similar to electricity ■ ***low:*** district heating = low average path lengths (due to transport losses)	***high*** *electricity:* ■ largest part still generated by centralised technologies (hydropower, import of nuclear and coal electricity) ■ centrality decreases with increasing degree of PV, wind and biomass *heat:* ■ domination of centralised gas and oil import structures ■ with decentral wood distribution and district heating increasing	***high/low*** *electricity:* ***low*** modules not yet possible, islanding only to avoid the distribution of faults *heat:* ***high*** ■ district heating form modules ■ gas grids are larger modules ■ oil and wood heat are non-network technologies ■ hardly any connection among the technologies
implications for resilience of transition	***ambivalent*** *electricity:* ■ ***positive:*** high volatility of renewables on low voltage level can be balanced off ■ ***negative:*** the multi-level grid structure is too robust to allow for change, e.g., more cross linkages on the low voltage level *heat:* ■ ***positive:*** different co-existing structures facilitate change ■ ***negative:*** large investments needed for grid establishment and convergence	***negative*** ■ high centrality of existing technologies hinders the transition towards higher shares of renewables (which are more decentral) ■ large infrastructure projects are needed to change the existing grid infrastructure, establish regional storage capacities, etc.	***ambivalent*** *electricity:* ***negative*** higher modularity in electricity would allow integrate renewables easier on the low voltage level *heat:* ***rather positive*** local modules easier to change; convergence of gas and district heating (less modularity) and integration of regional storage are needed

Results and Interpretation: Assessing the Resilience of the Transition

High Diversity

Table 2 provides an overview of the empirical evidence from the Allgäu region's energy system for the diversity indicators. It shows the results for both, the social and technological subsystems. In addition, we provide an interpretation of these results for the resilience of the transition.

The social subsystem in the Allgäu region is characterised by a high diversity. Various social arenas are involved in building new institutions in the region. The arenas consist of a rather balanced number of actors and organisations while their organisation style, logics and time horizons of action differ significantly (table 2). In addition to the typology of social arenas proposed by Späth et al. (2007), we divided the industry arena in two sub-arenas: industry (i.e., electricians, construction or production firms) and energy industry (i.e., local energy producers or grid operators), since the energy industry differs largely from the remaining industry. While the sub-arena industry follows the proposed market logic and competition, the energy industry is still highly regulated and oriented towards the provision of public services. Additionally, for the policy arena we found that the involved actors were localised on different levels of administration (communal, district, state level). Thus, they include different regulatory contexts and can form links to other networks on a larger scale. We consider the integration of various viewpoints, logics of action and competences as very positive for the resilience of the transition. In addition, the rather balanced representation of the social arenas enhances the resilience, since a possible shock or drop-off in one arena would not fundamentally endanger the progress of the transition itself. >

The technological subsystem (encompassing electricity and heat production) is characterised by a rather high diversity. Several technology groups are involved in the regional energy production, their shares in the production are rather balanced and the technology groups differ strongly between one another, for example, in their resource base, weather dependency or storage ability (table 2). The regional renewable energy production covers 36 percent of the electricity and five percent of the heat demand (in 2011). The remaining share is being imported (produced by nuclear plants, coal and gas plants, oil and the national renewables mix). Regarding the resilience of the transition, the rather high dependency on imports is not per se a negative factor since it fulfils a certain backup function during the transition process. However, this shows clearly that the regional energy transition is embedded in a larger national and international context and dependent on the simultaneous progress of the transition on the larger scale. The high diversity of the regional energy production is nevertheless very positive. Shocks to particular technologies can be balanced off by other technologies (due to the balanced shares and the complementarity in their characteristics) which ensures not only the stability of the system but also the social acceptance for the further transition. Additionally, the existing plurality of technologies facilitates the transition towards higher shares of renewables, since no dominating technology with its related infrastructure hampers the (further) diversification and the related plurality of knowledge and skill types supports the transition course.

The connectivity of the social and technological subsystem should be increased, for example, by integrating new actors and fostering network convergence.

Medium Connectivity

Table 3 provides an overview on the empirical findings for the connectivity indicators as well as the assessment regarding their role for the resilience of the transition.

The social subsystem is characterised by a medium connectivity. Actors from different social arenas are more or less directly connected, the central actors belong to different arenas, and the modules in the network also encompass several social arenas (table 3, see also figure 1 in the *electronic appendix*[3]). For the resilience of a transition, the medium connectivity is very positive. It allows for cohesion in the local network and a rather quick distribution of ideas and information among the arenas. Furthermore, it also facilitates the implementation of alternative ideas and solutions which might evolve in semi-detached submodules of the network. Especially the representation of different arenas in the modules is very positive, since it ensures the integration of alternative views and solutions and avoids that particular modules become detached from the rest of the network. The existing core organisation (association), which coordinates the network in combination with several other central actors from other arenas, ensures an efficient coordination without high dependency on this single core organisation (for an overview on the network see figure 1 in the *electronic appendix*[3]).

The technological subsystem is characterised by a medium connectivity, depending whether the focus is on electricity or heat. For electricity, there is a low path length on the high-voltage grid but a high average path length on the low-voltage level. The electricity grid is still highly centralised, due to formerly dominating technologies leading to a low modularity. For the gas grid the average path lengths are also short on the high pressure level and higher on the low pressure level. However, for district heating, there is an overall short average path length, due to transportation losses. The centrality of oil supply and the gas grid is still high but decentralised district heating networks are increasing. Therewith the modularity in the heat grid structures rises. In terms of the resilience of the transitions the findings are ambiguous. On the one hand, the highly centralised electricity grid hinders the transition of the energy system. On the other hand, it balances the high volatility of renewables and compensates for regional differences on a national scale, which facilitates the transition. Additionally, higher modularity and shorter path lengths on the low-voltage level would be required as well as regional storage capacities. Regarding the heat grids, the higher modularity, lower centrality and shorter path lengths of heating technologies based on renewables are positive, but there is still an immediate need to overcome the large share of oil and gas supply. Regional storage and grid convergence could also facilitate the "heat transition".

Policy and Research Implications of a Resilient, but Potentially Stagnating Energy Transition

In this paper, we present an exemplary application of the theoretical conceptualisation of resilience as a "transformation model" (see Böschen et al. 2017, p. 222, in this issue). We did so by addressing the energy transition from a socio-technical perspective and applying the indicator set developed by Binder et al. (2017) to study the resilience of the transition itself. Our empirical application was the energy transition in the Allgäu region, Bavaria.

Resilience of the Transition – Policy Implications

Overall the Allgäu region has a high diversity and medium connectivity. According to the ideal typical scenarios proposed by Binder et al. (2017), this would imply either a high resilience of the transition or an intermediate state in a transition, where the transition stagnates. The interviewees' statements confirm the latter, since most of them claimed a recent standstill of the transition regarding both the further expansion of renewable resources in the technological subsystem as well as the further transition of the regional and national governance system. Policy implications for the future transition process are: the connectivity of the social subsystem should be increased, for example, by involving additional actors and industries like the tourism sector into the actor network and creating complementary core management organisations (e. g., in other cities) to reduce the centrality. Additionally, the connectivity of the technological subsystem should be enhanced, for example, by network and technology convergence (power-to-heat) or the development of regional storage capacities. The increasing volatility related to higher shares of renewables could be balanced off by a higher connectivity among and within the technology groups (for more details see Mühlemeier et al. 2017).

Methodological Implications

Our study has an explorative character. In this first empirical application of the indicator set, we had to rely on semi-quantified and qualitative data. The results show that we are able to use and interpret the indicators for assessing the resilience of the transition itself. However, especially for the electricity and heat grids it would have been desirable to use data on a regional scale to better quantify the technical indicators. The qualitative social network analysis, based on a snowball sampling was very insightful for an overview on the actor network's structure. Nevertheless, it only relied on the summary of the key actors' perceptions and does neither account for the variety of actors' individual perceptions nor does it allow for insights on the embeddedness of this core actor network in the entire regional governance system. In a next step, the extent to which a complete social network analysis would provide more detailed results and whether these would be significantly different from the results obtained in our semi-quantitative analysis should be envisaged.

Implications for Inter- und Transdisciplinary Research on Resilience of Transitions

The proposed indicator set calls for interdisciplinary research on resilience of transitions. An inter- and transdisciplinary research setting could be encouraged to quantify the indicators and discuss the results. This supports a common understanding of the current situation and the development of strategies for the next steps.

Further Research – Comparative Studies across Time and Cases

Further research should look into five main issues. First, to develop comparative studies across time. This means aiming at longitudinal studies to analyse the resilience of transitions over time and be able to understand the ability of the system to react to changes of boundary conditions while still keeping the transition upright. Second, to compare across cases studies to be able to validate and further develop the ideal-stylised scenarios presented by Binder et al. (2017). Third, in longitudinal studies learning of agents could be included in the analysis (for first attempts see Mühlemeier et al. 2017). It has to be evaluated whether additional indicators might be required. Fourth, to further develop the way the indicators can be measured, and which type of accuracy and details is required for obtaining meaningful results usable for policymakers. Fifth, the effectivity of the transition process and how this is mirrored in the results for the proposed indicators are additional aspects to be considered.

In conclusion, our approach allowed for a systematic comparative analysis of the social and the technological subsystem. With this first explorative empirical application we revealed comprehensive insights on the current structure of the social and technological subsystems and could evaluate their role for the resilience of the process.

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Und Aktion! – Konzeptualisierung der Rolle individuellen Akteurshandelns in sozio-technischen Transitionen am Beispiel der regionalen Energiewende im bayerischen Allgäu

Susan Mühlemeier[1,2] · Romano Wyss[1,2] · Claudia R. Binder[1,2]

Zusammenfassung Die deutsche Energiewende gilt als einer der herausforderndsten gesamtgesellschaftlichen Veränderungsprozesse unserer Zeit. Sie zieht einen grundlegenden politischen und ökonomischen Wandel in Deutschland und ganz Europa nach sich. Die fundamentalen Veränderungen, die in Folge der Energiewende stattfinden, sind besonders für Wissenschaftler im Bereich der Forschung zu Nachhaltigkeitstransitionen von Interesse. Die Forschung in diesem Bereich berücksichtigt jedoch bisher die Rolle des individuellen Akteurshandelns für systemische Transitionen noch viel zu wenig. Was treibt Akteure an, die maßgeblich zum Fortschritt der Energiewende in der Region beigetragen haben? Welche Strategien und Aktionsformen wählen sie um die Transition voranzutreiben, wie hängen diese Strategien und Aktionsformen vom sozialen und technischen Umfeld ab, das sie umgibt und wie reagiert dieses Umfeld auf das Handeln der Change Agents? Zur Untersuchung dieser Fragen wenden wir das Human-Environment Systems (HES) Framework (Scholz, 2011) erstmals auf sozio-technische Systeme an. Auf Basis einer exemplarischen Untersuchung des Fallbeispiels der regionalen Energiewende im bayerischen Allgäu schlagen wir eine Anpassung des HES Frameworks für sozio-technische Energiesysteme vor. Abschließend reflektieren wir, welchen Beitrag das adaptierte HES Framework zur Konzeptualisierung und einem besseren Verständnis von individuellem Akteurshandeln im Kontext sozio-technischer Transitionen leisten kann.

Schlüsselwörter Akteurshandeln · Umfeldwahrnehmung · Motive · Strategien · Energiewende · Allgäu

And Action! – Role of Individual Agency in Socio-Technical Transitions – the Example of a Regional Energy Transition in the Allgäu Region, Bavaria

Abstract The German "Energiewende" is one of the most ambitious societal transition projects in recent times. It causes fundamental political and economic changes in the energy system in Germany and the whole of Europe. These great societal and technological changes of the current energy regime are of particular interest for research on sustainability transitions. In this research strand, however, the role of individual agency for socio-technical transitions is hardly considered. What drives actors who decisively pushed the regional energy transition? Which strategies and types of action do they choose to foster the transition? How do individual strategies and actions depend on the socio-technical system environment and how does the socio-technical system environment react to the individual actions? To analyse these questions, we apply the Human-Environment Systems (HES) Framework (Scholz, 2011) for the first time to socio-technical systems. Based on an exemplary analysis of the regional energy transition in the Allgäu region in Germany, we propose an adaptation of the HES Framework for socio-technical systems. Finally, we reflect on how the adapted HES framework for socio-technical systems can contribute

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to a better understanding of individual agency in systemic transitions.

Keywords Human-environmental systems (HES)-framework · Socio-technical systems · Multi-level perspective (MLP) · Sustainability transitions

1 Einleitung

> Das waren zwei Hand voll Leute, die wollten das und das war für mich aus der heutigen Rückbetrachtung ein ganz seltener Umstand, wie vielleicht zwei Lichter auf dem Schneepflug, die getrennt takten und irgendwann zusammen takten. Das waren hier ein paar Lichter, die haben zusammen getaktet, aus der Landwirtschaft, Forstwirtschaft, Politik und Industrie (Forstwirt und Manager eines Bauunternehmens im bayerischen Allgäu).

Seit der Reaktorkatastrophe von Fukushima 2011 sind in einigen Ländern, vor allem auch in Deutschland, politische Entscheidungen gefallen, die den Weg zur Transition des Energieversorgungssystems klar in Richtung des Atomausstiegs und der Nutzung erneuerbarer Energien weisen. Mittlerweile sind einige Jahre vergangen, in denen auf allen Ebenen in Deutschland versucht wurde, die Veränderung des Energiesystems voranzutreiben: Auf technischer Ebene wurde der Zubau von Wind-, Sonnen-, Biomasse- und Erdenergie verstärkt, Speichertechnologien wurden weiterentwickelt und der Netzausbau vorangetrieben. Auf ökonomischer Ebene entwickelten sich neue Unternehmensformen (z. B. die Aufspaltungen der großen Energiekonzerne wie EON in Tochterfirmen oder die Gründung von Bürgergenossenschaften zur Finanzierung erneuerbarer Energien) und Marktstrukturen veränderten sich. Neben diesen technischen und ökonomischen Komponenten des Wandels rückte aber immer mehr auch die gesellschaftliche Seite der Energiewende in den Vordergrund und die Frage danach, wie sich der gesellschaftliche Umgang mit ökonomischen, technischen und ökologischen Veränderungen gestaltet.

Wissenschaftler, die im Bereich Transformationsforschung tätig sind, arbeiten seit langem an der Untersuchung der Wechselwirkungen zwischen sozio-ökonomischen und technischen Aspekten in systemischen Transformationen (de Haan und Rotmans 2011; Geels 2004; Geels und Kemp 2006; Geels und Schot 2007; Rotmans und Loorbach 2009). Hier werden z. B. neue Steuerungsmechanismen oder sich verändernde Machtstrukturen untersucht, die mit der Transformation einhergehen (Avelino und Rotmans 2009; Binder et al. 2014; Hecher et al. 2016; Loorbach et al. 2008). Bezüglich der Rolle von Akteuren in sozio-technischen Transitionen zog der Vorwurf, die Akteursebene und genauere Konzeptualisierung von Akteurshandeln sei in der Transitionsforschung unterrepräsentiert (Genus und Coles 2008; Smith et al. 2005; Westley et al. 2013), einige Arbeiten zur Konzeptualisierung und Analyse der Akteursebene in sozio-technischen Transitionen nach sich (Avelino et al. 2014; Avelino und Wittmayer 2016; Grin et al. 2011; Heins und Alscher 2013; Riddell et al. 2012; Sommer und Schad 2014; Wittmayer 2016; Wittmayer und Schäpke 2014). Fischer und Newig (2016) geben in ihrer Literaturanalyse dazu einen umfassenden Überblick über die unterschiedlichen Akteurskonzeptualisierungen in der Transitionsforschung und zeigen auf, dass gegenwärtig etwa gleich viele Beiträge einen systemischen wie einen Akteur zentrierten Zugang haben und damit sowohl die Akteursebene, als auch die Systemebene im Transitionsdiskurs ihre Berücksichtigung finden (Fischer und Newig 2016). Doch auch wenn man von einer umfassenderen Berücksichtigung der Akteursebene in sozio-technischen Transitionen sprechen kann, fehlt bisher nach wie vor ein Framework, das sowohl die Konstitution des Akteurshandelns berücksichtigt, das heißt unterschiedliche Einflussfaktoren auf das Akteurshandeln, wie z. B. individuelle Ziele, Wahrnehmung und Lernprozesse als auch seine Einbettung und Interaktion mit dem sozio-technischen System.

Um diese Konzeptualisierung des individuellen Akteurshandelns – eingebettet in ein komplexes systemisches Umfeld – zu ermöglichen, schlagen wir vor, das sog. Human-Environment Systems (HES) Framework (Scholz et al. 2011; Scholz 2011) am Beispiel von Energiesystemen auf sozio-technische Systeme in Transition anzuwenden – eine Anwendung des HES-Frameworks auf Energiesysteme wurde bereits von Binder et al. (2013) vorgeschlagen.

Das HES Framework basiert auf Erkenntnissen der Individualpsychologie, Umwelt-Entscheidungsforschung sowie den Systemwissenschaften und baut daher nicht nur auf etablierten Ansätzen zur Konzeptualisierung des individuellen Akteurshandelns auf, sondern auch auf einem profunden Verständnis komplexer Systeme. Das auf sozio-ökologischen Systemen basierte HES Framework kann auf sozio-technische Systeme übertragen werden, da beide Systemkonzeptualisierungen komplexe Systeme zugrunde legen: Gesellschaft und Umwelt, bzw. technologisches Umfeld werden als inhärent vernetzte und interdependente Subsysteme verstanden, deren Koevolution dies Gesamtentwicklung des Systems ausmacht. Menschliches Handeln ist in diese systemische Umgebung eingebettet und evoziert systemisches Feedback, das dann wiederum Ausgangsbedingung für neue Handlungen sind. Arbeiten zu sozio-technische Systemen (Geels 2002) legen dazu Giddens Strukturationstheorie zugrunde (Giddens 1984), das Mensch-Umwelt System folgt dem Prinzip der Komplementarität und verschiedenen Regulationsmechanismen der Subsysteme (Scholz 2011; Scholz und Binder 2004).

Das HES Framework liefert somit einen wertvollen Zugang, wie die Interaktion zwischen Akteurshandeln und systemischem Umfeld auch in sozio-technischen Systemen besser verstanden werden kann.

Dieser Beitrag verfolgt somit folgende Ziele:

- Übertragung des HES Frameworks auf sozio-technische Systeme und Vorschläge zu seiner Adaptation für sozio-technische Systeme.
- Exemplarische Anwendung des HES Frameworks auf individuelles Akteurshandeln in sozio-technischen Energiesystemen am Beispiel der regionalen Energiewende im bayerischen Allgäu.
- Reflexion zum Beitrag des adaptieren HES Frameworks für die Konzeptualisierung individuellen Akteurshandelns in sozio-technischen Systemen in Transition

Zur Bearbeitung dieser Ziele wird in einem ersten theoretischen Abschnitt das Verständnis sozio-technischer Transitionen auf Basis der Multi-Level Perspektive (MLP) (Geels 2002, 2011) zugrunde gelegt und in der Folge die Grundannahmen des HES-Frameworks erläutert. In einem zweiten Schritt übertragen wir das HES Framework auf sozio-technische Systeme und schlagen konzeptionelle Anpassungen vor. Im dritten Schritt wenden wir das angepasste HES Framework auf die Fallstudie der Energiewende im bayerischen Allgäu an. Dazu stellen wir zunächst die Entwicklungen in der Region und unser methodisches Vorgehen vor, bevor wir anschließend exemplarische Ergebnisse zur empirischen Anwendung des HES Frameworks präsentieren. Zuletzt reflektieren wir, wie dieses angepasste Framework z. B. an die MLP anschlussfähig sein kann und diskutieren andere Verwendungsmöglichkeiten und weiteren Forschungsbedarf, um aufzuzeigen, wie das HES Framework in den „transition studies“ aufgenommen werden könnte und einen Beitrag zum besseren Verständnis der Rolle des Akteurshandelns in sozio-technischen Systemen liefern kann.

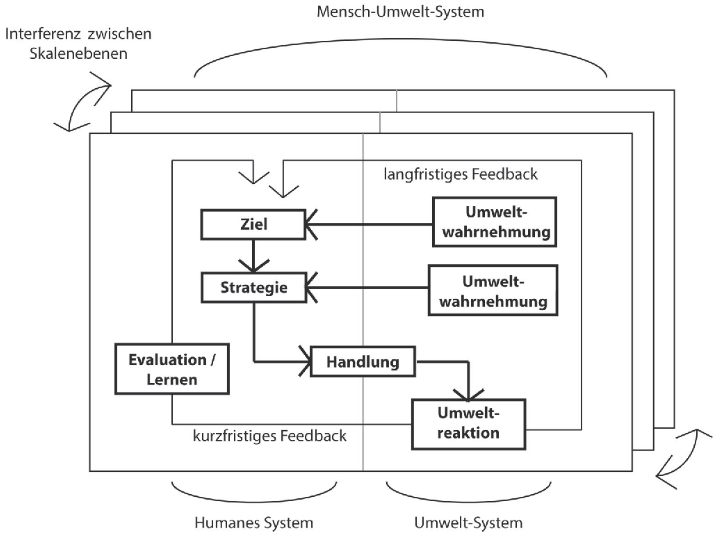
2 Theoretischer Hintergrund – Multi-Level Perspective und Human-Environment Systems Framework

Um das Handeln des Individuums in dieser Untersuchung genauer zu definieren, wird der Begriff der Change Agents verwendet, der in den Wirtschaftswissenschaften bereits seit einiger Zeit für die Rolle von Unternehmern und Firmen in Transitionsprozessen angewandt wird (vgl. z. B. Neffke et al. 2014). Als Change Agents werden im Rahmen dieser Untersuchung jedoch nicht nur Unternehmer verstanden werden, sondern in einem erweiterten Begriffsverständnis alle Akteure, die den Wandel des Energiesystems aktiv vorantreiben (z. B. auch Politiker oder zivilgesellschaftlich Engagierte, vgl. dazu Späth et al. 2007).

Um das Akteurshandeln innerhalb des Transformationsprozesses eines sozio-technischen Systems zu verorten, wird die sog. Multi-Level-Perspektive (MLP) (Geels 2002) als Ausgangspunkt verwendet. Sie hat sich mit einigen Überarbeitungen (Geels 2011) als viel beachteter Analyserahmen für sozio-technische Systeme in Transformation etabliert. Die MLP identifiziert drei Strukturationsebenen, die ein sozio-technisches System prägen: die „Nische“, das „Regime“ und die „Landschaft“. Die MLP erklärt die Transition dieses Systems dadurch, dass ein grundlegender Wandel in der „Landschaft“ stattfindet (z. B. der gesamtgesellschaftliche Wertewandel bezüglich der Haltung zur Atomkraft), das bestehende „Regime“ unter Druck setzt (das Regime umfasst z. B. die bisherige politische Regelung zur Energieversorgung oder die gängigen Marktstrukturen) und somit soziale und technische Innovationen aus der „Nische“ in das Regime übernommen werden (z. B. die technische Entwicklung der Photovoltaik-Zellen und das Entwickeln neuer Finanzprodukte zur Finanzierung der Zellen). Die Multi-Level-Perspektive rückt somit die Nischenprozesse (und damit implizit das Handeln von Nischenakteuren) als einen entscheidenden Faktor in den Fokus der Untersuchung und bietet die Möglichkeit, das individuelle Akteurshandeln innerhalb des Transformationsprozesses zu verankern. Da die MLP jedoch – wie oben erläutert – als Analyserahmen für gesellschaftliche Strukturationsprozesse in sozio-technischen Transitionen entwickelt wurde und nicht zur Analyse der Konstitution des einzelnen Akteurshandelns, das die Strukturation vorantreibt (oder verhindert), fehlt der MLP eine entsprechende Konzeptualisierung, wie sich Akteurshandeln konstituiert, bzw. wie es mit dem systemischen Umfeld interagiert.

Dazu ziehen wir das Human-Environment Systems (HES) Framework (Scholz et al. 2011; Scholz 2011) aus dem Bereich der Umwelt-Entscheidungsforschung hinzu. Das HES Framework konzeptualisiert als „Prozess-Struktur Modell“ (Scholz und Binder 2003, 2011, S. 453–454) einerseits die Struktur eines Systems (Entitäten und deren Beziehungen) und andererseits humane Entscheidung- und Handlungsprozesse, die das System verändern (Scholz und Binder 2011). Humane Handlungsprozesse werden dabei als Ergebnis einer Interaktion zwischen individuellen Zielen, Umweltwahrnehmungen, Strategien und Lernprozessen konzeptualisiert (vgl. Abb. 1). Die erfolgte Handlung erzeugt dann wiederum Reaktionen der Umwelt auf unterschiedlichen räumlichen Skalen und zeitlichen Horizonten (primary und secondary feedbacks), die erneut vom humanen System wahrgenommen werden, einen Lernprozess verursachen und den Handlungsprozess beeinflussen können (vgl. Abb. 1). Das HES Framework lenkt die Aufmerksamkeit der Untersuchung daher explizit auf die Wechselwirkung zwischen individueller Handlung und verschiedener systemischer Ebenen.

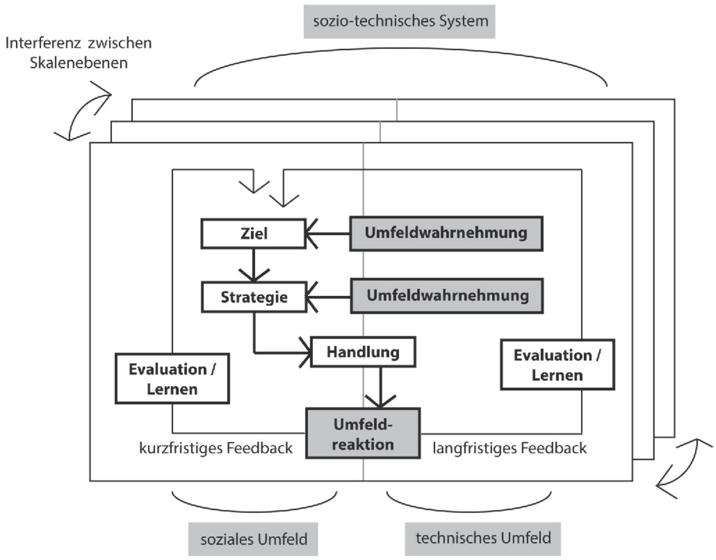
Abb. 1 HES Framework. (Eigene Darstellung, vereinfacht nach Scholz et al. 2011: 455)



Das HES Framework basiert auf den sieben Postulaten für Mensch-Umwelt Systeme (Scholz 2011), die hier kurz erläutert werden sollen:

- *P1 Komplementarität*: Mensch-Umwelt Systeme werden als komplexe Systeme verstanden, in denen die humanen und ökologischen Subsysteme miteinander verwoben und voneinander abhängig sind. Das humane Subsystem und das Umweltsystem stellen gleichzeitig jedoch zwei vollkommen verschiedene Systeme dar, die nach unterschiedlichen Regelmechanismen funktionieren (Scholz 2011; Scholz und Binder 2004). Die Verbindung zwischen diesen beiden Subsystemen wird durch die Umweltwahrnehmung des Menschen, sein Handeln und das Feedback der Umwelt auf das Handeln hergestellt (Scholz und Binder 2003).
- *P2 Hierarchie:* Mensch-Umwelt Systeme lassen sich nach unterschiedlichen Hierarchieprinzipien gliedern (Scholz und Binder 2003, 2004). Regelmechanismen übergeordneter Systeme sorgen dabei für mehr Stabilität als Regelmechanismen untergeordneter Systeme (Scholz und Binder 2003, S. 8) (z. B. Präferenzen des Individuums sind leichter veränderbar und somit weniger stabil als Normen einer Gesellschaft). Scholz und Binder (2003) und Scholz (2011) gliedern das soziale System basierend auf den entsprechenden Regelmechanismen in folgende Levels: Individuum, Gruppe, Organisation, Institution, Gesellschaft und übergesellschaftlich/supranational (Scholz 2011, S. 419; Roland W. Scholz und Binder 2003, S. 10). Parallel dazu lässt sich auch das Umweltsystem in Hierarchieebenen gliedern, Scholz (2011) schlägt dazu folgende Levels vor: Gemeinschaft, Ökosystem, Landschaft, Ökoregion und Biosphäre (Scholz 2011, S. 414).
- *P3 Interferenz:* Mensch-Umwelt Systeme beinhalten verschiedene Levels, die sich gegenseitig über die Levelgrenzen aber auch innerhalb eines Levels beeinflussen können. Teilsystem kann somit sowohl über- und untergeordnete als auch gleichgeordnete Systeme beeinflussen (Scholz, 2011, S. 427)
- *P4 Rückkopplungen (Feedbacks):* Da Mensch-Umweltsysteme als eingebettete Systeme (nested systems) konzeptualisiert werden, entstehen Rückkopplungen (Feedbacks) zwischen diesen Systemen (vgl. Interferenz). Auf Basis des in den Systemwissenschaften grundlegenden Konzept der Hysterese schlägt Scholz (2011) zwei Typen von Rückkopplungen in Mensch-Umweltsystemen vor: Rückkopplungen erster Ordnung, die im direkten zeitlichen Zusammenhang mit einer Aktion stehen sowie Rückkopplungen zweiter Ordnung, die in einem weiteren zeitlichen Abstand zur Aktion stehen (Scholz 2011, S. 432). Für jede Form des Feedbacks gilt, dass Systeme nach einer Handlung in einem physisch veränderten Zustand sind (Scholz und Binder 2004) und Feedbacks grundsätzlich auch über die angesprochenen Levels hinweg passieren (vgl. Interferenz).
- *P5 Menschliche Entscheidungen:* Menschliche Systeme werden nach Scholz (2011) auf jedem Level von Ent-

Abb. 2 Das HES Framework adaptiert nach Scholz 2011 (*Änderungen grau hinterlegt*). (Eigene Darstellung)



scheidungsprozessen und resultierenden Handlungen geprägt. Entscheidungen sind dabei von individuellen Zielen, der Umweltwahrnehmung und einer bewussten Strategiewahl geprägt. Ziele werden dabei als eher stabile unterliegende Struktur verstanden, die situationsbedingt zur Strategieauswahl aktiviert werden; Strategien stellen eine Art Aktionsplan dar, der die Handlungsausführung lenkt (Scholz und Binder 2004, S. 3). Scholz (2011) konzeptualisiert humane Systeme daher als planvoll handelnd, die ihre Strategien bewusst nach deren Nützlichkeit für das Ziel auswählen (Scholz 2011, S. 443; Scholz und Binder 2004, S. 3). Weiterhin ist das Handeln humaner Systeme auch durch Lernprozesse geprägt, die aus der Evaluation von (i) geplantem Handeln, (ii) geschehenen Handeln oder der (iii) Umweltreaktion resultieren können (Scholz und Binder 2003, S. 6)

- *P6 Umweltwahrnehmung & -bewusstsein*: Humane Systeme nehmen ihre Umwelt wahr und diese Wahrnehmung hat einen entscheidenden Einfluss auf ihre Ziele, Strategiewahl, Handlung und ihre Lernprozesse. Scholz und Binder (2003) schlagen drei Archetypen des Umweltbewusstseins vor, die aus der Umweltwahrnehmung resultieren: umwelt-ignorant (die Effekte des eigenen Handelns auf die Umwelt werden nicht wahrgenommen, kein Einfluss auf die individuellen Ziele und Strategien), umwelt-bewusst (Rückkopplungen erster Ordnung zwischen der Umwelt und dem menschlichen Verhalten werden wahrgenommen, Ziel und Strategiebildung werden von der Umweltwahrnehmung beeinflusst) und umwelt-geleitet (auch Rückkopplungen zweiter Ordnung werden wahrgenommen, Ziele und Strategien werden maßgeblich beeinfluss, was in einem altruistischen Handeln münden kann, das heißt eigene Ziele und Präferenzen werden zur Vermeidung negativer Umwelteffekte zurückgestellt) (Scholz 2011, S. 444; Scholz und Binder 2003, S. 6)
- *P7: Umwelt zuerst:* Scholz (2011) schlägt vor, dass jede Analyse eines Mensch-Umwelt Systems mit einer präzisen Systemanalyse des Umweltsystems beginnen sollte, in der Struktur, Mechanismen und Rückkopplungen genau verstanden werden, um darin die weiterführende Analyse des Handelns im humanen System einbetten zu kommen. Dieses Postulat wird von Scholz selbst auch als normativ aufgeladenes bezeichnet, das klar den Ursprung des HES-Framework in den Nachhaltigkeit-, bzw. Umweltwissenschaften aufzeigt und nicht nur zum Verständnis, sondern auch zur besseren Lösung von Mensch-Umwelt Problemen beitragen will (Scholz 2011, S. 448).

Tab. 1 Ebenen des sozialen, ökologischen und technologischen Subsystems. (Eigene Darstellung)

Soziales Subsystem	Ökologisches Subsystem	Technologisches Subsystem
Individuum	Individuum/Gemeinschaft	Technologische Komponenten des Artefakts
Gruppe		Technologisches Artefakt
Organisation	Ökosystem	Technologie
Institution	Landschaft/Ökoregion	
Nationale Gesellschaft		Technologiegruppe
Supranationale-Gesellschaft	Biosphäre	

3 Adaptation des HES Frameworks für sozio-technische Systeme

3.1 Erweitertes Systemverständnis

Wie bereits in der Einleitung erwähnt, basiert das HES Framework auf der Annahme sozio-ökologischer Systeme, geht in der Konzeption des Systems jedoch wie auch die Studien zu sozio-technischen Systemen von „complex systems“ aus, sodass eine Übertragung naheliegt, zumal einerseits sozio-technische Systeme ökologische Komponenten als Ressourcen mit in das technologische Subsystem integrieren (Geels, 2004) und andererseits Scholz und Binder (2004) ein eher breit angelegtes Umweltverständnis zugrunde legen: „Human-Environmental Systems include all environmental and technical systems that are relevant for and affected by humans“ (Scholz und Binder 2004, S. 1). Scholz und Binder (2004) inkludieren technologische Komponenten somit in ihrer Definition von Mensch-Umweltsystemen, dennoch sind technologische Aspekte nicht weiter explizit konzeptualisiert, da das Forschungsinteresse zur Entwicklung des HES Frameworks ursprünglich vorwiegend in der Analyse des Einflusses von Umweltwahrnehmungen auf das Akteurshandeln lag. Für die Transition sozio-technischer Systeme spielen diese ökologischen Aspekte zwar ebenfalls eine wichtige Rolle, dennoch sind Wahrnehmungen der technologischen und sozialen Umwelt mindestens ebenso wichtig. Beispielsweise beeinflusste der Reaktorunfall in Fukushima als technologischer Faktor die Energiepolitiken und den Fortschritt der Energiewende in Deutschland und Zentraleuropa entscheidend, wie dagegen der Preiszerfall von fossilen Brennstoffen und Elektrizität als sozialer Faktor die Energiewende in jüngster Zeit vor Schwierigkeiten stellte. Wir schlagen daher vor, die Termini *Umwelt* und *Umweltwahrnehmung* für die Anwendung des HES-Frameworks auf sozio-technische Systeme in *Umfeld* und *Umfeldwahrnehmung* zu wandeln, um damit das erweiterte Systemverständnis zu verdeutlichen und Missverständnissen vorzubeugen (vgl. Abb. 2).

Für die Anwendung des HES Frameworks auf sozio-technische Systeme, konzeptualisieren wir somit ökologische Elemente als in das technologische Subsystem eingebettete Ressourcen und integralen Bestandteil des sozio-technischen Systems (vgl. sozio-technisches Systemverständnis (Geels 2004)). Dieses sozio-technische und ökologische System wird dabei, wie von Scholz (2011) und Geels (2004) vorgeschlagen, ebenfalls als komplexes, auf unterschiedlichen Skalenebenen interdependentes und komplementäre Subsysteme umfassendes System konzeptualisiert (vgl. Postulat 1).

3.2 Mehr-Ebenen Konzept

Vergleichbar zu den von Scholz (2011) vorgeschlagenen Ebenen des sozialen und ökologischen Subsystems kann auch das technologische Subsystem in mehrere Ebenen untergliedert werden (Postulat 2). Für Energiesysteme schlagen wir folgende Ebenen vor: technologische Komponenten, technologisches Artefakt, Technologie und Technologiegruppe. Die unterste Ebene der technologischen Komponenten umfasst alle Komponenten, die zur Funktion des technologischen Artefakts nötig sind. Im Falle einer Wasserkraftanlage z. B. Turbinen, Leitungen, Dämme etc. Die Ebene des technologischen Artefakts umfasst für den Fall des Energiesystems die einzelnen Produktionsanlagen (wie z. B. ein Windrad), die Ebene der Technologie fasst alle Anlagen einer Technologie (z. B. PV-Dachflächen und Freiflächenanlagen) zusammen und die Technologiegruppe fasst mehrere Technologien z. B. zur Strom- oder Wärmeproduktion, bzw. netzgebundene oder nicht Netzgebundene Technologien zusammen. Listet man die Ebenen aller drei Subsysteme gemeinsam auf (vgl. Tab. 1) wird deutlich, dass die Aggregationsschritte für die einzelnen Subsysteme – aufgrund ihrer Eigengesetzlichkeit (Postulat 1) – jedoch nicht gleich groß sind und somit nicht zu jedem Level jedes Subsystems ein Äquivalent in den anderen Subsystemen definiert werden kann.

Dennoch ist es hilfreich diese Untergliederung für jedes einzelne Subsystem vorzunehmen, da Umfeldwahrnehmungen (Postulat 6), Umfeldreaktionen (Postulat 4) und Interferenzen (Postulat 3) innerhalb aber auch zwischen den Subsystemen somit präzisiert, lokalisiert und analysiert werden können. So kann z. B. die deutschlandweit virulente Windkraftproblematik untergliedert werden in Aspekte, die das Technologische Artefakt (das einzelne Windrad) oder die Technologie (Windkraft) betreffen aber auch dessen Aus-wirkung auf bestimmte ökologische Individuen (z. B. Rotmilan) und die Reaktionen im sozialen Umfeld auf Ebene der Gruppe (Windkraftgegner) sowie der Institution (bayerische Abstandregelung für Windräder).

3.3 Soziale Interferenzmechanismen

Mit diesem erweiterten Systemverständnis wird jedoch nicht nur das technologische Subsystem in die Betrachtung integriert, sondern es erfolgt auch eine stärkere Berücksichtigung der Mechanismen auf und zwischen den unterschiedlichen Ebenen im sozialen System. Im von Scholz (2011) vorgeschlagenen HES Framework, ist das gesellschaftliche Subsystem zwar nach seinen Regelmechanismen in unterschiedlichen Ebenen gegliedert („Hierarchieebenen“ (Postulat 2)) und mit dem Konzept der Interferenz auch die Interaktion zwischen den gesellschaftlichen Ebenen angelegt (Postulat 3), doch hat sie in den bisherigen Anwendungen des HES keine größere Berücksichtigung gefunden (Binder et al. 2013; Scholz und Binder 2003, 2004, 2011). Wir schlagen daher mit unserem Umfeld-Begriff auch eine dezidiertere Berücksichtigung und genauere Analyse der Interferenzmechanismen zwischen unterschiedlichen gesellschaftlichen Ebenen vor (z. B. Institutionalisierung, Strukturation etc.). Für die Energiewende meint das z. B. die deutschlandweite Gründung von Vereinen für die Förderung erneuerbarer Energien oder die Gründung von Bürgerenergiegenossenschaften, aber auch die Entwicklung nationaler Politiken, wie das Erneuerbare-Energien-Gesetz oder der Entscheid zum Atomausstieg. Diese explizite Berücksichtigung der Interferenzmechanismen zwischen den sozialen Eben ermöglicht ein besseres Verständnis der gesamtgesellschaftlichen Veränderungsprozesse und schafft die Basis für eine bessere Anschlussmöglichkeit des HES Frameworks an die Arbeiten der Transitionsforschung, worauf wir in der Diskussion noch vertiefter eingehen werden.

Wir schlagen somit eine gleichwertige Betrachtung gesellschaftlicher, technologischer und ökologischer Aspekte sowie eine Berücksichtigung der Interferenzen in allen Subsystemen vor. Dies ermöglicht auch eine direkte Vereinbarkeit des Frameworks mit dem Leitbild Nachhaltiger Entwicklung. Dementsprechend schlagen wir auch vor Postulat 7 (Umwelt zuerst) hin zu „detaillierte Umfeldkenntnis“ abzuschwächen, denn eine profunde Kenntnis der Systemmechanismen ist zur Analyse und dem Verständnis der Rolle des Akteurshandelns entscheidend, nur sehen wir von einer stärkeren Gewichtung des ökologischen Subsystems ab und plädieren für eine gleichwertige Analyse des sozialen, technologischen und ökologischen Umfeldes.

Abgesehen von diesen Veränderungen bezüglich des Systemverständnis kann die Konzeptualisierung des Akteursverhaltens und seiner Interaktion mit dem systemischen Umfeld für eine Anwendung auf sozio-technische Systeme beibehalten werden. Diese hat sich für die Analyse des individuellen Akteurshandelns in der regionalen Energiewende im bayerischen Allgäu als sehr produktiv erwiesen und verändert sich nicht bei erweitertem Systemverständnis.

4 Anwendung des HES Frameworks auf sozio-technische Systeme – Fallbeispiel Change Agents in der Allgäuer Energiewende

Im Folgenden wenden wir das HES Framework unter der Berücksichtigung der vorgeschlagenen Erweiterungen auf die Energiewende im bayerischen Allgäu an. Dazu stellen wir zunächst die Entwicklungen des Energiesystems im bayerischen Allgäu vor sowie das untersuchte Netzwerk der sog. Change Agents, die die Energiewende in der Region entscheidend vorangetrieben haben. Anschließend erläutern wir unser methodisches Vorgehen und präsentieren exemplarische Ergebnisse unserer Fallstudie für die Anwendung des HES Frameworks auf das Energiesystem.

4.1 Die Untersuchungsregion bayerisches Allgäu

4.1.1 Die Region

Das bayerische Allgäu gilt als eine *der* Pionierregionen Deutschlands hinsichtlich des Fortschritts der Energiewende: Der Anteil erneuerbarer Energien am Gesamtstromverbrauch liegt im Allgäu bei ca. 49 % (Bayern 35 %, Deutschland 28 % (BSTMWI 2016)) und erste Initiativen und Vereinsgründungen finden sich in der Region schon in den 1990er-Jahren – weit vor dem Erneuerbare-Energien-Gesetz (EEG) 2001. Vor allem aber hinsichtlich des aus der lokalen Gesellschaft heraus getragenen Energiewende-Engagements und des Beitrags einzelner Individuen zum Transformationsprozess ist das Allgäu bekannt. Zahlreiche mittelständische Unternehmen sowie Bürgergenossenschaften sind an der Produktion und Weiterentwicklung erneuerbarer Energien beteiligt, viele Vereine vertreten die Interessen der Akteure und einzelne Individuen stehen im Zentrum der Transition.

Die Region umfasst die vier Landkreise Ost-, Ober- und Unterallgäu sowie Lindau und die kreisfreien Städte Memmingen, Kaufbeuren und Kempten und liegt am südwestlichen Alpenrand Bayerns (vgl. Abb. 3).

Abb. 4 zeigt für die Untersuchungsregion den generellen Anstieg von Produktionsanlagen für erneuerbare Energien vor allem aber einen enormen Zubau der Anlagen zur Stromproduktion aus Sonnenenergie. Von 2000 bis 2013 haben diese von einigen wenigen auf über 35.000 Anlagen mit einer gesamt installierten Leistung von rund 800 GWh

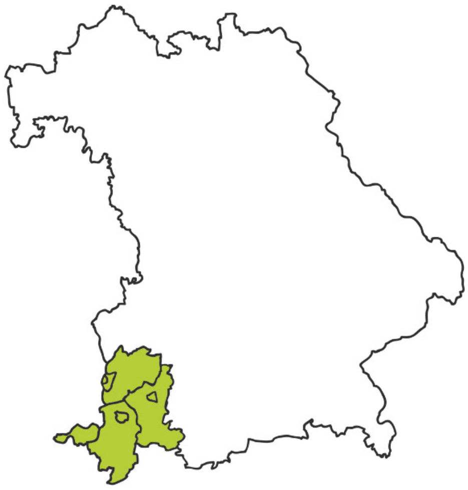


Abb. 3 Die Untersuchungsregion „bayerisches Allgäu". (Eigene Darstellung)

im bayerischen Allgäu zugenommen. Auch bei den Anlagen zur Stromproduktion aus Wasserkraft und der Biomassenutzung ist ein deutlicher Zuwachs erfolgt, wobei die Ausgangslage bei der Wasserkraft im Jahr 2000 mit knapp 200 Anlagen deutlich höher war als bei der Biomasse (knapp 50 Anlagen). Bis 2013 wurde der Anlagenpark zur Wasserkraft- und Biomassenutzung je auf fast 350 Anlagen ausgebaut. Deutlicher zeigt sich der Zuwachs der Biomassenutzung noch bei der Installierten Leistung (vgl. Abb. 4b): von ca. 30 GWh wurde dieser auf etwa 380 GWh erhöht. Bei der traditionell in der Region stark genutzten Wasserkraft fiel der Zuwachs mit etwa 200 GWh zwischen 2000 und 2013 geringer aus. Die Windkraft erfuhr einen verhalteneren Ausbau auf etwa 90 GWh. Klärgase bleiben nur sehr gering und Geothermie ungenutzt.

Bezüglich der Umfeldreaktion im sozialen Subsystem wurden in Abb. 5 exemplarische „Meilensteine" des Institutionalisierungsprozesses zu erneuerbaren Energien in der Region zusammengestellt. Es zeigt sich deutlich, dass sich die regionale Energiewende nicht nur in Vereins- und Firmengründungen manifestierte, sondern der Fortschritt auch in Form der Schaffung neuer Stellen (Energiemanager), der Auszeichnung von Gemeinden (z. B. Energiegemeinde) und der Schaffung regionaler Klimaschutz- und Energiewendeleitbilder sichtbar wurde.

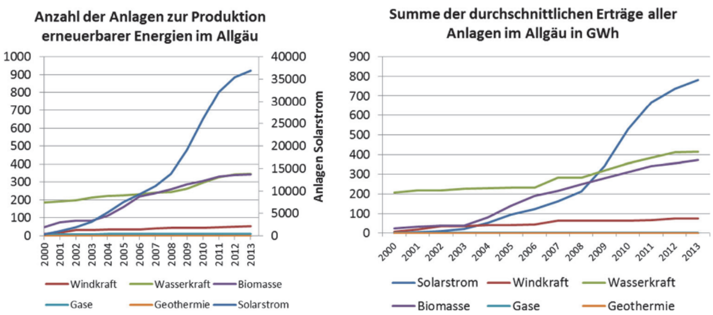
Es wird deutlich, dass in der Region in den 1990er und 2000er-Jahren eine enorme Beschleunigung der Energiewende im sozialen und technologischen Subsystem erfolgt ist und somit das Umfeld auf die Handlungen der Change Agents enorm positiv reagiert hat.

4.1.2 Die Akteure

Die in unserer Studie befragten zentralen Change Agents der Region sind in den Bereichen Land- und Forstwirtschaft, Handwerk (Elektro- und Lüftungstechnik), Energieberatung, Energie- und Abfallwirtschaft sowie Regionalentwicklung und Bankenwesen tätig (vgl. Abb. 6). Die meisten verfügen über eine technische Ausbildung, bzw. ein Ingenieursstudium und sind zusätzlich ehrenamtlich engagiert. Sie stammen entweder gebürtig aus der Region Allgäu oder leben schon seit mehr als 10 Jahren dort. Die meisten leben und arbeiten in und um Kempten, dem Oberzentrum der Region, wo auch viele Organisationen, Unternehmen sowie Politik und Verwaltung angesiedelt sind. Alle Akteure sind männlich und im Alter zwischen 40 und 65. Die meisten unter ihnen können als sog. Entscheidungsträger bezeichnet werden, da sie entweder Unternehmensinhaber, Geschäftsführer, Bürgermeister oder Landräte, Vereinsvorstände oder Leiter einer Organisation sind.

Großteils kennen sich die befragten Akteure persönlich und seit langen Jahren. Dadurch, dass die meisten auch in mehreren (oft ehrenamtlichen) Positionen tätig sind, sind sie untereinander mehrfach und stark vernetzt. Sie ver-

Abb. 4 Ausbau der erneuerbaren Energien im Allgäu. (Quelle: Deutsche Gesellschaft für Sonnenenergie e. V. [o. J.]; Datenbestand vom: 21.02.2014, eigene Darstellung)



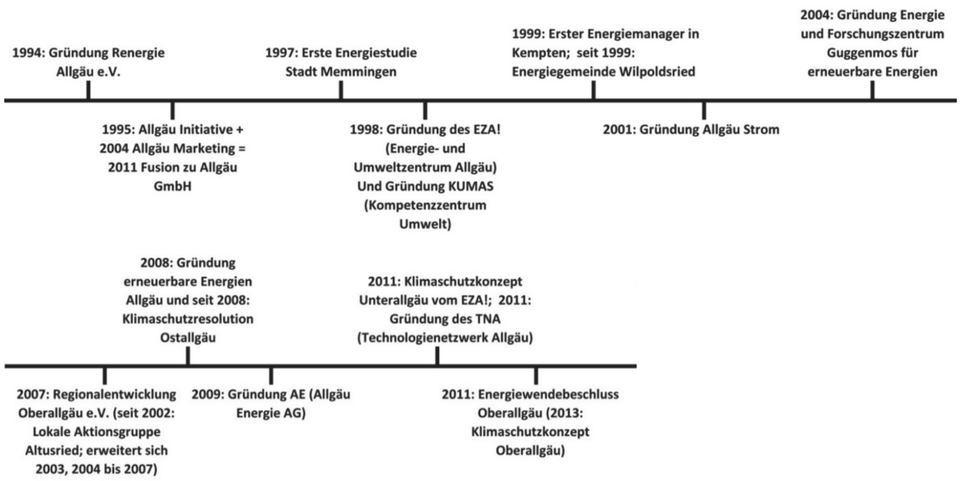


Abb. 5 Institutionalisierungsprozess im Allgäu. (Eigene Darstellung)

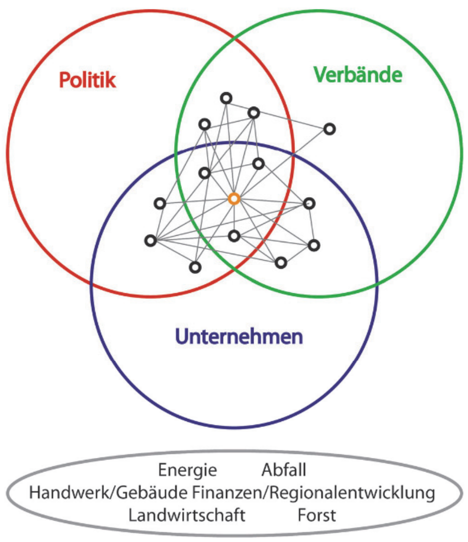


Abb. 6 Netzwerk der zentralen Akteure der Allgäuer Energiewende. (Eigene Darstellung)

binden durch diese Ämterhäufung unterschiedliche gesellschaftliche Bereiche in einer Person: viele sind als Politiker auch Unternehmer und Vereinsvorstand und andersherum (vgl. Überlappungsbereiche in Abb. 6). Die Akteure treffen daher je nach Kontext (ob in der Politik oder im Verein) in unterschiedlichen Funktionen und Konstellationen immer wieder aufeinander. Im Zentrum dieses Akteursnetzwerks steht das Umwelt- und Energiezentrum Allgäu (eza!)[1], da hier alle Akteure in unterschiedlichster Weise aktiv, beteiligt oder affiliiert sind (vgl. oranger Punkt im Zentrum in Abb. 6).

Alle Befragten haben im Laufe der letzten 20 Jahre zu technischen und/oder sozialen Innovationen in der Region beigetragen: es wurden neue Antriebstechniken, Energiegewinnungsprozesse oder Verteilnetzstrukturen entwickelt, ebenso wie neue finanzielle Beteiligungsmodelle, Veranstaltungs- und Vernetzungsformate oder neue Institutionen gegründet.

4.2 Methodisches Vorgehen

Als räumliche Ebene unserer Fallstudie wurde „die Region" (sieben Landkreise) gewählt, da somit nicht nur die lokale, unmittelbare Wirkungsebene der Akteure (Kommune), sondern auch ihre Einbettung in die übergeordnete Skalenebene integriert und mögliche Interferenzen berücksichtigt werden konnten (Regierungsbezirk, Bundesland). In 2014/2015 wurden insgesamt 14 explorative Experteninterviews mit zentralen Change Agents der regionalen Energiewende im bayerischen Allgäu geführt. Als Change Agents wurden dabei Akteure definiert, die in der Region maßgeb-

[1] eza! ist eine gemeinnützige GmbH zur Förderung erneuerbarer Energien und effizienter Energienutzung und wird getragen von Kommunen, Wirtschaft und Initiativen des Allgäus (http://www.eza-allgaeu.de/ueber-eza/).

lich zur Pionierphase der Energiewende beigetragen hatten. Darunter fielen Akteure, die entweder technische und soziale Innovationen geschaffen hatten (z. B. Ingenieure, Unternehmensgründer, Vereinsgründer) oder bei deren Implementation unterstützend tätig waren (z. B. Politiker, Unternehmer). Die Interviews wurden nach dem sog. Schneeballverfahren (snowball sampling) geführt: Ausgangspunkt der Befragung (point of entry) waren dabei ein lokal sehr gut vernetzter Banker, zu dem ein persönlicher Kontakt bestand sowie ein Mitarbeiter der regionalen Energiewendeorganisation, die aus der Sekundärdatenanalyse als wichtigste Organisation in der Region ermittelt wurde. Beide wurden nach weiteren zentralen Change Agents der Pionierphase der regionalen Energiewende gefragt, die wiederum in ihren Interviews nach weiteren Namen gefragt wurden, bis sich der Kreis der genannten Akteure geschlossen hatte. In den leitfadengestützten Experteninterviews wurden (i) die Motive für das Engagement und die Wahrnehmung der eigenen Rolle im Energiewendeprozess, (ii) der wahrgenommene Verlauf der Energiewende und (iii) die als förderlich oder hinderlich wahrgenommene Einflussfaktoren erfragt. Zur Auswertung der transkribierten Interviews wurden die Aussagen der Befragten mit MAXQDA softwarebasiert kodiert (www.MAXQDA.de) und inhaltlich kategorisiert. Es wurde dabei ein qualitativ-strukturierter Analysezugang gewählt, bei dem die Transkripte nach den Kategorien des angepassten HES Frameworks – (i) Ziele/Motive der Akteure, (ii) Strategien und (iii) positive und hinderliche Umfeldwahrnehmung auf unterschiedlichen Ebenen – sortiert wurden (strukturierende qualitative Inhaltsanalyse (Mayring 2010)). Weiterhin wurden öffentlich verfügbare Sekundärdaten zum technischen Ausbau und dem gesellschaftlichen Institutionalisierungsprozess der erneuerbaren Energien in der Region hinzugezogen, um die soziale und technologische Umfeldreaktionen zu untersuchen. Für das technologische Subsystem wurden öffentlich verfügbare Daten zum Anteil der erneuerbaren Energien auf Landkreisebene analysiert (vgl. energymaps.info) sowie die Ergebnisse einer regionalen Energieflussanalyse hinzugezogen (vgl. Mühlemeier et al. in press). Für die Analyse des Institutionalisierungsprozesses wurden Vereins- und Organisationsgründungen in der Region auf Basis einer online-Recherche nachgezeichnet. Die Ergebnisse dieser Studie werden im Folgenden exemplarisch dargestellt.

4.3 Exemplarische Anwendung des HES Frameworks auf die regionale Energiewende im bayerischen Allgäu

Im Folgenden präsentieren wir exemplarisch einige der Ergebnisse aus der oben genannten Studie zur regionalen Energiewende im bayerischen Allgäu, um die Anwendung des HES Frameworks auf sozio-technische Systeme zu illustrieren.

4.3.1 Umfeldwahrnehmungen und Ziele: die Handlungsmotive der Change Agents

Die für das Engagement in den Anfängen der regionalen Energiewende im Allgäu in den 1990er und frühen 2000er-Jahren genannten Handlungsmotive der befragten Change Agents können in Abhängigkeit von den genannten Umfeldwahrnehmungen in drei Typen untergliedert werden:

- Die meisten Akteure nannten Motive im Bereich „grundlegende Überzeugung für die Wichtigkeit des Ausbaus der erneuerbaren Energien". Diese Zielkategorie wurde einerseits im Zusammenhang mit der Wahrnehmung globaler Umweltprobleme, wie z. B. der Klimaerwärmung oder der Endlichkeit fossiler Ressourcen genannt, andererseits aber auch mit der Wahrnehmung technologischer Probleme, wie der Möglichkeit eines Reaktorunfalls und der Problematik des Ersetzens des Anteils der Kernkraft an der Stromproduktion durch erneuerbare Energien und schließlich mit der eher gesellschaftlichen Sorge um die Lebensbedingungen zukünftiger Generationen („wenn einen die Zukunft der Menschheit interessiert, dann beschäftigt man sich automatisch mit energiepolitischen Fragen" (A1))
- Die zweite große Zielkategorie konnte im Bereich „technische Optimierung der Energieversorgung" aus regionalen Quellen und „Engagement in der Region" gruppiert werden. Diese Zielkategorie wurde im Zusammenhang mit der Wahrnehmung lokal vorhandener Technologien zur Produktion von Energie aus regional verfügbaren erneuerbaren Energien erwähnt, sowie der Sorge um die regionale Entwicklung des Allgäus, die regionale Wertschöpfung und Möglichkeit in dieser Region leben und arbeiten zu können.
- Schließlich konnten zwei weitere Zielkategorie im Bereich „Entwicklung von Geschäftsmodellen" in der Energiewende ermittelt werden, die damit vorwiegend ökonomische Motive umfasste sowie Motive im Bereich „etwas praktisch gestalten und umsetzen", die vor allem die eigene Wirksamkeit (vor Ort) betonte. Im Zusammenhang mit diesen Motiven wurden keine direkten Umfeldwahrnehmungen genannt.

Diese drei Bereiche der Zielkategorien spiegeln die von Scholz (2011) vorgeschlagene Typologie zum Grad der Umfeldwahrnehmung wider, wobei die letzte Gruppe auf eine geringe bis nicht vorhandene Wahrnehmung von Umfeldeinflüssen hindeutet, die zweite Gruppe deutet auf Umfeldwahrnehmungen erster Ordnung hin (direkte Effekte) und die erste Gruppe zeigt Wahrnehmungen von vorhandenen und potenziellen Rückkopplungen zweiter

Ordnung (zeitlich weiter entfernt). Die Akteure nannten Ziele aus mehreren Bereichen gleichzeitig, sodass die Zielbereiche pro Akteur überlappen und keine Typenbildung der untersuchten Akteure nach den Zielbereichen und Umfeldwahrnehmungen vorgenommen werden kann.

4.3.2 Strategien und Handlungen der Change Agents

Für die Strategien und Handlungsformen der Change Agents in der Pionierphase der Energiewende konnten vier Strategie- und Handlungsbereiche ermittelt werden. Aufgrund der in den Interviewleitfäden jedoch noch nicht vorgesehenen expliziten Unterscheidung zwischen Strategiewahl und erfolgter Handlung, muss dieser Bereich hier zusammengefasst betrachtet werden.

- Gut zwei Drittel der Befragten nannte Handlungsformen und Strategien im Bereich *Wissensaufbau und gezielte Wissensvermittlung* durch kontinuierliche Erweiterung des eigenen Wissens, die Schulung der Mitarbeiter (zum Teil durch gezielte außerregionale Vernetzung) oder die Information der Bevölkerung (z. B. durch Aufbau von Energieberatungsagenturen, regionalen Messen und Informationsveranstaltungen). Weiterhin fielen hierunter auch Handlungsformen wie Vereins- und Netzwerkgründungen, der gezielte Austausch und das sich Vernetzen mit regionsexternen Experten und politischen Instanzen (z. B. in EU-Fachkreisen).
- Etwa die Hälfte der Befragten nannte Handlungsformen und Strategien, die sich im Bereich *Bildung strategischer Allianzen* zusammenfassen ließen. Genannte Strategien waren hierbei z. B. die Pflege des persönlichen Netzwerks, gezieltes Einbinden von regionalen Schlüsselpersonen aus Politik und Wirtschaft sowie die Beteiligung der regionalen Bevölkerung zur Schaffung grundlegender Akzeptanz und eines tragfähigen regionalen Netzwerks, welches das Engagement zur Energiewende unterstützte.
- Ein Drittel nannte Strategien und Handlungen im Bereich *Mobilisierung regionalen Kapitals*, z. B. durch finanzielle Beteiligung der regionalen Bevölkerung, forcierte Kooperation mit regionalen Energieversorgern und Unternehmen (z. B. regional beschränkte Ausschreibungen) oder der Gründung von Bürgerenergiegenossenschaften mit kleinen Anteilen; auch um Unabhängigkeit von großen Geldgebern zu schaffen. Darunter fiel z. B. auch die Entwicklung erster Finanzprodukte im Bereich PV-Finanzierung, die später auch außerhalb des Allgäus übernommen wurden.
- Abschließend nannten alle befragten Handlungen, die sich im Bereich *Innovationen schaffen* zusammenfassen ließen und natürlich mit der Auswahl der Change Agents zusammenhing. Sie alle hatten entweder zur Entwicklung technologischer Innovationen (z. B. eines Hauses, das sich nach der Sonneneinstrahlung ausrichtet oder einer optimierten Müllverbrennungstechnologie), dem Errichten neuer Produktionsanlagen (Windkraft, Biogasanlagen) oder der Gründung von eigenen Firmen im Bereich technologischer Lösungen zu erneuerbaren Energien oder deren Vertriebsmöglichkeiten (z. B. regionaler Holzvermarktungsverbund) beigetragen.

Zusammenfassend lässt sich festhalten, dass die Handlungsformen sowohl im technologischen als auch im sozialen Subsystem erfolgten und dabei auf unterschiedlichen Hierarchieebenen: von der Ausbildung oder Beteiligung von Individuen, hin zur Gründung von Gruppen und Organisationen, bzw. von dem Bau einer Produktionsanlage hin zur Entwicklung einer neuen Technologie. Durch die eingangs bereits erwähnte Mehrfacheinbettung und das vielseitige Engagement der Change Agents, konnten für dieses Akteursnetzwerk keine Typen gebildet werden, wonach bestimmte Akteure nur in einem bestimmten Handlungsbereich tätig wären. Vielmehr scheinen die Change Agents auf unterschiedlichen Ebenen und in unterschiedlichen Bereichen des Energiesystems zu wirken.

4.3.3 Umfeldreaktionen, Interferenzen und Evaluationen der Change Agents

Neben der Kenntnis der allgemeinen Umfeldreaktionen bzw. der generellen Systementwicklungen (Postulat 7), die im vorherigen Abschnitt zum Fallstudienbeschrieb (Abschn. 4.1.1) bereits erläutert wurden, legt das HES Framework den Analysefokus aber vor allem auch auf die von den Change Agents wahrgenommenen Umfeldreaktionen, die im Zusammenhang mit ihrem Handeln stehen.

Im Kontext dieser exemplarischen Anwendung konnte zwar noch keine detaillierte Erhebung der wahrgenommenen Umfeldreaktionen auf die einzelnen Handlungen der Change Agents vorgenommen werden, dennoch können im Folgenden einige exemplarische Beispiele für positiv und negativ wahrgenommene Umfeldreaktion genannt werden.

- Als *positive Umfeldreaktionen* wurden auf Ebene des Individuums bzw. der Gruppe der starke Zusammenhalt unter den Change Agents, die positive Resonanz aus diesem Akteursnetzwerk und dem weiteren persönlichen Umfeld der Change Agents genannt, die sie in ihrem Handeln bestärkten. Auf der Ebene der *Organisation* konnten viele Kommunen von der Investition in erneuerbare Energien (energetische Sanierung ihrer Liegenschaften) und der Genehmigung von Anlagen (Fernwärmenetze, Windkraft) überzeugt werden. Die von den Change Agents angestrebte regionale Vernetzung von Unternehmen und Organisationen im Bereich erneuerbare Energien, z. B. zu Produktionstechnologien aber auch verwandte Sektoren, wie der Gebäudesanierung, wurde von den regional ansässigen Unternehmen angenommen und entsprechende Netzwerke konnten entstehen. Dies geschah auch mit der Unterstützung und positiven Resonanz der regionalen Wirtschaftsverbände. Im Kontext dieser Netzwerke konnten in den Anfängen erste Pilotanlagen (z. B. zu Müllverbrennung) in Kooperation mit dem regionalen Energieanbieter realisiert werden, und später sowohl einige Firmen zur Energieproduktion (v. a. aus Biomasse und PV) durch die Change Agents und regionale Partnerfirmen gegründet werden, als auch größere Forschungsprojekte in der Region mit externen Partnern realisiert werden (z. B. zur Erforschung intelligenter Netze mit hohen Anteilen an erneuerbaren Energien). Auf der Ebene der *Institutionalisierung* wurden von den Change Agents hervorgehoben, dass etliche Kommunen die Klimaschutz- und Energiewendepolitiken übernommen hätten, die von Ihnen initiiert wurden und z. B. eben regionale Klimaschutzmanager- und Energieberatungsstellen geschaffen wurden. Ein anderer Change Agent berichtete, wie die von ihm entwickelten Finanzierungsmodelle für PV Anlagen nicht nur regional von den Kommunen, sondern auch überregional übernommen wurden. Aktive Kommunen wurden darüber hinaus auch mit etlichen Preisen ausgezeichnet (z. B. Klimaschutzpreise oder dem european energy award). Auf der Ebene der regionalen *Gesellschaft* wurde hervorgehoben, dass viele Allgäuer sich an Energieproduktionsgenossenschaften finanziell beteiligt hätten und somit nicht nur die Finanzierung von den Change Agents initiierten Projekte ermöglicht haben, sondern zudem auch eine breite Akzeptanz für die Energiewende in der Region als positive Umfeldreaktion evaluiert wurde (vgl. auch Mühlemeier und Knöpfle 2016).

- Demgegenüber wurden von den Change Agents jedoch auch einige *negative Umfeldreaktionen* wahrgenommen, die im direkten Zusammenhang mit ihrem Handeln standen. Auf der Ebene der regionalen Gesellschaft war oftmals das erhoffte Publikum für die initiierten Informationsveranstaltungen und Messen ausgeblieben, was eine gewisse Frustration bei den Change Agents hervorrief, ebenso wie die oftmals langwierigen Diskussionen in Gemeinderatssitzungen zur Umsetzung der Klima- und Energiepolitiken sowie der Genehmigungen von Produktionsanlagen. Auf Ebene der *Organisationen* wurden besonders sachlich falsche Medienberichte über die erneuerbaren Energien im Allgemeinen oder aber „hämische“ Berichte über gescheiterte Pilotprojekte als negative Umfeldreaktion wahrgenommen, die das eigene Engagement besonders erschwerten. Manche Change Agents reflektierten auch über die Problematik, dass ihr Unternehmen oder ihre Organisation stark gewachsen sei und nun mit Personalwechseln und Neueinstellung das Problem der Wissensweitergabe und des Commitments zum Energiewendeengagement als negatives Feedback ihre Arbeit erschwere. Weiterhin wurde von einem Change Agent auch der massive Widerstand etablierter Großunternehmen in der Region gegen eine von ihm mit initiierte lokale Ressourcenvertriebsstruktur genannt, der ihm große Steine in den Weg gelegt hatte. Zuletzt wurde das entstehen regionaler Gegnergruppierungen („Wutbürger“) v. a. gegen Windkraftanlagen genannt, die als Reaktion auf den von den Change Agents vorangetriebenen Ausbau der Windkraft in der Region gegründet wurden und ein Voranschreiten des Ausbaus verlangsamten oder blockierten.

Zusätzlich zu den aufgeführten Umfeldreaktionen, nannten die Change Agents auch weitere Umfeldeinflüsse, die zwar nicht im direkten Zusammenhang mit ihrem Handeln standen, dennoch von den Change Agents als entscheidende Einflussfaktoren evaluiert wurden. Es handelt sich dabei um Entwicklungen, die im Kontext der Energiewende auf übergeordneten Ebenen des sozialen Systems lokalisiert wurden und einen Einfluss auf die untergeordnete Ebene des Akteurshandelns hatten. Diese Interaktion zwischen den Ebenen des sozialen Subsystems können daher als Interferenzen verstanden werden können (Postulat 3).

- Als *positive Interferenz* von Ebene der Gesellschaft, bzw. der Institutionen nannten die Akteure die bundesweit etablierten Fördermaßnahmen für die Energiewende, die zwar nicht als direkte Umfeldreaktion auf ihr Handeln gesehen werden können, dennoch als enorm wichtige und fördernde Faktoren wahrgenommen wurden, die ihr Engagement in der Region, vor allem aber die Akzeptanz bei der Bevölkerung für ihr Handeln entscheidend unterstützte.
- Daran anknüpfend führten die Befragten auch einige *negative Interferenzen* an: die oben genannten „Wutbürger“ hätten nach Ansicht der Change Agents enorm dazu beigetragen, dass die bayerische Landesregierung eine sehr restriktive Abstandregelung für Windkrafträder (10 h) etablierte und der von den Change Agents forcierte Ausbau der Windkraft in Bayern praktisch zum Erliegen kam. Ebenfalls im Bereich der Politik, nahmen die Change Agents die fehlende klare Linie der Bundesregierung zum weiteren Verlauf der Energiewende als besonders negativ wahr: Hier fehlte nach ihrer Ansicht eine entsprechende „Umfeldreaktion“, um widersprüchliche Entwicklungstendenzen und Fehlinvestitionen zu vermeiden. Auf Bundesebene, bzw. internationaler Ebene nannten viele Change Agents die Summe aus dem Lobbyismus der großen Energiekonzerne, dem niedrigen Preis für fossile Brennstoffe sowie dem Zerfall des Elek-

trizitätspreises als die negativsten Umfeldreaktionen, die das deutschlandweite Fortschreiten der Energiewende entscheidend verlangsamen und auch für die Change Agents vor Ort enorme Barrieren erzeugt. Durch diese nationalen und internationalen Entwicklungen fehlt den Haushalten, Firmen und Kommunen jeglicher Anreiz in weitere Maßnahmen zum Fortschritt der Energiewende zu investieren und das Engagement der Change Agents stößt aktuell kaum mehr auf positive Umfeldreaktionen in der Region.

Die jüngsten Entwicklungen, die überwiegend als negative Interferenzen wahrgenommen wurden, erzeugten bei den Change Agents eine grundlegende Frustration. Viele gaben an, aus den jüngsten Interferenzen gelernt zu haben, sich nicht mehr gleichermaßen für das Vorantreiben der regionalen Energiewende zu verausgaben und z. B. keine Informationsveranstaltungen mehr zu initiieren und auch den nationalen und bundesweiten Austausch zurückzufahren. Vielmehr konzentrierten sie sich auf ihr berufliches Engagement, das nach wie vor in Verbindung mit der Energiewende steht (z. B. Tätigkeit bei Stadtwerken, Energieagenturen oder im Bereich Gebäudesanierung). Das allgemeine Fazit der Change Agents war es, jetzt schlicht abzuwarten, bis sich die systemischen Faktoren (wie Ressourcen- oder Strompreise) wieder besserten und die Energiewende wieder mit größeren Schritten voranschreite.

Rekapituliert man die exemplarischen Ergebnisse aus dieser empirischen Anwendung des HES Frameworks, hat sich gezeigt, dass es sich bei dem untersuchten Fall um ein Netzwerk von Change Agents handelt, die ähnliche, bzw. sich stark überlappende Ziele verfolgen und Strategien wählen. Ihre Handlungen sind dabei auf unterschiedlichen Ebenen lokalisiert (Weiterentwicklung einer Technologie Bau einer Anlage, Gründung einer Organisation oder Etablierung einer Politik). Sie sind dabei selbst in vielen gesellschaftlichen Bereichen verankert (u. a. Politik, Vereine, Verbände, Wirtschaft und Forschung) und verbinden diese in ihrem Akteursnetzwerk. Dieses gesellschaftlich breit vernetzte und regional gut verankerte Netzwerk konnte dann zunächst eine sehr positive Umfeldreaktion in der Region evozieren – natürlich eingebettet in die bundesweiten Entwicklungen mit Zubau der Erneuerbaren und Institutionalisierung der Energiewende. In jüngster Zeit nahmen die Change Agents jedoch viele negative Umfeldreaktionen auf unterschiedlichen Ebenen des sozialen Subsystems wahr, die zu einer Stagnation der Energiewende und persönlicher Frustration und Resignation der Change Agents führte.

5 Diskussion und abschließende Bemerkungen

Mit der exemplarischen empirischen Verwendung des HES Frameworks für die Fallstudie der regionalen Energiewende im Allgäu konnte gezeigt werden, dass das HES Framework mit einer Erweiterung des zugrundeliegenden Systemverständnisses gut auf sozio-technische Systeme angewandt werden kann. Es unterstützt die Analyse des individuellen Akteurshandelns in komplexen Systemen und leistet damit einen entscheidenden Beitrag dazu, die Dynamiken systemischer Transitionen besser zu verstehen. Und gerade für das Verständnis der Entwicklung und Veränderung von Menschen planvoll gestalteter technologischer Subsysteme erscheint die genauere Untersuchung der Treiber und konstituierenden Mechanismen des Akteurshandelns besonders wertvoll.

Der erweiterte Umfeldbegriff hat sich besonders in den Umfeldwahrnehmungen der Akteure bestätigt, die sie im Zusammenhang mit ihren Handlungsmotiven, Strategien und Handlungsformen anführten. Hier wurden nicht nur ökologische Motive wie der Klimawandel oder die Endlichkeit der fossilen Brennstoffe genannt, sondern z. B. auch die Sorge um das Wohl zukünftiger Generationen oder der regionalökonomischen Entwicklung des Allgäus. Der erweiterte Umfeldbegriff ermöglicht daher ein deutlich komplexeres Verständnis der Faktoren, die das Akteurshandeln in systemischen Transitionen konstituieren. Zusätzlich hat sich die explizite Berücksichtigung der Dynamiken auf unterschiedlichen Hierarchieebenen vor allem im sozialen System als sehr hilfreich erwiesen. Es konnte beispielhaft gezeigt werden, wie das Engagement der Change Agents zunächst positive Umfeldreaktionen auf allen gesellschaftlichen Ebenen erzeugte und somit von der Gruppen- auf die Ebene der Institutionen und regionalen Gesellschaft gehoben wurde. Mit fortschreitendem Institutionalisierungsprozess nahmen die Change Agents aber auch zunehmend negative Umfeldreaktionen und Interferenzen auf unterschiedlichen gesellschaftlichen Ebenen wahr. Mit der Terminologie der MLP gesprochen zeigt dies, dass die Nische an Gleichgesinnten, in der die Change Agents anfangs tätig war, mittlerweile im Regime des Energiesystems angekommen war und auf entsprechenden Widerstand stieß. Diese eingangs vorgeschlagene explizite Berücksichtigung der Interferenzen zwischen den unterschiedlichen Ebenen (hier vor allem im sozialen System) hat sich daher als sehr gewinnbringend erwiesen.

Für die weitere Konzeptualisierung dieser Interferenzen zwischen den Ebenen des sozialen Subsystems wäre ein konzeptioneller Anschluss an die MLP sehr gewinnbringend, da die MLP speziell die Analyse von Institutionalisierung und Strukturationsprozessen in Transitionen – bzw. den Interferenzmechanismen zwischen unterschiedlichen sozialen Ebenen – herausarbeitet. Ein Zusammen-

Tab. 2 Soziale Ebenen des HES Frameworks und Strukturationsebenen der MLP. (Eigene Darstellung)

HES Framework	Regulationsmechanismen	MLP	Strukturationsniveau
Individuum, Organisation	Individuelle Normen, Werte, Ziele	Niche	Geringe Strukturation, wenig institutionalisierte Akteursnetzwerke, unabhängig von der gängigen Regimelogik, schnelle Veränderung
Institution, Gesellschaft	National geteilte juristische, ökonomische, politische und kulturelle Praktiken	Regime	Dominierende Regeln, Normen, Gesetze, wie z. B. Politik, Märkte oder auch die Energieversorgung funktioniert, langsamere Veränderung
Suprагesellschaftliche Ebene	Übernationale Werte und Visionen (z. B. Menschenrechte, Klimaschutzabkommen)	Landschaft	Grundlegende Wertevorstellungen, Weltanschauungen, langfristige Trends, sehr langsame Veränderung

bringen des individualpsychologischen Hintergrunds des HES Frameworks sowie des stärker soziologisch geprägten Hintergrunds der MLP könnte eine umfassende Konzeptualisierung von Akteurshandeln in systemischen Transitionen ermöglichen und damit einen hilfreichen Beitrag zur Weiterentwicklung der Transitionsforschung leisten. Wir schlagen vor, die von Scholz (2011) etablierten Gesellschaftsebenen mit ihren entsprechenden Regulationsmechanismen den Strukturationsebenen in der MLP zuzuordnen (vgl. Tab. 2).

So könnte das HES Framework für die Transitionsforschung anschlussfähig gemacht werden und die zusätzliche Konzeption des Akteurshandelns mit Zielen, Strategien und Umfeldwahrnehmungen, die das HES-Framework bringt, in die Studien zu sozio-technischen Systemtransitionen integriert werden.

Neben der expliziteren Berücksichtigung der Rolle des Akteurshandelns und einer Struktur für dessen empirische Analyse, könnte das HES Framework z. B. auch einen Beitrag dazu leisten, die bisher als unterkonzeptualisiert geltende Landschaft weiter zu überarbeiten. Dieses höchste Strukturationsniveau könnte so z. B. aus Sicht des Individuums in interne (internalisierte) und externe Normen und Werte, bzw. gesellschaftliche Großtrends untergliedert werden. Die internalisierten Normen und Werte wären dabei beim Individuum in Form von Zielen und Motiven zu lokalisieren, die externen Normen und Werte im sozialen Umfeld, das vom Individuum wahrgenommen bzw. evaluiert wird und ebenfalls Einfluss auf das resultierende Verhalten hat. Es zeigt sich deutlich, dass ein enormes Potenzial zur gegenseitigen konzeptionellen Bereicherung zwischen der MLP bzw. der Transitionsforschung und dem HES Framework bzw. den Mensch-Umwelt Studien vorhanden ist.

Einschränkend müssen jedoch folgende Limitationen festgehalten werden: unsere Anwendung und die daraus abgeleiteten Implikationen basieren lediglich auf einer exemplarischen Fallstudie, die explorativ und rein auf die Wahrnehmung der Change Agents fokussiert war. Das Berücksichtigen anderer Umfeldwahrnehmungen (z. B. von Politikern, Unternehmern und der regionalen Bevölkerung) könnte hier eine methodische Ergänzung sein. Weiterhin ist die Verschränkung qualitativer und quantitativer Methoden zur Systemanalyse aber auch zur Erhebung der Umfeldwahrnehmung eine wichtige Ergänzung. Zur verbesserten Analyse der Kausalitäten zwischen Umfeldwahrnehmungen und Handlungen, könnten mit den Befragten gemeinsam z. B. Causal Loop Diagramme erarbeitet werden. Sie bieten eine einfache und transdisziplinär nutzbare methodische Grundlage, sich auf die wichtigsten Wahrnehmungen und ihre kausale Relation zu den Handlungen zu konzentrieren. Abschließend möchten wir auch noch einmal betonen, dass das HES Framework vor allem für die Analyse individuellen Akteurshandelns entwickelt wurde und hierin seine größte Stärke liegt. Eine Anwendung für Gruppen und Organisationen müsste anhand weiterer empirischer Arbeit kritisch geprüft werden.

Weiterer Forschungsbedarf besteht unserer Ansicht nach zum einen in der Anwendung des Frameworks auf andere Sektoren (z. B. Mobilität oder Ernährung) und einer genaueren Untersuchung der Feedbacks und Interferenzen zwischen den verschiedenen Subsystemen aber auch innerhalb der Subsysteme zwischen den Ebenen. Zum anderen kann im weiteren Kontext der Transitionsforschung die empirische Anwendung des HES-Frameworks auch zur Analyse der Transitionsphasen über die Zeit angewandt werden, um zu verstehen, wie aus dem Wechselspiel zwischen Umfeldwahrnehmung, Akteurshandeln, Umfeldreaktion und deren Evaluation über längere Zeiträume bestimmte Transitionspfade entstehen. In diesem Zusammenhang könnte analysiert werden, inwiefern die Motive, Strategien und daraus resultierenden Handlungsweisen der Change Agents z. B. „regimekonform" sind oder nicht und welchen Einfluss dies auf die Geschwindigkeit und den Erfolg der Transition hat. Weiterhin könnte somit auch dem Lernen von Akteuren ein größeres konzeptionelles Gewicht gegeben werden. Es könnte beispielsweise stärker berücksichtigt werden wie sich Motive, Umfeldwahrnehmungen und Handlungen von Change Agents über die Zeit verändern aber auch wie diese Veränderungen in das systemische Umfeld eingebettet sind – zum Beispiel welchen Einfluss soziale Netzwerke auf die individuellen Wahrnehmungen und Verhaltensweisen ausüben. Damit würde die Rolle von individuellem und sozialem Lernen in systemischen Transitionsprozessen stärkere Berücksichtigung finden.

Schließlich sollte in der Transitionsforschung weiter an der Erarbeitung eines Frameworks für sozio-technische Transition gearbeitet werden, dass sowohl systemische Transitionsmechanismen, wie z. B. die Rolle von Strukturationsprozessen berücksichtigt als auch das genaue Verständnis der Rolle des Akteurshandelns, seiner konstituierenden Faktoren sowie seiner Einbettung und Interaktion in und mit dem systemischen Umfeld. Damit würde der Forderung nach der Einbettung von agency nachgekommen und ein entscheidender Beitrag zur Dynamisierung der Transitionsframeworks geleistet. Der Vorschlag des Anschlusses des HES Frameworks an die MLP stellt einen ersten Schritt in diese Richtung dar.

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Doctoral candidate’s contribution

The doctoral candidate is the only and main author of the publication. Theoretical conceptualisation, empirical analysis and writing of the publication was done by the doctoral candidate.

Author's accepted Manuscript[1]

Titel:
Grosse Stadtwerke - theoretische und empirische Exploration eines besonderen Akteurs in der Energiewende Deutschlands und der Schweiz

English title:
Urban utility companies – a theoretical and empirical exploration of a particular actor in the German and Swiss energy transition

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Zusammenfassung:
Grosse Stadtwerke sind in Deutschland und der Schweiz fester Bestandteil der Akteurslandschaft des Energiesektors. Durch die föderal-subsidiäre Organisation der Energiesektoren dieser beiden Länder kommen ihnen systemrelevante Aufgaben wie das Management von Verteilnetzen oder die Sicherstellung der Daseinsvorsorge für «ihre Stadt» zu. Im öffentlichen und wissenschaftlichen Diskurs zur Rolle verschiedener Akteursgruppen im Kontext der Energiewende wird ihnen jedoch bisher wenig Beachtung geschenkt. Ziel dieses Beitrages ist es daher die Spezifika des Akteurstypos „grosse Stadtwerke" theoriegeleitet herauszuarbeiten und die aktuelle Situation der Stadtwerke – ihre Herausforderungen und strategischen Antworten – auf Basis empirischer Evidenz aus Deutschland und der Schweiz darzustellen. Methodisch basiert dieser Beitrag auf einer explorativ-qualitativen Studie, die Ergebnisse aus Literaturanalyse, Dokumentenanalyse, 38 Experteninterviews aus beiden Ländern (2017) und zwei in der Schweiz durchgeführten Expertenworkshops (2018) zusammenführt. Die Studie zeigt, dass die Spezifika grosser Stadtwerke auf Basis der Public Corporate Governance Literatur und Arbeiten zu Network Industries erklärt werden können. Daraus können auch ihre besonderen Herausforderungen, wie z.B. das Spannungsfeld zwischen öffentlichem Interesse und Marktfähigkeit, das multidimensionale Verhältnis zwischen Eigentümer und Unternehmen oder die Eigengesetzlichkeit von Netzwerkindustrien abgeleitet werden. Im Rahmen dieser Studie zeigt sich, dass die Rolle der grossen Stadtwerke für die Energiewende weder als «Innovator», noch als «Hinderer» bezeichnen lässt, sondern vielmehr als «intelligent follower» und «Ingenieur der Energiewende».

Schlagworte:
Grosse Stadtwerke, public corporate governance, network industries, Charakteristika, Herausforderungen, strategische Antworten, Energiewende, Deutschland, Schweiz

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English abstract:
Urban utility companies are key players in the Swiss and German energy sector. Due to the federalist and subsidiary governance structure of the two countries' energy sector, they perform highly system relevant tasks, as e.g. managing the distribution grids or ensuring the public services for "their city". In the public and scientific discourse on the role of different actor groups in the energy transition, however, not much attention is paid to urban utility companies. This contribution aims at a theoretical and empirical exploration of these particular actors by analysing their characteristics, specific challenges and strategic answers in the context of the energy transition. For this purpose, the article derives analytical dimensions for the analysis of urban utility companies from scholarly literature on transition studies, network industries and public corporate governance and empirically analyses characteristics and the current situation of urban utility companies in Germany and Switzerland. Methodologically, this article is based on an explorative, qualitative study, which synthesises results from a literature analysis, a document analysis, 38 expert interviews in both countries (in 2017) and two expert workshops conducted in Switzerland (in 2018). The study shows, how the characteristics of urban utility companies can be explained based on public corporate governance and network industries literature. This also allows to identify and understand their particular challenges, as e.g. the fields of tension among public and private interest in the firms and the multi-dimensional relationship of owner or the particularities of network industries. Finally, this article points out, that the role of urban utility companies in the Swiss and German energy transition is neither just "inhibitor" nor pure "innovator", but can be labelled as "intelligent follower" and "engineer of the energy transition"

Key-words in English:
Urban utility companies, public corporate governance, network industries, characteristics, challenges, strategic answers, energy transition, Germany, Switzerland.

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1 Einleitung

Ich persönlich denke schon, die [Stadtwerke] sind die Energiewende, wer macht es denn sonst? [CH1]

Die Stadtwerke werden strukturell gebraucht, wer übernimmt denn sonst die Rolle in diesen regionalen Strukturen? die Großen versuchen gerade Big Data zu machen – ok, aber da nehme ich doch lieber jemanden, der sich da auskennt, wie Google. Aber die Frage «wer kann das regional?» die entscheidet sich danach, wer versteht die Region, die Umgebung in der die handelnden Akteure eingebunden sind und da sehe ich die Stadtwerke in einer guten Ausgangsoption [DE3][2]

Grosse Stadtwerke sind in Deutschland und der Schweiz fester Bestandteil der Akteurslandschaft des Energiesektors[3]. Seit über hundert Jahren versorgen sie die grossen Ballungszentren wie Köln, München, Zürich oder Genf mit grundlegenden Infrastrukturdienstleistungen und erfüllen ihren öffentlichen Auftrag der Daseinsvorsorge bzw. des Service Public. Neben der Versorgung mit Elektrizität, Gas und Wasser umfasst dies oft auch Fernwärme, Abfallmanagement, öffentlichen Nahverkehr oder Telekommunikationsdienstleistungen, wie die Breitbandinternetversorgung. Sie sind dabei meist im vollen oder mehrheitlichen Besitz der Stadt und wurden in unterschiedlichen rechtlichen Formen als Regiebetriebe, GmbHs oder AGs aus der Stadtverwaltung ausgegliedert. Sie agieren damit als öffentliche Unternehmen mit mehr oder weniger Eigenständigkeit.

In der öffentlichen Diskussion zur Umsetzung der politisch gesetzten Energiewendeziele, zu Erwartungen an die unterschiedlichen Akteure des Sektors und zu deren Positionierung für oder gegen die Energiewende, finden die grossen Stadtwerke doch bisher keine grössere Berücksichtigung. Sie werden weder als Hinderer der Energiewende wahrgenommen, wie etwa die grossen Konzerne und Elektrizitätsproduzenten oder gar die Petroindustrie noch als die Treiber der Energiewende und Innovatoren, wie z.B. Energiegenossenschaften, Start-ups in Energieproduktion und -dienstleistung oder gar manch kleines Stadtwerke. Es scheint so, als stünden sie zwischen diesen Polen, waren schon immer da, erfüllen ihren öffentlichen Auftrag im Hintergrund und werden sonst nicht weiter wahrgenommen.

Ähnlich gestaltet sich die Situation im wissenschaftlichen Diskurs. Fragt man nach der Rolle von Akteuren in der Energiewende, stösst man bald auf die Arbeiten im Feld der sozio-technischen *sustainability transitions* (für einen Überblick siehe Markard et al. 2012). Dieses noch recht junge Forschungsfeld, das sich u.a. aus der Innovationsforschung und den *evolutionary economics* entwickelt hat, konzeptualisiert die Energiewende als grossen sozio-technischen Wandlungsprozess, in dem sich technologische Innovationen und gesellschaftliche Entwicklungen gegenseitig befördern und beeinflussen, bzw. ko-entwickeln (Geels 2005; Kemp und Rotmans 2005; Kemp et al. 2007). In diesem Forschungsgebiet standen zunächst vor allem systemische Perspektiven auf Transitionsprozesse im Vordergrund, sprich Arbeiten zum „mainstreaming“ bzw. Strukturation von technologischen Innovationen (Geels 2002, 2004, 2010), der Diffusion von Innovationen (Hekkert et al. 2007; Markard et al. 2015; Weber und Hoogma 1998; Wüstenhagen et al. 2003) oder dem Management solcher Transitionsprozesse (Schot und Geels 2008; Kemp et al. 1998; Hoogma et al. 2004). Lange dominierte daher ein eher generisches Bild von Akteurstypen und deren Rollen im Transitionsprozess den Diskurs, welches vorwiegend aus der *social movement theory* entlehnt wurde (Gamson 1975 zitiert von Fligstein und McAdam 2011, 2012; Fligstein 2013) und von Fligstein und McAdam in den Kontext der *strategic action field*

[2] Zitat aus den anonymisierten Interviewtranskripten auf denen die empirische Untersuchung dieser Studie basiert (siehe Abschnitt 3 Methodik der Studie. DE steht dabei für deutsche Interviewpartner, CH für Interviewte aus der Schweiz.
[3] Dies trifft auch auf den österreichischen Staat zu, diese Studie fokussiert sich jedoch ausschließlich auf den Vergleich des deutschen und Schweizer Falles.

theory gestellt wurde: entweder wurden Akteure als sog. *Incumbents* konzeptualisiert – Akteure, die Teil des alten Systems sind und neue Entwicklungen zu verhindern suchen - oder aber sog. *Challengers* - Akteure, die versuchen Innovationen zu befördern und das System zu ändern (Wassermann et al. 2015; Berlo et al. 2017; Geels 2014; Geels et al. 2014; Kungl und Geels 2017). Parallel dazu wurde auch der Begriff der „intermediaries" im Kontext sozio-technischer Transition untersucht (Guy et al. 2011; van Lente et al. 2003; Moss 2009; Backhaus 2010), doch auch hier handelt es sich um ein sehr generisches Verständnis von Akteuren, die zwischen andere Akteuren „vermitteln" (Moss 2009). In jüngster Zeit befassten sich parallel verschiedene Strömungen vermehrt auch mit einer Verfeinerung der Akteursperspektive, indem z.B. Fragen nach generellen Einflussfaktoren auf Akteure untersucht wurden (Fuenfschilling und Truffer 2016; Fünfschilling 2014) oder spezifischer Fragen der Macht von Akteuren (Avelino und Wittmayer 2016; Gailing und Moss 2016; Geels 2014) oder ganz konkret ihrem Investitionsverhalten im Kontext erneuerbare Energien untersucht wurden (Bergek et al. 2013). Zudem wurde auch ein verfeinertes Bild von den oft negativ als Hinderer konnotierten *Incumbents* erarbeitet und aufgezeigt, wie diese im Verlauf eines Transitionsprozesses unterschiedliche Rollen einnehmen können (Smink 2015; Smink et al. 2015; Wesseling 2015; Kishna 2015). Doch, obwohl mittlerweile ein deutlich stärkerer Fokus auf der Untersuchung von Akteursverhalten in Transitionen liegt, wurden bisher Stadtwerke im Allgemeinen eher wenig, bzw. die grossen Stadtwerke kaum spezifisch als Akteure in der Transition des Energiesektors untersucht (Berlo und Wagner 2011). Die Untersuchung grosser Stadtwerke ist bisher vor allem von empirischen Analysen und Berichten geprägt, die entweder von Beratungsagenturen, regierungsnahen oder Nicht-Regierungsorganisationen erstellt wurden (Kairies-Lamp und Plazek 2014; Edelmann 2016; Finus 2012; Vettori et al. 2016), einen explorativen Überblick über alle Akteure des Energiesektors geben (Gochermann 2016) oder auf sehr spezifische Aspekte, wie Investitionspolitiken, Kooperation, oder die Darstellung der Entwicklung einzelner Stadtwerke eingehen (Brabänder et al. 2016; Debor 2017; Lutz 2000; Weller und Funk 2014; Zemlin und Kotrotsios 1996).

Eine theoriebasierte Analyse der Spezifika, Herausforderungen und strategischen Antworten der grossen Stadtwerke im Kontext der Energiewende wurde bisher jedoch bisher kaum unternommen (der Autorin ist lediglich das Grundlagenbuch von Bräunig und Gottschalk (2012) bekannt).

Darüber hinaus zeigt die empirische Realität, dass die Stadtwerke als öffentliche Unternehmen – obwohl grosse und traditionelle Konzerne im Energiesektor – nicht in das klassische Bild des innovationsverhindernden *Incumbents* passen, denn ihre Eigentümer, die Städte, geben ihnen oftmals noch ambitionierte Energiewendeziele vor als die nationale Energiepolitik (2000 Wattgesellschaft - Elektrizitätswerke Zürich), traditionell haben sie eher weniger in konventionelle Energie investiert (in Deutschland hatte z.B. nur München lange Anteile an Kernkraftwerken), unterstützten im Rahmen ihres Daseinsvorsorgeauftrages meist bereits früh Energiesparmassnahmen, bauten Energieberatungen auf und unterstützten Bürger finanziell beim Investment in erneuerbare Energien. Dennoch wäre es auch nicht zutreffend, sie als *Challenger*s zu konzeptualisieren, da sie wie gesagt, in öffentlichem Besitz und durch ihre lange Tradition fester Bestandteil des bestehenden Gouvernanzsystems sind. Sie betreiben traditionell die Strom- Gas- und Wasserverteilnetze der Stadt, bewirtschaften damit ein (natürliches) Monopol und sind Teil eines sehr stark reglementierten Umfeldes. Sie hingegen als „intermediaries" zu bezeichnen wäre ebenfalls verkürzt, da es sich bei den grossen Stadtwerken – im Gegensatz zu vielleicht manch einem kleinen Energieversorgungsunternehmen – nicht um einen reinen Verteiler von Energie an Endkunden und damit Vermittler zwischen Produktion und Konsumption handelt, sondern um voll integrierte Energieunternehmen, die alle Wertschöpfungsstufen traditionell im eigenen Haus bewirtschaften: Produktion in eigenen Anlagen, Investition in neue Anlagen, Netzbetrieb, Energiehandel und -vertrieb sowie Grosskundenberatung und diverse weiterer Energiedienstleistungen.

Zur Untersuchung der Rolle der grossen Stadtwerke in der Transition des Energiesektors muss sich somit zusätzlich anderer theoretischer Grundlagen bedient werden, um ihre Spezifika als öffentliche Unternehmen und Infrastrukturdienstleister mit Daseinsvorsorgeverpflichtung konzeptualisieren.

Ziel dieses Beitrages ist es daher auf Basis der Literatur zur Gouvernanz öffentlicher Unternehmen und Staatseigener Betriebe sowie der Arbeiten im Bereich der Netzwerkindustrien, die Spezifika des bisher wenig berücksichtigten Akteurstypos „grosse Stadtwerke“ theoriegeleitet zusammenzutragen und die Situation der Stadtwerke in der aktuellen Energiewende Deutschlands und der Schweiz – als zwei Länder mit politisch festgesetzten Energiewendezielen und föderalen Staatsstrukturen – vergleichend empirisch zu analysieren. Der Beitrag befasst sich im Zuge dessen mit folgenden Forschungsfragen:

- Welche Untersuchungsdimensionen lassen sich aus der Theorie ableiten, die die Besonderheiten der Stadtwerke als öffentliche Unternehmen, Infrastrukturdienstleister mit Daseinsvorsorgeauftrag im netzwerkbasierten Energiesektor widerspiegeln?
- Welche spezifischen Charakteristika, Herausforderungen und strategischen Antworten der grossen Stadtwerke in der Energiewende Deutschlands und der Schweiz können empirisch herausgearbeitet werden?
- Wie kann auf Basis dieser theoretischen und empirischen Grundlagen die Rolle der grossen Stadtwerke in der Energiewende diskutiert werden?

Dieser Beitrag ist dazu wie folgt aufgebaut: Zunächst werden theoretische Dimensionen zur Untersuchung von Stadtwerken abgeleitet. Anschliessend werden die Ergebnisse der empirischen Untersuchung zu Charakteristika, Herausforderungen und strategischen Antworten der grossen Stadtwerke in Deutschland und der Schweiz vergleichend dargestellt. Abschliessend werden die aus der Theorie abgeleiteten Dimensionen diskutiert und über die Rolle der Stadtwerke in der Energiewende sowie deren Zukunft reflektiert.

2 Theoretischer Hintergrund – Stadtwerke als öffentliche Unternehmen in Netzwerkindustrien

Im folgenden Abschnitt werden grosse Stadtwerke im theoretischen Diskurs zu öffentlichen und staatseigenen Unternehmen sowie der Netzwerkindustrien verankert, um zentrale Untersuchungsdimensionen abzuleiten, die die Spezifika der grossen Stadtwerke als besondere Akteursgruppe abbilden. Die erarbeiteten Untersuchungsdimensionen umfassen daher sowohl Charakteristika der Organisation Stadtwerk an sich, als auch seiner Situation im ökonomischen, technischen und politischen Kontext des Energiesektors. Die Untersuchungsdimensionen wurden dazu in prozessuale und strukturelle Dimensionen untergliedert und sollen zukünftigen Arbeiten als analytische Perspektiven dienen, um den Akteur «grosses Stadtwerk» in seiner Komplexität besser zu verstehen.

Arbeitsdefinition: Stadtwerke werden im Rahmen dieses Beitrags als öffentliche Unternehmen, bzw. Entitäten (*agencies*), konzeptualisiert, die als eigenständige Einheiten auftreten und einen öffentlichen Auftrag zur Daseinsvorsorge, bzw. Service Public haben. Wie die meisten öffentlichen Unternehmen agieren sie dabei heute nicht nur in stark regulierten Kontexten (wie dem Wasser- oder Stromnetzbetrieb), sondern auch in einem marktwirtschaftlich organisierten Umfeld und müssen Profite für den Eigentümer erwirtschaften.

2.1 Prozessuale Untersuchungsdimensionen

Liberalisierung und Korporatisierung in der Energieversorgung

Ein wichtiger Aspekt zum Verständnis der Spezifika grosser Stadtwerke in ihrer heutigen Form, ist der neo-liberale Paradigmenwechsel, der in Europa seit den 1980er Jahren stattgefunden hat und zusammen mit der europäischen Integration in den 1990er Jahren dazu führte, dass neben anderen Infrastruktursektoren auch der Energiesektor europaweit liberalisiert wurde. Es wurden Staatsmonopole aufgebrochen und ein europäischer Markt in der Energieversorgung geschaffen (Finger 2006; Weizsäcker et al. 2006; Finger und Künneke 2011). Arbeiten des *Public Corporate Governance* Ansatzes heben besonders hervor, wie damit einhergehend die Energieversorgung aus der Verwaltung ausgegliedert und – je nach Rechtsform – mehr oder minder eigenständige Energieversorgungsunternehmen geschaffen wurden. Diese Korporatisierung ging einher mit einem grundlegenden Wandel im Verständnis der Rolle des Staates: der Staat war nicht mehr selbst der Leistungserbringer in der Energieversorgung, sondern Eigentümer von Energieversorgungsunternehmen und Gewährleister der Daseinsvorsorge (Schedler et al. 2011: 45ff.) Viele Energieversorgungsunternehmen, und vor allem viele Stadtwerke, sind nach wie vor in öffentlichem oder zumindest teilweise öffentlichem Besitz geblieben, um eine direkte demokratische Kontrolle über die kritische Infrastruktur Energieversorgung zu ermöglichen. In Deutschland wurde nach anfänglicher Privatisierung einiger Stadtwerke in jüngster Zeit wieder eine «Rekommunalisierungswelle» verzeichnet, da die Bürger die direkte Kontrolle wieder zurückerlangen wollten (siehe auch Berlo und Wagner 2013). In der Schweiz gab es bisher keine Privatisierung grosser Stadtwerke, lediglich eine institutionelle Verselbstständigung (Korporatisierung). In beiden Ländern sind die grossen Stadtwerke daher nach wie vor oder wieder (vorwiegend) in öffentlichem Besitz. Neben der direkten demokratischen Kontrolle durch Eigentümerschaft, spielt aber auch die Reregulierung des liberalisierten Energiesektors eine zunehmend entscheidende Rolle, um die Daseinsvorsorge zu garantieren. Diese wird in den Arbeiten der *Public Corporate Governance* eher wenig berücksichtig - darauf wird weiter unten im Kontext der *Network Industries* noch genauer eingegangen.

Aus diesem kurzen historischen Rückblick lassen sich bereits einige sehr zentrale Untersuchungsdimensionen für grosse Stadtwerke ableiten: i) **Korporatisierung**: grosse Stadtwerke wurden ausgegliedert und agieren (bis auf wenige Schweizer Ausnahmen) heute als eigenständige Unternehmen ii) **Öffentliches Eigentum**: Die grossen Stadtwerke befinden sich nach wie vor oder wieder in öffentlichem Eigentum; iii) **Daseinsvorsorge**: Sie haben nach wie vor einen öffentlichen Auftrag zur Daseinsvorsorge.

Kulturwandel von Verwaltung und Ingenieurswissen hin zu mehr Unternehmertum

Einhergehend mit dem oben angesprochenen neo-liberalen Paradigmenwechsel fand und findet in den öffentlichen Unternehmen über den formal-organisationalen Wandel auch ein Kulturwandel statt, durch die Strömung des *New Public Managements* beeinflusst wird (Florio und Fecher 2011). Die in die öffentliche Verwaltung zur Effizienzsteigerung eingeführten privatwirtschaftlichen Organisationsmechanismen ziehen ebenfalls eine Übernahme von Verhaltensweisen und Sichtweisen aus der Privatwirtschaft nach sich, die im Kontext öffentlicher Unternehmen mit dem Term ***Public Entrepreneurship*** zusammengefasst werden kann (für einen Überblick über die Debatte siehe z.B. Bernier und Hafsi 2007; Greiling et al. 2013). Flachere Hierarchien, unabhängigere und schnellere Entscheidungen, stärkere Risikoorientierung oder auch eine erfolgsorientierte Entlohnung werden darunter z.B. verstanden. Für den Energiebereich spezifisch kommt noch hinzu, dass dieser aufgrund seiner Technologieintensivität von Ingenieuren und entsprechendem Wissen, Fähigkeiten und Sichtweisen dominiert wurde. Die Korporatisierung der Energieversorgungsunternehmen im Allgemeinen verlangt nun eine stärkere Integration von betriebswirtschaftlichen Wissensformen und Kompetenzen, ohne dabei jedoch die technologischen Grundlagen zu verlieren. Eine weitere wichtige Untersuchungsdimension für grosse Stadtwerke stellt daher der **Kulturwandel hin zu mehr Unternehmertum** dar.

Spannungsfeld zwischen öffentlichem Interesse und Marktfähigkeit der öffentlichen Unternehmen

Mit der erwähnten Korporatisierung in der Energieversorgung prallen nun ökonomische und gesellschaftliche Logiken aufeinander. Der Ansatz des *Public Corporate Governance* beschreibt eben dieses Spannungsfeld zwischen Marktlogik und öffentlicher Daseinsvorsorge als zentrale Untersuchungsdimension (Schedler et al. 2011; Schedler et al. 2007; Schedler und Finger 2008). Öffentliche Unternehmen müssen auf der einen Seite die **Erfüllung des öffentlichen Interesses** gewährleisten, u.a. dass alle Bürger, bzw. Einwohner Zugang zur Grundversorgung haben, dass diese zu einem fairen Preis angeboten wird, sowie die dafür nötige Infrastruktur aufgebaut und erhalten wird. Auf der anderen Seite erwarten die Eigentümer, dass die öffentlichen Unternehmen **erfolgreich am Markt agieren** und Profit erwirtschaften (siehe Abbildung 1). Dies ist besonders für die Stadtwerke entscheidend, da die Einnahmen aus der Energieversorgung den Stadthaushalt füllen und eine Finanzierung der defizitären Daseinsvorsorgebereiche wie dem öffentlichen Transport ermöglichen. Als weitere Untersuchungsdimension kann daher das Spannungsfeld zwischen ökonomischer und gesellschaftlicher Logik festgehalten werden, das öffentliche Unternehmen auszeichnet.

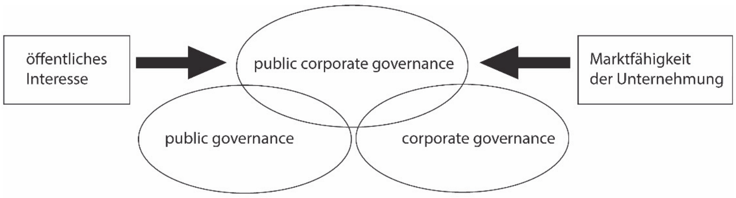

Abbildung 1: Spannungsfeld öffentlicher Unternehmen zwischen öffentlichem Interesse und Marktfähigkeit (eigene Darstellung basierend auf Schedler et al. 2011: 19)

2.2 Strukturelle Untersuchungsdimensionen

Die multidimensionale Rolle(n) der öffentlichen Hand gegenüber dem öffentlichen Unternehmen

Damit einhergehend ist das mehrdimensionale Verhältnis zwischen der öffentlichen Hand und dem Unternehmen ein weiteres Spezifikum öffentlicher Unternehmen. Die öffentliche Hand tritt **in mehreren Rollen** auf und hat daher unterschiedliche Erwartungen und Ansprüche an das Unternehmen (Schedler und Finger 2008; Schedler et al. 2011). Sie ist gleichzeitig Eigentümerin, die auf die Einnahmen und Prosperität des Unternehmens fokussiert ist, Regulator, die die Gewährleistung der Daseinsvorsorge kontrolliert, Legislative, die Gesetze zum Energiemarktdesign, Netzbetrieb aber auch zur Energiewende oder Digitalisierung vorgibt, Exekutive, die als Steuerbehörde, Umwelt- oder Wirtschaftsministerium auftritt oder Judikative. Die im *Public Corporate Governance* Ansatz, bzw. auch in den Arbeiten zu Staatseigenen Betrieben besonders hervorgehobene Rolle ist die des Eigentümers. Ein verbreiteter Theorieansatz zum Verständnis dieses spezifischen Verhältnisses ist die sog. *Principal-Agent Theory*. Sie erklärt, dass der Staat als Eigner (Prinzipal) durch die Ausgliederung des operativen Geschäfts an das öffentliche Unternehmen, bzw. Stadtwerk (Agent) keine direkte Kontrolle und volle Information mehr über dessen Handeln hat (Rentsch 2017 nach Jensen und Meckling 1976). Um diese Kluft zu überwinden wird meist eine sog. Eignerstrategie festgelegt mit Eignerzielen, die dem öffentlichen Unternehmen die strategische Ausrichtung vorgibt. Schedler et al. (2007) geben einen schematischen Überblick, wie diese strategischen Vorgaben im Idealfall auf staatlicher Seite von der Legislative über die Exekutive in die Unternehmensführung gelangen und konzeptualisieren hier einen sog. äusseren und inneren Controllingkreis (siehe Abbildung 2). Der äussere Kontrollkreis umfasst dabei die öffentlich-demokratische Kontrolle, der innere die unternehmerisch-betriebswirtschaftliche. Ein wichtiger Aspekt ist dabei, dass sich die beiden Kreise im Führungsboard der öffentlichen Unternehmen überlagern (Schedler und Finger 2008): hier interagieren Verwaltungsrat und Geschäftsführung und arbeiten an der Abstimmung der beiden Kreise.

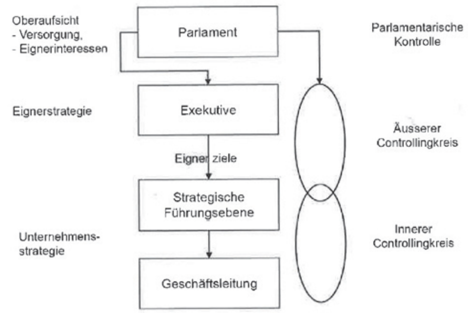

Abbildung 2: Eigner-bezogene Governance öffentlicher Unternehmen (Schedler et al. 2011: 78)

Für die Überbrückung der Kluft zwischen Prinzipal und Agent in öffentlichen Unternehmen wurden zudem andere Instrumente aus der *Corporate Governance* übernommen: Jahresberichte, Eigentümerversammlungen, aber auch *Stakeholder-Management* Massnahmen (Victor et al. 2012: 63). Weiterhin sind auch allgemeine Staatsziele, wie z.B. Beschlüsse zum Ausbau erneuerbarer Energien, dem Ausstieg aus der Kernkraft, der Klimapolitik oder ganz grundlegend das allgemeine Verständnis der Daseinsvorsorge von essentieller Bedeutung (Victor et al. 2012: 18). Der Staat bzw. die öffentliche Hand tritt hier nicht als Eigentümerin, sondern in ihren anderen Rollen auf, die die weiteren gesellschaftlichen Interessen vertreten. Das multidimensionale Verhältnis zwischen öffentlicher Hand und öffentlichem Unternehmen, das sich in **Eignerstrategie und Eignerzielen** einerseits, in **sozio-politischen Zielen** andererseits manifestiert und im **Unternehmensboard** (bestehend aus Verwaltungsrat und Geschäftsleitung) zusammenkommt, kann daher als weitere wichtige Untersuchungsdimensionen festgehalten werden.

Infrastrukturnetzwerke, Monopol und Re-Regulierung

Stadtwerke sind, sowohl als Stromversorger, als auch als Gas- und Wasserversorger und manchmal als Betreiber des schienengebundenen öffentlichen Nahverkehrs, Akteure in sog *Network Industries*. Diesen Industriesektoren liegt ein Netzwerk zugrunde (Stromnetz, Wasser oder Gasleitungen, Schienen), die ein sog. natürliches Monopol darstellen (Finger 2006), das heisst, Wettbewerb und die dadurch entstehende Doppelstruktur ist schlicht nicht sinnvoll. Das hat zur Folge, dass diese Sektoren, zumindest für den Teil des Netzwerkbetriebs nicht marktbasiert, sondern staatlich und rein regulatorisch gemanagt werden. Dieser „physisch-technische Aspekt" und der starke regulatorische Einfluss auf die Unternehmen in Netzwerkindustrien, wird jedoch weder im *Public Corporate Governance* Ansatz, noch in den Arbeiten zu Staatseigenen Betrieben explizit berücksichtigt.

In den Arbeiten zu *Network Industries* wird diesen Besonderheiten Rechnung getragen und besonders die Effekte und Entwicklungen im Kontext der Liberalisierung dieser Industrien thematisiert (siehe z.B.

(Florio 2017; Finger und Jaag 2015; Belloc und Nicita 2016; Finger und Künneke 2011). Ein weites Untersuchungsfeld ist dabei Analyse von der Ko-Evolution technologischer Innovationen und regulatorischem Rahmen (Crettenand und Finger 2013; Finger et al. 2005). Im Kontext dieser Arbeiten werden aktuelle Fragen der Gouvernanz des Energiesektors untersucht: Dürfen Netzbetreiber z.B. Speichereinheiten oder Reservekraftwerke betreiben und die Kosten im Monopol „sozialisieren“? Wie werden Flexibilitäten im Markt Design geregelt? Welche Rolle spielen Demand-Side-Management oder die Block Chain Technologie? Weiterhin wird in den Arbeiten zu Network Industries auch explizit der Einfluss von Regulierungen auf den Sektor untersucht, so z.B. die mit der Liberalisierung entstandene Rolle des Regulators (Finger und Varone 2006a, 2006b) oder aber der in jüngster Zeit vorhaltende Trend der Re-Regulierung des Energiesektors (Finger 2006; Künneke 2009). All diese Fragen stellen sich zeitgleich allgemein für die Gouvernanz des heutigen und zukünftigen Energiesektors, jedoch auch ganz konkret für die öffentlichen Unternehmen an der Schnittstelle zwischen Mark und Monopol, Produktion und Netz.

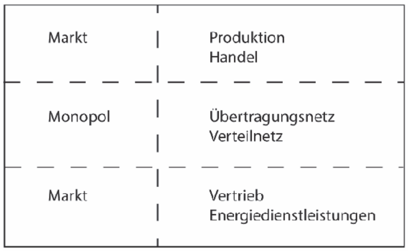

Abbildung 3: Überblick über die Wertschöpfungsstufen im Energiesektor (eigene Darstellung verändert nach Brunekreeft et al. 2015)

Wichtige Untersuchungsdimensionen für Stadtwerke als Akteure in Netzwerkindustrien sind daher **die Überbrückung der divergierenden Markt- und Monopollogiken**, die **Ko-entwicklung von neuen Technologien und regulatorischem Rahmen** sowie der generelle Trend der **Re-regulierung** des Energiesektors.

Tabelle 1 fasst die oben dargestellten Untersuchungsdimensionen noch einmal zusammen und verweist auf die theoretischen bzw. empirischen Quellen, aus denen diese entnommen wurden.

Tabelle 1: Untersuchungsdimensionen für grosse Stadtwerke – konzeptualisiert als öffentliche Unternehmen in Netzwerkindustrien

Untersuchungsdimension	**Quelle**
Prozessuale Dimensionen	
Liberalisierung und Korporatisierung in der Energieversorgung	*Public Corporate Governance / Network Industries* (Schedler et al. 2011; Finger und Künneke 2011)
Kulturwandel von Verwaltung und Ingenieurswissen hin zu mehr Unternehmertum	*Public Entrepreneurship* (Bernier und Hafsi 2007; Greiling et al. 2013)
Spannungsfeld zwischen öffentlichem Interesse und Marktfähigkeit der öffentlichen Unternehmen	*Public Corporate Governance* (Schedler et al. 2011; Schedler und Finger 2008)
Strukturelle Dimensionen	

Die multidimensionale Rolle(n) der öffentlichen Hand gegenüber dem öffentlichen Unternehmen	*Public Corporate Governance, State-owned Enterprises* (Schedler et al. 2011; Schedler und Finger 2008; Victor et al. 2012)
Infrastrukturnetzwerke, natürliches Monopol und Re-Regulierung	*Network Industries* (Finger und Jaag 2015; Finger und Varone 2006a; Crettenand und Finger 2013)

3 Methodik der Studie

Dieser Beitrag basiert auf einer explorativen, qualitativen Studie, die Ergebnisse aus eine theoretischen Literaturanalyse, Dokumentenanalyse und in 2017 durchgeführten Experteninterviews zusammenführt.

Die **theoretische Literaturanalyse** wurde in einem mixed sampling (Schlagwortsuche und Schneeballprinzip) in den Bereichen *Transition Studies, State-owned Enterprises, Public Enterprises, Public Corporate Governance, Network Industries* sowie generell in Arbeiten zu „Stadtwerken" im Kontext der Energiewende durchgeführt. Für die Transition Studies beschränkte sich die Suche auf akteursfokussierte Frameworks und Theorien zur Analyse der Rolle von Stadtwerken in der Energiewende; in den anderen Forschungsbereichen wurde explorativ nach relevanten Untersuchungskriterien für Stadtwerke in der Energiewende gesucht, wobei „relevant" nicht nur aus der Literatur, sondern auch durch das Vorwissen der Autorin aus ihren empirischen Untersuchungen definiert wurde. Es handelt sich daher um einen iterativen Ansatz und eine nicht repräsentative Literaturanalyse, die vor allem dem bisher wenig berücksichtigten Untersuchungsgegenstand geschuldet ist. Besagtes Vorwissen entstand zunächst aus einer ebenfalls explorativen Dokumentenanalyse der in Abschnitt 1 zitierten Berichte von Beratungsagenturen, Unternehmensberichten und –homepages, aus denen ein allgemeines Verständnis des Akteurs und seiner Besonderheiten entstand (z.B. über die Geschichte der Stadtwerke).

Herzstück der **empirischen Analyse** sind jedoch **38 Experteninterviews**, die in Deutschland und der Schweiz von März bis Juni 2017 mit Forschern, Unternehmensberatern und Verbandsvertretern geführt wurden, die mit Stadtwerken arbeiten. Weiterhin wurden vor allem aber auch Mitarbeiter dem strategischen Management oder der operativen Führungseben der grossen Stadtwerke, sowie einiger mittlerer Stadtwerke befragt. In durchschnittlich einstündigen Leitfaden-gestützten Interviews wurden die Interviewten auf Deutsch, Französisch und Englisch zu ihrer persönlichen Sicht auf **Charakteristika der grossen Stadtwerke, Herausforderungen in der Energiewende und deren strategische Antworten** befragt. Die Interviews wurden anonymisiert, zusammenfassend transkribiert und softwarebasiert ausgewertet (MAXQDA.de). Eine Übersicht über die Interviewpartner findet sich in Tabelle A.1 im Anhang.

Die Analyse der Interviews erfolgte dabei in einem semi-strukturierten Prozess: die Transkripte wurden zunächst nach «Eigenschaften der Stadtwerke», «Herausforderungen» und «strategische Antworten» gruppiert und codiert, weitere Subkategorien wurden induktiv aus den Nennungen der Interviewten gebildet. Die Analyse und Interpretation der Nennungen erfolgte schliesslich auf Basis der oben präsentierten Untersuchungsdimensionen.

Bei den hier untersuchten grossen Stadtwerken – die alle auch mit Interviews abgedeckt wurden - handelt es sich um die Stadtwerke München, Rheinenergie (Energiesparte der Stadtwerke Köln) und enercity (Energiesparte der Stadtwerke Hannover) für Deutschland, sowie die Industriellen Betriebe Basel, die Services Industriels de Genève (Stadtwerke Genf) und das Elektrizitätswerk der Stadt Zürich (die auch Wasser und Telekommunikation anbieten). Diese Stadtwerke wurden nach folgenden Kriterien ausgewählt: sie gehören zu den grössten Stadtwerken innerhalb des eigenen Landes (nach Umsatzzahl), sind mindestens zu 75 % im Besitz der Stadt und haben eine lange Firmentradition (Gründung mind. anfangs des 20.Jahrhunderts). Es stehen somit die traditionellen Akteure im Vordergrund und das Phänomen der Rekommunalisierung wurde aussenvor gelassen.

Tabelle A.2 (im Anhang) gibt einen Überblick über die Strukturdaten der ausgewählten grossen Stadtwerke.

Abschliessend wurden im Juni 2018 zwei Expertenworkshops in der Schweiz durchgeführt, um die erarbeiteten Charakteristika und Herausforderungen, vor allem aber die Rolle der Stadtwerke in der Energiewende der Schweiz zu diskutieren.[4] Beide Workshops - ein deutschsprachiger in Zürich und ein französischsprachiger in Lausanne – waren dabei identisch aufgebaut: i) Präsentation der Ergebnisse (Charakteristika, Herausforderungen, aktuelle Rollen der grossen Stadtwerke), ii) Diskussion möglicher Modelle über die zukünftige Rolle der grossen Stadtwerke sowie iii) abschliessende Diskussion über die Rolle der grossen Stadtwerke für die Resilienz des Energiesektors während der Transition. An beiden Workshops nahmen Experten aus der Branche teil, wobei darauf geachtet wurde sowohl vorherige Interviewpartner als auch vorher nicht interviewte Experten einzuladen (vgl. Tabelle 2). Die Ergebnisse der Workshops wurden anonymisiert schriftlich zusammengefasst und zur kritischen Reflektion der Interviewergebnisse verwendet.

Tabelle 2: Übersicht über Teilnehmer der Expertenworkshops (eigene Darstellung)

	Forschung	Verband/ Verein	Politik/ Verwaltung	Grosses Stadtwerk	Mittleres Stadtwerk	Beratung
Teilnehmer Zürich	I	I	I (Kommune)	I	I	II
- vorher interviewt	I	I			I	I
Teilnehmer Lausanne	I		III (Bund, Kanton, Kommune)	I	I	I
- vorher interviewt				I		I

4 Charakteristika, Herausforderungen und strategische Antworten der grossen Stadtwerke in der Energiewende in Deutschland und der Schweiz

Im Folgenden werden nun die Ergebnisse der empirischen Untersuchung der Charakteristika, Herausforderungen und strategischen Antworten der grossen Stadtwerke in der Schweiz und Deutschlands im Kontext der Energiewende präsentiert. Es werden daher zunächst die Eigenschaften der untersuchten grossen Stadtwerke dargestellt, anschliessend die aktuellen allgemeinen Herausforderungen im

[4] Aus organisatorischen und finanziellen Gründen konnten keine Workshops in Deutschland durchgeführt werden.

Energiesektor und die besonderen Herausforderungen für die Stadtwerke aufgezeigt und schliesslich strategische Antworten der Stadtwerke auf diese Herausforderungen erläutert.

4.1 Charakteristika grosser Stadtwerke: öffentliche Unternehmen, Netzwerkbetreiber und Teil föderaler Staaten

Die **Kernaufgabe** der grossen Stadtwerke in Deutschland, wie in der Schweiz, ist das **Zurverfügungsstellen von Infrastrukturdienstleistungen** für „ihre" Stadt. Die organisatorische Struktur der Stadtwerke variiert dabei je nach individueller Situation in der Stadt: während die meisten grossen Stadtwerke Energie und Wasserversorgung in einem Unternehmen organisieren, sind meist Telekommunikation, öffentlicher Verkehr oder Abfallmanagement in „Schwesterfirmen" organisiert, die ebenfalls im Eigentum der Stadt sind (variierende horizontale Integration). Und wie für jedes Unternehmen spielt die horizontale Integration auch für die grossen Stadtwerke eine wichtige Rolle hinsichtlich der Risikostreuung und Diversifikationsmöglichkeiten.

Weiterhin gibt es einen entscheidenden Unterschied hinsichtlich der **rechtlichen Form** der grossen Stadtwerke in Deutschland und der Schweiz. In Deutschland sind sie als unabhängige Firmen unter **privatem Recht** organisiert, in der Schweiz sind alle grossen Stadtwerke als **Unternehmen öffentlichen Rechts** organisiert - lediglich Zürich bildet eine Ausnahme, da die Elektrizitäts- und Telekommunikationsversorgung nach wie vor Teil der Stadtverwaltung sind, die Gasversorgung jedoch in einer privatrechtlichen AG ausgelagert wurde. Unter den Interviewten herrschte Uneinigkeit darüber, ob die rechtliche Form einen entscheidenden **Einfluss auf die unternehmerischen Gestaltungsmöglichkeiten** der Stadtwerke habe [„die rechtliche Form ist nicht so entscheiden, es geht mehr um Persönlichkeiten. So lange der Verwaltungsrat die Firmenstrategie beeinflusst, ist Kontrolle da" DE8; „jede rechtliche Form hat ihre Mittel und man kann ein öffentliches Unternehmen gestalten als wäre es ein Teil der Stadtverwaltung oder eine AG" DE6; „die rechtliche Form macht einen entscheidenden Unterschied: sie beeinflusst die Flexibilität, die finanziellen Ressourcen, die Denkweisen und die Profiorientierung" CH16]. Trotz der enormen Vielfalt und Unterschiede zwischen den grossen Stadtwerken, waren sich die Interviewten jedoch in zwei Aspekten einig, die diesen Akteurstypos besonders machen: sie sind **Querverbundsunternehmen**, die nicht nur mehrere Infrastrukturdienstleistungen abdecken (**multi-utility**) sondern in ihrer Energiesparte auch mehrere Energieformen (**multi-energy**) (vgl. Abbildung 4). Dies unterscheidet sie tendenziell von grossen Energiekonzernen wie EON oder RWE, aber auch von Regionalversorgern in Deutschland oder Schweizer Kantonswerken, die auf die Strom- und Gasversorgung fokussiert sind („wie Romande Energie oder Groupe E, die hauptsächlich in der Elektrizitätsversorgung aktiv sind" (CH8)).

Ein weiteres Charakteristikum, das alle grossen Stadtwerke teilen, ist ihre **vertikale Integration.** Grosse Stadtwerke sind typischerweise voll integrierte Unternehmen, die vor allem in ihrer Energiesparte Produktion, Verteilung, Vertrieb und Dienstleistungen anbieten [„vom Kraftwerk bis zur Steckdose, die decken alles ab" CH16]. Das heisst, sie produzieren und vermarkten nicht nur, sondern besitzen und betreiben auch unterschiedliche Verteilnetze (Strom, Gas- und Fernwärmenetze aber auch Transport, Wasser und Telekommunikationsnetze). Da diese Verteilnetze ein natürliches Monopol darstellen, sind **sie gleichzeitig in Märkten und in Monopolen aktiv** (vgl. Abbildung 4). Hier unterscheiden sich Deutschland und die Schweiz abermals grundlegend: während grosse Stadtwerke in Deutschland voll in den europäischen Markt integriert ist und ihre Netze abgekoppelt von Produktion und Vertrieb betreiben (**unbundling**), trifft die Schweizer Stadtwerke die unbundling Regulierung nicht, da die Schweiz kein politisches Mitglied der EU ist. Sie können daher alle Wertschöpfungsstufen in einem Unternehmen betreiben. Zusätzlich haben die Schweizer Stadtwerke nach wie vor ein Monopol im Vertrieb von

Strom und Gas an Haushalte (bzw. Kunden unter 100.000 kWh pro Jahr) in ihrem Verteilnetzgebiet, da der Schweizer Markt nur teil-liberalisiert wurde – für Grosskunden.[5]

Wie bereits in den Untersuchungsdimensionen erwähnt, stellt die **öffentliche Eigentümerschaft bei gleichzeitiger Korporatisierung** ein weiteres distinktes Merkmal der grossen Stadtwerke dar. Es wird daher von ihnen erwartet, dass sie gleichzeitig **Daseinsvorsorge** leisten und **Profit für die Stadtverwaltung** erwirtschaften, damit diese ihre defizitären Dienstleistungen finanzieren kann. Daher macht es die spezifische Situation der Stadtwerke aus, dass die Stadt Ihnen nicht nur als ihr Eigentümer (Shareholder) gegenübertritt, sondern auch als Vertreterin des öffentlichen Interesses (Stakeholder). In der Organisation der Daseinsvorsorge unterscheiden sich die beiden Länder Deutschland und die Schweiz wiederum deutlich: In Deutschland beschränkt sich die Daseinsvorsorge auf den im Monopol organisierten Bereich der Netzinfrastrukturen und wird über Gebühren und Steuern finanziert. Für die Energieversorgung hingegen überwacht der Regulator, die Bundesnetzagentur, die Gewährleistung der Daseinsvorsorge. In der Schweiz ist die Gewährleistung und Erbringung der Daseinsvorsorge (nach wie vor) in der Hand der Städte und durch die Monopolsituation in der Energieversorgung der Haushalte auch auf den Vertrieb ausgeweitet. So ist es Aufgabe einer jeden Stadt, faire Energietarife für ihre Bürger zu definieren. Und nachdem die Schweizer Stadtwerke den Netzbetrieb organisatorisch nicht separieren müssen, können sie ihre Unterschiedlichen Dienstleistungen querfinanzieren [„Die Nicht-Trennung von Netz und Produktion erleichtert es, die Verluste im Absatz – z.B. durch Energieeffizienz – mit den Netzeinnahmen zu kompensieren“ DE14]. Kernaufgabe der Schweizer Stadtwerke ist es daher, die Daseinsvorsorge auf Ebene der Stadt sicher zu stellen.

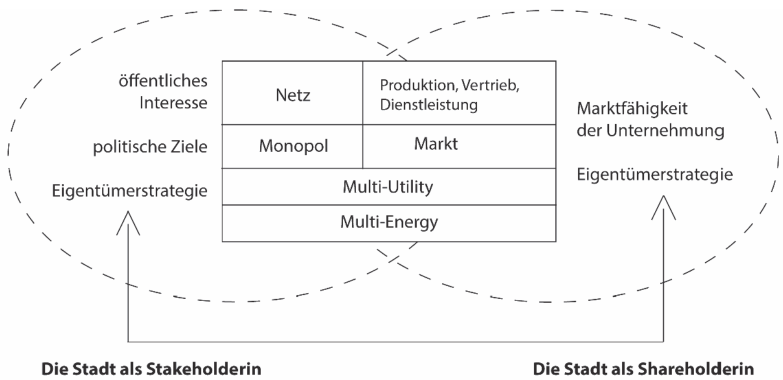

Abbildung 4: Überblick über die Charakteristika grosser Stadtwerke (eigene Darstellung)

4.2 Globale und spezifische Herausforderungen der grossen Stadtwerke in Deutschland und der Schweiz

Globale Herausforderungen des Energiesektors

Die regulatorischen und technologischen Rahmenbedingungen des deutschen und Schweizer Energiesektors waren über eine lange Zeit sehr stabil und statisch. In den letzten 20 Jahren wurden jedoch sukzessive drei globale Wandlungsprozesse in Gang gesetzt, die auch vor den beiden untersuchten

[5] Diese spezifische Situation der Schweiz ist Teil der aktuellen Verhandlungen mit der EU und wird sich wahrscheinlich in naher Zukunft ändern.

Ländern nicht Halt machen: Erstens, die bereits erwähnte **politische Integration in die Europäische Union**, welche die **Liberalisierung** und anschliessende Neu-Regulierung der des Energie, bzw. Elektrizitätssektors zur Folge hatte. Die damals geschaffenen Märkte müssen bis heute gestaltet und re-reguliert werden [„vor fünf Jahren war Marktdesign nicht einmal ein Begriff in der Debatte, das zeigt, wie sich die Dinge ändern“ DE8]. Die grossen Stadtwerke sehen sich immer stärkerem und diversifizierterem Wettbewerb gegenüber [„Start-ups, Energievermarktungsplattformen wie Verivox, aber auch Google, Telekom, die Datenbeherrscher, die wissen wie man mit Daten umgeht“ DE9]; aber auch Kundenansprüche nehmen zu [„die Kunden übertragen Ihre Ansprüche, die sie aus anderen Dienstleistungssektoren gewohnt sind auch auf Energie. Heute bestellt, morgen muss es da sein“ DE2]. Zweitens, die politische Wende hinsichtlich der Dekarbonisierung der Energieproduktionstechnologien und des Atomkraftausstieges, wofür in Deutschland der Begriff **Energiewende** geprägt wurde. Die in diesem Kontext in ganz Europa aufgesetzten Förderprogramme für erneuerbare Energien hatten einen massiven Zuwachs dezentraler Erzeugungskapazitäten, steigende Volatilität in der Produktion und Bi-Direktionalität in den Netzen sowie zusammenbrechende Elektrizitätspreise und eine Explosion der Anzahl der in der Energieversorgung involvierten Akteure zur Folge. Da dezentrale und kleinteilige Produktion vorwiegend in Verteilnetze einspeist, ist es an den grossen Stadtwerken, diesen Wandel technisch aber auch sozioökonomisch zu managen. Drittens, der generelle Trend der **Digitalisierung** und Smartness im Energiesektor, der nicht nur eine massive Beschleunigung des Informationsaustausches zur Folge hat, sondern auch neue Geschäftsfelder und Produkte im Energiesektor möglich macht. Die grossen Stadtwerke müssen hier nicht nur den Wandel mitgehen, sondern sehen sich auch einer immer stärkeren Konkurrenz durch neue Akteure aus anderen Sektoren gegenüber.

Diese drei Mega-Trends verursachen eine **regulatorische Offenheit und Geschwindigkeit von regulatorischen und technologischen Veränderungen**, denen sich der Sektor bisher nicht gegenübersah. Diese Herausforderungen stellen sich für alle traditionellen Akteure im Energiesektor gleichermassen, für die grossen Stadtwerke ergeben sich jedoch noch weiteren Herausforderungen, die aufgrund ihrer Charakteristika für sie spezifisch sind.

Besondere Herausforderungen der grossen Stadtwerke

Die beiden Global-Trends der Liberalisierung und der politischen Wende hin zu einer nachhaltigeren Energieversorgung verursachen **widersprüchliche Erwartungen** an die grossen Stadtwerke, die aufgrund ihrer öffentlichen Eigentümerschaft für sie von besonderer Relevanz sind. Im Kontext der Energiewende bedeutet das öffentliche Interesse nun nicht mehr nur **Versorgungssicherheit und Systemstabilität** der Infrastruktur, **lokales Engagement** z.B. durch Teilnahme in Stadtratssitzungen oder Sponsoring lokaler Events, sondern auch der **Ausbau erneuerbarer Energieproduktion**, das Investment in **neue Infrastrukturen**, das Umsetzen von **Energieeffizienzmassnahmen** auf systemischer und individueller Ebene. [„Die Stadt ist mehr als nur die Eigentümerin, sie ist Stakeholder. Sie hat politische Erwartungen und ist in einer Doppelrolle: Eigentümerin und politische Akteurin. Und so setzt sie als Eigentümerin politische Ziele.“ DE10; „Geldverdienen ist die Haupterwartung der Politik. Natürlich sagen die immer, bitte denkt an die Energiewende aber trotzdem ist die Hauptanforderung, dass sie Profit erwirtschaften sollen“ DE18]. Folglich sind in den **Eigentümerstrategien** grosser Stadtwerke oftmals nicht nur **widersprüchliche Ziele zwischen der privatwirtschaftlichen und der öffentlichen Seite** verankert, sondern auch die **öffentlichen Interessen in sich widersprüchlich**. Im Vergleich zu rein privatwirtschaftlichen Energieunternehmen, für die die politischen Ziele und das öffentliche Interesse extern zu ihrem Unternehmen sind, müssen die grossen Stadtwerke in Deutschland und der Schweiz, die politischen, wie auch die privatwirtschaftlichen Ziele ihrer Eigentümerin gemäss ihrer Zielvorgaben erfüllen. Weiterhin sind die grossen Stadtwerke in beiden Ländern **Teil einer föderalen Staatsorganisation** und auf kommunaler Ebene angesiedelt. Politische Ziele und öffentliches Interesse kommen daher nicht nur direkt von der Stadt und ihren Einwohnern, sondern auch von Ländern, Kantonen, dem Bund und Europa. Zwischen diesen Ebenen sowie auch zwischen den Kommunen oder Ländern kann es erhebliche **Unterschiede hinsichtlich der politischen Ziele und wirtschaftlichen Erwartungen** geben, was die grossen Stadtwerke vor erhebliche Herausforderungen im Wettbewerb stellen kann. In der Schweiz sind die Unterschiede dabei besonders gross, da einige Kantone die Stadtwerke als Teil der öffentlichen Hand organisieren und diese nach wie vor als Leistungserbringer des Service Public sehen. Die Stadtwerke werden daher ganz offen auch mit der Umsetzung der Energiepolitik beauftragt. Andere Kantone sehen die öffentliche Hand dagegen als Gewährleisterin des Service Public und davon abgekoppelt in eigenständigen Unternehmen, die Stadtwerke als Leistungserbringer die auf «Kundenansprüche und Systemanforderungen» reagieren aber «keine Energiepolitik machen» [CH17].

Dieses Aufeinanderprallen öffentlicher und privatwirtschaftlicher Interesse sowie die unterschiedlichen Verständnisse des Verhältnisses zwischen Stadt und Stadtwerk spiegeln sich in grossen Stadtwerken beider Länder unter anderem auch in **unterschiedlichen Ansichten zur Besetzung des Verwaltungsrats und Geschäftsführung** wider. Das öffentliche Interesse spricht für die demokratische Repräsentation der Bürger im Verwaltungsrat, das privatwirtschaftliche Interesse spricht für unternehmerische und manchmal auch technologische Kompetenzen. Die Interaktion zwischen Verwaltungsrat und Geschäftsführung stellt sich in vielen grossen Stadtwerken daher nicht immer ganz leicht dar. [„Wer sitzt denn im Verwaltungsrat eines grossen Stadtwerks? Lokalpolitiker. Und die wenigsten haben ein profundes Verständnis des Energiesektors, der Rest hat Kommunalpolitische Interessen und will eigentlich nur Geld für die Daseinsvorsorge“ DE3; „im Verwaltungsrat ist die Frage, wer sind diese Politiker? Sind das Experten im Energiebereich und in der Politik oder sind sie mehr wie informierte Bürger?“ DE12]

Die oben erwähnten globalen Herausforderungen erfordern darüber hinaus auch einen **grundlegenden Wandel in der Firmenkultur sowie der individuellen Profile und Kompetenzen der Mitarbeiter** grosser Stadtwerke [«Wir sind schon strukturkonservativ, was im Grunde ja auch lange zum Geschäft gepasst hat – wir legen Leitungen in die Erde, die halten hundert Jahre, da brauchte man nicht viel Flexibilität im Geiste aber das ändert sich gerade und das wird schon ein Prozess, der uns auch einiges an kultureller Veränderung abverlangt“ DE10]. Entrepreneurship, Risikoaffinität Innovationsfähigkeit sind ebenso gefordert wie die Beschleunigung von Entscheidungsprozessen, gesteigerte Kompetenzen in Marketing und Kundenbeziehungen, neue Management- und Arbeitsformen und letztlich Fähigkeiten und Wissen für smarte Technologien. Grosse Stadtwerke beider Länder waren jedoch lange Zeit gekennzeichnet von **Verwaltungs- und Ingenieursdenkweisen** und Organisationskulturen, die es ihnen erlaubten die Daseinsvorsorge für die Stadt zu gewährleisten [„Grosse Stadtwerke sind von einem bestimmten Mitarbeitertyp gekennzeichnet: ein technologieorientierter Ingenieur, der aber gleichzeitig in sozialen Dimensionen denkt und nicht den Profit des Unternehmens zum Ziel hat, sondern das Funktionieren der gesamten Stadt.“ DE16] Diese Denkweisen und Kulturen passen sich nur langsam an die neuen Rahmenbedingungen eines liberalisierten Sektors an [„es hängt nicht an den Strukturen, sondern an der Denkweise der Leute und die wird man nicht binnen weniger Monate ändern“ DE3]. Neben der Anpassung an die liberalisierten Rahmenbedingen wird jedoch erwartet, dass die Stadtwerke nach wie vor konstant und zuverlässig ihre Daseinsvorsorge erfüllen und zeitgleich in unsicheren und volatilen Märkten als erfolgreiches Unternehmen agieren. Ihre Hauptherausforderung ist daher der **organisationale Wandel bei einer konstanten öffentlichen und privatwirtschaftlichen Performance**.

Ein zweites grosses Feld spezifischer Herausforderungen – besonders für die deutschen Stadtwerke - ist die **Diskrepanz** zwischen dem **regulatorischen Rahmen**, der im **Kontext der Liberalisierung geschaffen** wurden und den **technischen Anforderungen der erneuerbaren Technologien**. Damit die grossen Stadtwerke dezentrale, verstreute und volatile Erneuerbare in das Verteilnetz integrieren und managen können, sind smarte Netz- und Anlagensteuerung, Speichertechnologien und Flexibilitätsmechanismen entscheidende Mittel um die Versorgungssicherheit zu garantieren. Es besteht hier ein entscheidender Regulierungsbedarf, hinsichtlich z.B. Fragen nach der Berechtigung von Verteilnetzbetreibern, Produktionsanlagen zum Netzausgleich zu installieren und zu betreiben oder nach der Finanzierung dieser Anlagen nach Markt oder Monopollogik, müssen jedoch neu reguliert werden. [„Integriertes Ressourcenmanagement ist mit unbundling sehr kompliziert. Selbst wenn man Verträge zum Datenaustausch hat, der klassisch voll integrierte Energieversorger würde hier besser funktionieren. Die können entscheiden: will ich LED Lampen installieren oder eine neue Anlage bauen. CH10]. Auf übergeordneter Ebene bedeutet dies, dass der regulatorische Rahmen mit dem Ziel der Liberalisierung teilweise widersprüchlich zum regulatorischen Rahmen für die Energiewende ist und grosse **Herausforderungen für die strategische Ausrichtung und Investmententscheidungen in grossen Stadtwerken** verursacht – besonders in der Schweiz im Hinblick auf die Unsicherheit in den politischen Verhandlungen mit der EU. [„Die ganze unbundling Regulierung wurde vor der Energiewende und der Digitalisierung geschaffen und sie hindert diese jetzt. Die Energieversorger bekommen kein Feedback über den Bedarf und die Reaktionen ihrer Kunden. Das war einmal für ein ein-direktionales System entworfen und muss in Zukunft überarbeitet werden" DE3; „wenn jemand die Verantwortung hat, soll er schliesslich auch die Eingriffsmöglichkeiten haben" DE12]

4.3 Strategische Antworten: Anpassung an Marktlogiken und In-Wert-Setzen der Besonderheiten

Die Antworten der grossen Stadtwerke auf das oben präsentierte weite Spektrum an Herausforderungen können für beide Länder generell in zwei Bereiche untergliedert werden: Auf der einen Seite das Sich-Anpassen an die Marktlogiken durch die Übernahme strategischen Verhaltens aus der Privatwirtschaft; auf der anderen Seite die strategische In-Wert-Setzen der spezifischen Charakteristika, um den unterschiedlichen Ansprüchen gerecht zu werden und den globalen Herausforderungen entgegenzutreten.

Anpassung an Marktlogiken

Obwohl die Liberalisierung in Deutschland schon weiter fortgeschritten ist als in der Schweiz, nannten die Interviewten in beiden Ländern, jüngste Strategieüberarbeitungsprozesse und anschliessende **organisationale und kulturelle Wandlungsprozesse** in den grossen Stadtwerken als Haupthandlungsweisen im Kontext der Liberalisierung. Sie erwähnten das Etablieren und Institutionalisieren von **Innovationsprozessmanagement**, das Aufbauen einer Innovationskultur, das Integrieren **neuer Profile und Kompetenzen** sowie **neuer Management- und Arbeitsformen** [„wir haben dann ganz einfach Task-Forces über mehrere Disziplinen hinweg gebildet. Kleine Gruppen von sechs Leuten, die projektweise an einem Thema arbeiteten" DE9; „Neulich hat mir eine Mitarbeiterin eines grossen Stadtwerks erzählt, dass sie keine Visitenkarten mehr hat, da sie nicht jedes Jahr neue bestellen möchte. Sie wartet noch, bis sie weiss, in welcher Abteilung des Unternehmens sie dann angesiedelt sein wird" DE16; „Produktdesign wird schneller, es gibt Innovationszyklen und Betaversionen die „on the go" verbessert werden" CH3]. Themen wie die Steigerung der Kundenorientierung, der **Kosteneffizienz** aber auch das **Suchen nach neuen Geschäftsmodellen** – näher oder ferner dem eigenen Kerngeschäft – neue Produkte in Vertrieb und Dienstleistungen sowie das **Investment in erneuerbare Energieproduktion** jenseits ihres klassischen Verteilnetzgebietes, wurden in fast jedem Interview in beiden Ländern erwähnt

[„die Kostenreduktion und das Suchen nach neuen business models sind die beiden Hauptthemen die wir haben“ DE2; „sie investieren stark in Erneuerbare jenseits ihres Stadtgebiets, z.B. Windparks in der Nordsee DE12; „die versuchen alle mehr Vertrieb und neue Produkte aufzubauen, aber es gibt bisher kein grosses Stadtwerk was ein völlig neues Geschäftsmodell hat“ DE17]

Um die gesteckten Ziele zu erreichen kaufen die grossen Stadtwerke – ähnlich wie die grossen Energiekonzerne – IT oder Ingenieursfirmen, um das nötige Wissen zu inkorporieren. Darüber hinaus **Kooperieren** sie aber auch mit etablierten und neu auftretenden Akteuren aus anderen Industrien (z.B. IT, Telekommunikation, Automobilhersteller), besonders für die Entwicklung neuer Geschäftsmodelle. [„nach dem Motto if you can’t beat them, join them“ DE14; „strategische Allianzen in Produktion, Netzbetrieb, IT und Energiedienstleistungen ... und nicht nur horizontale, sondern auch Kooperationen mit privatwirtschaftlichen Akteuren“ DE15; „diese Kooperation hat es allen Beteiligten erlaubt zu lernen und Investitionskosten zu reduzieren“ CH8]. In Deutschland wurde zudem die Kooperation mit anderen Stadtwerken aus anderen Städten (**inter-city cooperation**) aber auch mit den Schwesterfirmen in der eignen Stadt betont (**intra-city cooperation**). [“Wir wollen Erlebniswelten für den Kunden kreieren – add-ons zum traditionellen Produkt, plus-Angebote basieren auf Digitalisierung und dafür kooperieren wir mit unseren Schwesterfirmen“ DE10].

In-Wert-Setzen der Besonderheiten

Neben der Übernahme von privatwirtschaftlichen Strategien um auf die globalen Herausforderungen zu reagieren, nutzen die grossen Stadtwerke in beiden Ländern auch ihre besonderen Charakteristika Netzwerkbetreiber, Querverbunds- und multi-energy Unternehmen zu sein. Auf der einen Seite **stärken sie ihre Monopolposition** in ihren unterschiedlichen Geschäftsfeldern, indem sie in Netzkonzessionen investieren oder neue Netzinfrastrukturen aufbauen, wie z.B. das Breitbandnetz oder Fernwärmenetze [„die machen alle Breitband, das ist Infrastruktur, das ist nah an ihrem Kerngeschäft“ DE12; die neuen Geschäftsfelder sind Telekommunikation und Wärme – deswegen investieren sie in den Breitbandausbau und Fernwärmenetze, denn sie denken, dass sie in Elektrizität und Gas ihren Profit verlieren werden“ CH17]. Auf der anderen Seite nutzen die grossen Stadtwerke in beiden Ländern ihre multi-energy Position und **investieren auch in die Netzkonvergenz**, z.B. mit der Installation von Kraft-Wärme-Kopplungsanlagen in Fernwärmenetzen oder Power-to-X Pilot-Lösungen, für die sie ihr Gasnetz nutzen. Basieren auf diesen Investitionen, offerieren vor allem die grossen Stadtwerke in Deutschland **neue Paketprodukte** im Vertrieb oder bieten **Technologiemanagement-Pakete** für Prosumer, grosse Gebäudekomplexe und Firmen sowie für ganze Stadtquartiere an. [„Es sollte ein modulares Produktdesign geben, Pakete wo der Kunde Teile hinzufügen und entfernen kann – zum Beispiel für Industriegebäude würden wir Sicherheitsleistungen zukaufen in das Paket, aber so viel wie möglich der Paketleistungen würden wir selbst anbieten, um das meiste für uns herauszubekommen. Und bevor Amazon anfängt Energie zu verkaufen, wollen wir Services verkaufen“ DE10]. Die Bündelung ihrer assets und Kompetenzen erscheint als die Kernstrategie.

Darauf aufbauend untersuchen die grossen Stadtwerke in beiden Ländern in Kooperation mit ihren „Schwesterfirmen“ auch Möglichkeiten für die **Sektorkopplung** zu Telekommunikation und öffentlichem Verkehr. So versuchen sie nicht nur ihre Produktpalette zu diversifizieren und den Profit für die Stadt zu erwirtschaften, sondern mit dieser Diversifikation versuchen sie auch ihre Systemmanagementfunktion und damit ihre Performance in der Daseinsvorsorge zu optimieren. [„Sektorkopplung ist eine Chance, wir haben alle Netze und können sie zusammengenommen optimieren“ DE10].

Schliesslich nutzen die grossen Stadtwerke in beiden Ländern auch ihre besondere Position als lokal eingebettete und vernetzte öffentliche Unternehmen und **nutzen ihre öffentlichen Vertreter zur Repräsentation ihrer Interessen**. Zusätzlich sind alle grossen Stadtwerke auch Teil von **Branchenverbänden** durch die sie ihre Interessen vertreten lassen und **lobbyieren parallel dazu auf nationaler und europäischer Ebene** auch bilateral. Interessanterweise erwähnten lediglich die in der Schweiz Interviewten explizit die Zusammenarbeit mit lokalen Politikern „das Stadtparlament und die Bürger sind ihre täglichen und ersten Partner, auf die sie immer als erstes abzielen" CH4; „wir haben unterschiedliche politische Ebenen aber auf der lokalen Ebene haben wir eine Starke Beziehung zur Stadtverwaltung" CH11]. In beiden Ländern war dagegen das **stakeholder-involvement** und die damit verbundene enge Zusammenarbeit mit „ihren Bürgern" ein wichtiges Thema. So stärken sie ihre Kundenbeziehung und verbessern ihr Innovationsmanagement um auf den wachsenden Konkurrenzdruck zu reagieren. [„wir kooperieren mit unseren Kunden und machen Design Thinking Workshops um Pilotprodukte zu entwickeln, Dinge auszuprobieren, zu experimentieren und schneller zu werden" CH3].

Generell gesprochen, sehen sich die grossen Stadtwerke in beiden Ländern ähnlichen Herausforderungen gegenüber und entgegen diesen – trotz einiger Unterschiede im Detail - auch mit ähnlichen strategischen Antworten. Dennoch wurden Interviews Unterschiede bezüglich **der grossen strategischen Linien** deutlich: die grossen Stadtwerke in Deutschland fokussieren sich aktiv auf **Wachstumsstrategien** und pushen die weitere **Umsetzung der Energiewende** [„sodass wir wachsen können. Wir müssen jenseits unsere Stadtgebietes schauen um Geschäfte zu machen" DE9]. Gleichzeitig betonten sie aber auch ihre **Re-Orientierung hin zur Kommune und der lokalen Ebene** um eine Netzwerker-Rolle in ihrem traditionellen Gebiet wahrzunehmen [„nach wie vor mit der Stadt und den kommunalen Strukturen in einer guten Weise kooperieren um uns als Infrastrukturversorger im kommunalen Umfeld zu präsentieren und sichtbar zu bleiben" DE11]. Grosse Stadtwerke in der Schweiz investieren dagegen mehr darin **schneller und flexibler zu werden** und engagierten sich noch mehr für **inhouse-Umsetzungen** [„Agilität zu etablieren, Wandel zu erlauben und dabei die Traditionen respektieren, Verlässlichkeit und Langfristorientierung wahren, was ein asset im digitalen Zeitalter sein kann" CH11; „so viel Marktverantwortung wie möglich zu erlangen, das führt auch zu mehr Agilität" CH18]. Zusätzlich betonten ein paar der Schweizer Interviewte auch, dass die grossen Stadtwerke hinsichtlich der Energiewende **doppelseitige Strategien** fahren – pro und contra. [„Von der Zivilgesellschaft werden sie als starke Akteure der Energiewende gesehen, aber gleichzeitig müssen sie ihre Geschäfte machen und ihre Profite in Zukunft sichern, daher gibt es zwei Köpfe in den Unternehmen" CH19].

5 Diskussion der Untersuchungsdimensionen

Die empirische Untersuchung der Charakteristika, Herausforderungen und strategischen Antworten grosser Stadtwerke in der Energiewende Deutschlands und der Schweiz impliziert zwei Ergebnisse für die theoretische Diskussion zur Konzeptualisierung der Stadtwerke.

Einerseits **bestätigen** sie **die eingangs theoretisch erarbeiteten Untersuchungsdimensionen**. Die durch die Liberalisierung verursachte Korporatisierung und der entsprechende organisatorische und kulturelle Wandel ist in den grossen Stadtwerken bis heute ein wichtiges Thema. Die an die öffentliche Eigentümerschaft gekoppelte Widersprüchlichkeit zwischen öffentlichen und privatwirtschaftlichen Zielen und Rollen der Eigentümerin zeigt sich in der empirischen Realität sogar noch komplexer, da der Wandel des politischen Interesses hin zur Energiewende als widersprüchlich zu den für die Liberalisierung geschaffenen Regeln wahrgenommen wird. Dies spiegelt auch die in den Netzwerkindustrien diskutierte Schwierigkeit der Diskrepanz zwischen regulatorischem Rahmen und technologischem Wandel wieder. Stadtwerke sind als Netzwerkbetreiber auf den regulatorischen Rahmen angewiesen, der jedoch vielfach (noch) nicht an den momentan schnell voranschreitenden Technologiewandel angepasst ist.

Andererseits **zeigen die empirischen Ergebnisse** auch noch **weitere Untersuchungsdimensionen** auf, die in der eingangs herangezogenen Literatur nicht explizit erwähnt wurden.

Multiple politische Ebenen in föderalen Staaten – kommunal bis europäisch

Der *Public Corporate Governance* Ansatz unterschiedet nicht explizit nach unterschiedlichen politischen Ebenen, auf denen die öffentlichen Unternehmen verankert sind, dennoch stellt die „politische Ebene“ eine wichtige Untersuchungsdimension und ein distinktes Unterscheidungsmerkmal von Stadtwerken zu anderen öffentlichen Unternehmen, wie z.B. den Staatseigenen Betrieben (Post, Bahn) dar. Diese sind auf Bundesebene angesiedelt, haben daher ein nationales Versorgungsgebiet und interagieren vorwiegend auf bundespolitischer Ebene. Grosse Stadtwerke sind hingegen auf städtischer und damit kommunaler Ebene angesiedelt. Die städtischen Interessen sind daher oftmals direkt in ihrer Eigentümerstrategie eingeschrieben, ihre Einnahmen fliessen direkt in den Stadthaushalt um anderen, defizitären Daseinsvorsorgeverpflichtungen zu finanzieren und sie sind darüber hinaus auch mit politischen Interessen der anderen föderalen Ebenen (bis hin zur EU) konfrontiert. Ihre Einbettung in den Städtischen Kontext und die finanzielle Abhängigkeit von der Stadt stellen eine distinkte Besonderheit der Stadtwerke dar, die bei Staatseigenen Betrieben in dieser direkten Ausprägung nicht thematisiert wird.

Wertschöpfungstiefe und -breite der Stadtwerke - multi- utility und multi-energy

Im Gegensatz zu den Staatseignen Betrieben auf nationaler Ebene, die traditionell auf einen Sektor fokussiert waren und im Kontext der Nationalstaatenbildung auf nationale Ebene gehoben wurden, haben sich die Stadtwerke im Zuge der aufkommenden Urbanisierung herausgebildet und wurden „verstaatlicht“ um die Versorgung der Städte mit grundlegenden Infrastrukturen zu garantieren. Im Zuge der Korporatisierung wurden die verschiedenen Infrastrukturdienstleistungen in Querverbundsunternehmen mit einer hohen Wertschöpfungsbreite organisiert (multi-utility). Im Energiebereich ist dabei besonders, dass die grossen Stadtwerke traditionell mehrere Energieformen zur Strom und Wärmeproduktion in einem Unternehmen abdecken – wohingegen die grossen Konzerne traditionell reine Stromproduzenten waren. Arbeiten der *Network Industries* nehmen auf diese besondere Eigenschaft der Stadtwerke Netzwerke in unterschiedlichen Sektoren und Energieformen zu betrieben jedoch bisher keine explizite Rücksicht.

Die eingangs aufgeführten Untersuchungsdimensionen werden daher auf Basis der empirischen Untersuchung daher wie folgt angepasst:

Tabelle 3: überarbeitete Untersuchungsdimensionen für grosse Stadtwerke (eigene Darstellung)

Untersuchungsdimension	**Quelle**
Prozessuale Dimensionen	
Liberalisierung und Korporatisierung in der Energieversorgung	*Public Corporate Governance / Network Industries* (Schedler et al. 2011; Finger und Künneke 2011)
Kulturwandel von Verwaltung und Ingenieurswissen hin zu mehr Unternehmertum	*Public Entrepreneurship* (Bernier und Hafsi 2007; Greiling et al. 2013)
Spannungsfeld zwischen öffentlichem Interesse und Marktfähigkeit der öffentlichen Unternehmen	*Public Corporate Governance* (Schedler et al. 2011; Schedler und Finger 2008)

Strukturelle Dimensionen	
Die multidimensionale Rolle(n) der öffentlichen Hand gegenüber dem öffentlichen Unternehmen	*Public Corporate Governance, State-owned Enterprises* (Schedler et al. 2011; Schedler und Finger 2008; Victor et al. 2012)
Infrastrukturnetzwerke, natürliches Monopol und Re-Regulierung	*Network Industries* (Finger und Jaag 2015; Finger und Varone 2006a; Crettenand und Finger 2013)
Multiple politische Ebenen in föderalen Staaten – kommunal bis europäisch	*Empirische Untersuchung*
Wertschöpfungstiefe und -breite der Stadtwerke – multi- utility und multi-energy	*Empirische Untersuchung*

Zusammenfassend kann festgehalten werden, dass die grossen Stadtwerke durch eine Integration der theoretischen Konzepte der Forschung zu öffentlichen Unternehmen und Netzwerkindustrien konzeptualisiert und untersucht werden können. Dennoch hat sich gezeigt, dass die Stadtwerke über durch besondere Charakteristika gekennzeichnet sind, die in beiden Forschungssträngen bisher keine explizite Berücksichtigung finden. Hier ergibt sich daher spannender weiterer Forschungsbereich, um diesen, im föderalen Staatskonzept besonderen, Akteurstypos näher zu untersuchen.

Einschränkend muss bei diesem explorativen Ansatz festgehalten werden, dass die Aussagen der interviewten Experten an ihren zeitlichen Kontext (Sommer 2017, bzw. für die Workshops Sommer 2018) gebunden sind. Da sich der Energiesektor der Schweiz und Deutschlands aktuell in grossen Schritten wandelt, würden die Befragten möglicherweise gewisse Aspekte bereits anders einschätzen. Und auch wenn versucht wurde mit der Wahl und Anzahl der Interviewten und den zusätzlichen Workshops eine möglichst breite Wissenbasis zu generieren, so handelt es sich bei den Aussagen der Experten um persönliche Einschätzungen, die zwar eine intersubjektive Realität darstellen, jedoch keine Objektivität für sich beanspruchen können.

Auch hinsichtlich der Analyse ergeben sich Einschränkungen: Zum einen basieren die hier präsentierten Ergebnisse auf der subjektiven Analyse und Interpretation der Autorin, sodass die Ergebnisse an ihr Vorwissen und ihre Analysekompetenzen gebunden sind. Zum anderen kann der iterative Untersuchungsprozess aus empirischer und theoretischer Analyse, der diesem Beitrag zugrunde liegt, gewisse Biases verursachen. Um dieser Schwierigkeit qualitativer Forschungsarbeit zu entgegnen, wurde einerseits versucht, die Antworten der Interviewten so neutral wie möglich zu analysieren und diese andererseits durch die Erkenntnisse aus den Expertenworkshops (zumindest für die Schweiz) zu komplementieren, um so ein möglichst vollständiges Bild zu generieren.

6 Abschliessende Überlegungen: Die Rolle der Stadtwerke in der Energiewende?

Abschliessend soll die eingangs aufgeworfene Frage nach der Rolle der grossen Stadtwerke in der Energiewende Deutschlands und der Schweiz wieder aufgenommen werden. Die anschliessenden Überlegungen haben dazu zwei Ebenen, zum einen die Reflektion der sich im Kontext der Energiewende ändernden Rolle der Stadtwerke für das Energiesystem, technologisch aber auch sozioökonomisch; zum anderen die Reflektion über den Beitrag, den die grossen Stadtwerke zum Fortschritt der Energiewende leisten, ebenfalls technologisch und sozioökonomisch.

Die Rolle, bzw. die Erwartungen an die Rolle der grossen Stadtwerke für das Energiesystem haben sich im Kontext der Energiewende geändert. Neben ihrer Funktion für die technologische Stabilität der Netze und der Stabilität und Qualität des Service Public in den Netzen, wird von ihnen auch der Zu-und Umbau dieser Netze erwartet, die ein erneuerbares Energiesystem unterstützen soll. In diesem Kontext übernehmen sie auch stärker die Rolle der Sektorkopplung und Netzkonvergenz, die ihnen auf Basis ihrer multi-energy und multi-utility Charakteristika sowie ihrer Eigentümerschaft der Netze «fast natürlich» zufällt. Die Kopplung der Sektoren Strom und Wärme aber auch Strom und Mobilität sowie Telekommunikation sind für die Umsetzung einer ganzheitlichen Energiewende, die auch die Wärme- und Mobilitätswende umfasst, von zentraler Bedeutung. Ebenso, wie die Netzkonvergenz zwischen Strom-, Gas- und Telekommunikationsnetzen, die eine lokale, digitalisierte und smarte Steuerung vermehrt dezentralisierter Energiesysteme ermöglicht.

Ihre Funktion als lokaler Systemmanager wurde im Laufe der Transition zudem deutlich erweitert: Stadtwerke sollen im Kontext des enormen Zubaus dezentraler Kapazitäten nicht mehr nur ihre eigenen Anlagen managen, sondern auch die ihrer Kunden oder anderer lokaler Produzenten. In Zukunft werden sie daher noch stärker in ihrer Rolle als lokaler Netzwerker gefragt sein. Dies betrifft dabei nicht nur die erwähnte technologische Integration, sondern auch das Etablieren von Kooperationen bzw. das Entwickeln von neuen Service Produkten für Prosumer um nach wie vor den nötigen Ertrag für ihre Eigentümerin zu erwirtschaften.

Weiterhin wird von den Stadtwerken im Kontext der Energiewende auch explizit erwartet, dass sie die städtische Infrastruktur der Digitalisierung anpassen und «smart» machen sowie weitere Produktionskapazitäten auf Basis erneuerbarer Energien zubauen, um die «Energiewende» vor Ort umzusetzen. Das Übersetzen solcher politischen Ziele in technologische Lösungen, sowie ihre ganz grundlegende Funktion «des Ermöglichers urbanen Lebens» haben sich daher nicht verändert, sie ist im Kontext der Energiewende nur vielschichtiger geworden.

Im Kontext der Expertenworkshops wurde die zentrale Bedeutung der Stadtwerke für die Energiewende einhellig bestätigt und vor allem ihre Rolle als lokaler «Vernetzer» sowie ihre zentrale Funktion für die «Wärmewende» besonders betont. Es wurde darüber hinaus jedoch auch kritisch angemerkt, dass die Stadtwerke nicht unabhängig von der nationalen und internationalen Regulierung des Sektors sowie der Rollen und dem Verhalten anderer wichtiger Akteure des Sektors gesehen werden können. Über die zukünftigen Rollen und möglichen Beiträge der grossen Stadtwerke zur Energiewende entscheidet daher massgeblich auch die Politikgestaltung auf lokaler, nationaler wie europäischer Ebene. Im Schweizer Kontext wurde dabei besonders die Schwierigkeit hervorgehoben, wie das subsidiäre bottom-up Prinzip des Energiesektors und die direkte demokratische Kontrolle über die lokale Energieinfrastruktur – die sich in der Organisation Stadtwerke kristallisieren - im Kontext der europäischen Integration weiter aufrechterhalten und z.B. mit liberalisierten Märkten in Einklang gebracht werden kann. Bezüglich dieser grundlegenden Fragen ergäbe sich sicherlich ein enormes Lernpotenzial zwischen föderalistisch organisierten Staaten wie Deutschland, der Schweiz, Österreich, den skandinavischen Ländern aber auch den USA.

Zusammenfassend kann festgehalten werden, die Stadtwerke spielen auf lokaler und (inter)nationaler Ebene eine wichtige Rolle für den Fortschritt der Energiewende. Wie eingangs erwähnt, sind sie dabei jedoch weder Hinderer noch Innovator, aber auch kein passiver Intermediär. Auf Basis der hier vorgestellten empirischen Ergebnisse zeigt sich, dass sie mehrere Rollen für die erfolgreiche Umsetzung der Energiewende übernehmen: zum einen können sie als «Ingenieure der Energiewende» gesehen werden. Politisch vorgegebene Ziele setzen sie in lokal stadtspezifische technologische Lösungen um, koppeln Netze und Sektoren, ermöglichen Innovatoren Pilotprojekte auf grösserer Ebene umzusetzen und liefern somit wertvolle Beispiele, die dem nationalen Projekt Energiewende dienlich sind. Andererseits sind sie aber auch die «Sozialarbeiter» der Energiewende, da sie für all jene Bevölkerungsschichten in erneuerbare Energien in grossem Stile investieren, die selbst keine Investitionen tätigen können und Energieeffizienzmassnahmen für alle Bürger der Stadt anbieten. In diesem Kontext leisten sie aber auch klar einen positiven Beitrag auf nationaler Ebene, da sie national und international in neue Erzeugungsanlagen aus erneuerbaren Energieanlagen investieren und den Zubau der Erneuerbaren unterstützen. Es bleibt jedoch kritisch zu hinterfragen, wie die Stadtwerke ihr lokales und internationales Engagement in der Energiewende in Zukunft ausbalancieren, denn z.B. das Investment kommunaler Gelder in Windkraftanlagen in Skandinavien wird nicht nur befürwortet.

Abschliessend kann zusammengefasst werden, obwohl die grossen Stadtwerke nicht die «first mover» der Energiewende sind, können sie doch als «intelligent followers» [DE16] gesehen werden, die sich aufgrund ihrer politisch oft vorwärtsgewandten Eigentümerin, eindeutig für die Energiewende engagieren. Darüber hinaus – und das ist vielleicht die wichtigste Funktion der Stadtwerke in diesem Kontext - stellen sie aber vor allem weiterhin die technologische und sozioökonomische Funktionsfähigkeit der städtischen Infrastrukturen sicher und leisten damit den entschiedensten Beitrag in der Absicherung des Systemumbaus bei laufendem Betrieb. Diese Funktion für die Resilienz des sich im Wandel befindlichen Energiesystems, wird im Verlauf dieser Studie noch weiter untersucht werden.

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Anhang

Tabelle A.1 Liste der Interviewpartner (anonymisiert)

Kurzzeichen des Tran-skripts	Branche des Interviewten	Position des Interview-ten	Interview-Situ-ation	Datum des Interviews	Dauer des Interviews
Schweiz					
CH1	Forschung	Professor	persönlich	02.03.17	01:00
CH2	Verband / Verein	EA St. Gallen	persönlich	09.03.17	01:16
CH3	Forschung	Doktorandin	persönlich	09.03.17	01:13
CH4	Forschung	Professor	persönlich	09.03.17	00:54
CH5	Forschungsinstitution/Stif-tung	Geschäftsführer	persönlich	10.03.17	01:05
CH6	Verband / Verein	Bereichsleiter	persönlich	10.03.17	01:08
CH7	Beratung	Geschäftsführer	persönlich	10.03.17	01:26
CH8	Großes Stadtwerk	Strategieabteilung	persönlich	17.03.17	02:36
CH9	Verband / Verein	Leiter	persönlich	20.03.17	00:39
CH10	Projektierungsfirma	Leitender Angestellter	persönlich	20.03.17	01:38
CH11	Großes Stadtwerk	Strategieabteilung	persönlich	20.03.17	00:55
CH12	Forschungsinstitution /Stif-tung	Geschäftsführer	persönlich	23.03.17	01:12
CH13	Verwaltung Bundesebene	Gruppenleiter	persönlich	24.03.17	01:13
CH14	Mittleres Stadtwerk	CEO	persönlich	27.03.17	01:08
CH15	Mittleres Stadtwerk	Mitglied Geschäftslei-tung	persönlich	31.03.17	00:49
CH16	Großes Stadtwerk	CEO	persönlich	04.04.17	01:16
CH17	Mittleres Stadtwerk	CEO	persönlich	07.04.17	01:52
CH18	Großes Stadtwerk	CEO	Telefon	19.04.17	00:18
CH19	Beratung	Leitender Angestellter	skype	19.05.17	00:53
CH20	Verband / Verein	Leiter	persönlich	21.05.17	01:07
Deutschland					
DE1	Beratung	Selbstständiger	persönlich	02.05.17	01:22
DE2	Beratung	Leitender Angestellter	Telefone	02.05.17	00:51
DE3	Forschung	Professor	skype	02.05.17	01:25
DE4	Forschung	Post-Doc	persönlich	05.05.17	01:01
DE5	Verband / Verein	Bereichsleiter	persönlich	05.05.17	01:30
DE6	Beratung	Geschäftsführer	persönlich	19.05.17	00:57
DE7	Großes Stadtwerk	CEO	persönlich	07.06.17	00:50
DE8	Forschung	2 Post-docs	persönlich	08.06.17	01:51
DE9	Großes Stadtwerk	Strategieabteilung	persönlich	08.06.17	00:56
DE10	Großes Stadtwerk	2 Mitarbeiter der Stra-tegieabteilung	persönlich	12.06.17	01:02
DE11	Beratung	Geschäftsführer	persönlich	13.06.17	00:50
DE12	Beratung	Leitender Angestellter	persönlich	14.06.17	01:52
DE13	IT Dienstleister	CEO	persönlich	15.06.17	00:53
DE14	Forschung	Professor	persönlich	16.06.17	01:03
DE15	Verband / Verein	Leiter	persönlich	16.06.17	01:20
DE16	Verband / Verein	Leiter	persönlich	16.06.17	01:06
DE17	Dienstleister	CEO	persönlich	07.07.17	00:51
DE18	Mittleres Stadtwerk	CEO	Telefon	10.07.17	00:50

Tabelle A.2: Strukturdaten der untersuchten grossen Stadtwerke in Deutschland und der Schweiz
(Quelle: Geschäftsberichte der Firmen, Geschäftsjahr jeweils in der Tabelle vermerkt)

Stadtwerk	Jährlicher Umsatz	Gründungsjahr	Eigentümerstruktur	Organisationelle Form	Geschäftsbereiche
Stadtwerke München SWM (DE)	6675 Mio. Euro (ohne ÖPNV und Schwimmbäder) (2017)	1899 Städtische Elektrizitäts- und Gaswerke, 1939 Stadtwerke München, 1998 Korporatisierung.	100% Stadt München	GmbH	Strom, Gas, Fernwärme, Dienstleistungen (sowie Wasser, Telekommunikation, ÖPNV)
Rheinenergie AG und Rheinenergie group (incl. Handel) (DE)	3647 Mio. Euro (2016)	1873 Gas- und Wasserwerke Stadt Köln, 1960 Korporatisierung, 2002 Rheinenergie AG	80% Stadt Köln, 20 % Innogy	AG	Strom, Gas, Fernwärme, Dienstleistungen (sowie Wasser)
Enercity AG (DE)	2101 Mio. Euro (2017)	1922 Städtische Betriebswerke, 1970 Korporatisierung, 1996 enercity AG	75 % Stadt Hannover, 24 % Thüga, 1 % Region Hannover	AG	Strom, Gas, Fernwärme, Dienstleistungen (sowie Wasser)
Services Industriels de Genève SIG (CH)	1065 Mio CHF (2017)	1896 als kommunale Firma der Stadt Genf, 1931 öffentliche Firma der Stadt, des Kantons und der anderen Gemeinden des Kantons.	55 % Kanton Genf, 30% Stadt Genf, 15% Gemeinden des Kantons	Unabhängige öffentliche Firma	Strom, Gas, Fernwärme, Dienstleistungen (sowie Wasser, Abfallwirtschaft, Telekommunikation)
Elektrizitätswerke Zürich EWZ (CH)	0.859 Mio. CHF (2016)	1890 als Department der Stadtverwaltung	100 % Stadt Zürich	Teil der Stadtverwaltung	Strom, Dienstleistungen (sowie Wasser, Telekommunikation)
Industrielle Betriebe Basel IWB (CH)	0.727 Mio CHF (2016)	1868 Munizipalisierung der Gasversorgung, 1899 Gründung der Stromversorgung, 1908 Trennung von Strom- und Gas- sowie Wasserversorgung, 1978 Wiedervereinigung in IWB,	100% Stadt Basel	Unabhängige öffentliche Firma	Strom, Gas, Fernwärme, Dienstleistungen (sowie Wasser, Telekommunikation)

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Doctoral candidate's contribution

The doctoral candidate is the only and main author of the publication. Theoretical conceptualisation, empirical analysis and writing of the publication was done by the doctoral candidate.

Manuscript

Title:

Dinosaurs in transition? A conceptual exploration of local incumbents in the Swiss and German energy transition.

Abstract

Incumbents' behaviour in sustainability transitions in the energy sector is gaining increasing scholarly attention. However, key characteristics of many incumbents in the energy sector are hardly taken into account: they are, for example, mostly public companies operating in infrastructure network industries. Furthermore, studies on incumbents in the energy sector do not consider the multi-scalar situation of federal energy governance systems, as in Germany and Switzerland. This paper presents six analytical categories, revealing the specifics of public energy companies and providing the basis for a more precise analysis. They are developed through an iterative theory building process, combining empirical evidence from German and Swiss urban utility companies and theoretical insights from *public corporate governance* and *network industries* literature. Finally, the paper discusses the linkage of these categories to the triple embeddedness framework (Geels, 2014) and their transferability to other infrastructure sectors, to enrich the understanding of public incumbents in sustainability transitions.

Keywords

Incumbents, triple embeddedness framework, public corporate governance, network industries, energy transition, urban utility companies, Germany, Switzerland

1 Introduction

Energy supply systems need to remain functional while undergoing fundamental changes like the European integration, liberalisation, decarbonisation, denuclearisation and digitalisation. Balancing the grids, compensating for overproduction and shortages on a large scale, maintaining the critical infrastructures but also deconstructing old infrastructures are only a few examples of what needs to be done "behind the scenes" of the ongoing sustainability transition in European energy systems. However, who are the players behind these traditional tasks, what shapes their behaviour in the context of the transition and finally, what is their role for the large-scale success of the energy transition. These are the research interests lying at the core of this paper, which consequently focuses on the investigation of incumbent's behaviour in the energy transition.

The analysis and understanding of incumbents' behaviour in sustainability transitions in the energy sector is gaining more and more attention (van Mossel et al. 2018). Various scholarly contributions are aiming at a more nuanced picture of incumbents' behaviour in the context of sustainability transitions, to overcome the - in transition studies widely established - dichotomy of positive challengers and negative incumbents (Kishna, 2015; Smink, 2015; Smink, Hekkert, & Negro, 2015; Wesseling, 2015). Van Mossel et al. (2018) provide a very valuable overview on current endeavours and contributions to enhance the understanding of incumbent behaviour in the context of transition studies. Among them, contributions which are related to the energy sector and which question the role of incumbents in the energy transition context represent an increasing share (Heiskanen, Apajalahti, Matschoss, & Lovio, 2018; Kungl, 2015; Kungl & Geels, 2017; Lauber & Sarasini, 2014; Leitzinger, 2015; Ngar-yin Mah, Wu, & Ronald Hills, 2017; Nijland, 2013; Sridhar, 2010; Wassermann, Reeg, & Nienhaus, 2015; Weigelt & Shittu, 2013).

Hitherto, the empirical work on incumbents' behaviour in energy transitions was mainly focussed on large energy utility companies, often acting on a national scale (e.g. EON and RWE, see e.g. (Lauber

& Sarasini, 2014; Ratinen & Lund, 2014), (Kungl, 2015; Kungl & Geels, 2018). In federal energy governance systems like Germany, Austria or Switzerland, however, incumbents are also located on the Länder / cantonal and the municipal level. The so called "Regionalversorger" (energy utility companies on the Länder level in Germany) or "Kantonswerke" (energy utility companies on the cantonal level in Switzerland) as well as the "Stadtwerke" and the "Gemeindewerke" (public service companies on the municipal level in both countries) play an important role for federal energy governance systems and thus for the long term success of the energy transition in these countries (Berlo & Wagner, 2011a, 2011b; Finus, 2012; Gochermann, 2016). The analysis of incumbents on the regional and local scale, consequently builds a fundamental component for the understanding of the energy transition in federal energy governance systems.

Furthermore, they share two main characteristics with most of the large national incumbents: they are public companies owned either by the Länder / cantons or by the cities / municipalities, and they are not only energy suppliers and energy producers but also network operators. And even if the European liberalisation obliged utility companies to separate the network business (unbundling), they still operate at the same time in a market-based regime (production / supply) as well as a monopoly regime (networks) (Brunekreeft, Buchmann, & Meyer, 2015). These key characteristics are hardly considered in scholarly work in incumbents in the energy sector, however, they allow for a more nuanced and increased understanding of incumbents' behaviour in the sustainability transitions of the energy sector. Among the mentioned regional and local incumbents in federal energy governance systems, this paper focuses on the analysis of large "Stadtwerke" – for the remainder of this paper, called urban utility companies (UUC). UUC represent an interesting and insightful mixture of being both at the same time, a large energy utility company with an international radius of action and high system relevance as well as a municipal firm with a strong local embeddedness. They combine characteristics of small and local, but also large and international public energy utility companies. Their analysis can thus facilitate the general understanding and theory building on public incumbents of different sizes and multiple scales in federal energy governance systems.

1.1 Conceptual framework

In transitions literature, the *triple embeddedness framework* (TEF), developed by Bruno Turnheim and Frank Geels (Geels, 2014; Turnheim & Geels, 2013) represents a comprehensive and well elaborated framework to analyse incumbents´ behaviour embedded in and interacting with its regulators and systemic context in sustainability transitions. It provides a concise structure for empirical analysis and offers a set of theoretical considerations based on which influence factors on the incumbent's behaviour as well as their strategic responses to them can be explained. Especially, it combines two major concepts of the *firm's environment* in organisational studies: "Some organization theories conceptualize the environment as institutional (Scott, 2001), others as groups of actors (Pfeffer & Salancik, 2003)" (van Mossel et al. 2018, p. 47). In the TEF, firms are embedded in both, an actor-network as well as a set of formal and informal rules, respectively institutions which influence their behaviour. Therefore, this paper employs the TEF as the underlying analytical framework for the study of urban utility companies (UUC).

However, the TEF has been designed as a framework of general validity and was thus not explicitly developed for the analysis of public companies operating in infrastructure network sectors like the energy sector. For the particular application of the TEF to urban utility companies, this paper thus proposes to complement the TEF with theoretical considerations from *public corporate governance*

(Frentrup, 2008; Lienhard, 2009; Schedler, Müller, & Sonderegger, 2011) and *network industries* literature (Finger & Jaag, 2015; Finger & Künneke, 2011; Künneke, 2009). In this respect, the paper presents six analytical categories for the study of urban utility companies, conceptualised as public companies in network industries, which can be used complementary to the TEF. It is important to underline that these categories do not aim at expanding or further developing the TEF, they should be considered as complementary and independent concepts for the particular analysis of public incumbents in infrastructure network industries.

1.2 Research aim and questions

By providing six analytical categories based on theoretical considerations from *public corporate governance* and *network industries* literature, this paper contributes to the continual theory building on incumbents in the energy sector, which are mostly publicly owned and operating infrastructure networks. With the link of the analytical categories to the TEF, this paper aims at enriching the scholarly endeavours of drawing a more nuanced pictures of incumbent behaviour in sustainability transitions. Finally, the paper initiates a discussion on parallels of incumbent behaviour in the energy sector and other network-based infrastructure sectors like the railway or the telecommunication sector and thus aims at contributing to comparison between infrastructure network sectors in transition studies.

The paper addresses the following research questions:

- RQ1: Which analytical categories can be derived for incumbents in the energy sector through the analysis and conceptualisation of urban utility companies (UUC) as public companies in network industries?
- RQ2: How can these analytical categories be linked to the triple embeddedness framework (TEF) (Geels 2014) and therewith linked to transition studies in general?
- RQ3: How can the analytical categories enrich the understanding of other incumbents in the energy sector and other network based infrastructure sectors?

The paper is structured as follows: Section 2 elucidates the characteristics of urban utility companies (UUC) in Germany and Switzerland and presents the concrete examples of six UUC in both countries as well as the different national contexts in which they are embedded. Section 3 explains the research design and the methodology of an iterative theory building process – combining theoretical considerations and empirical evidence - through which the analytical categories were developed. Section 4 first explains the TEF framework and subsequently presents the actual categories as well as their theoretical backgrounds in *public corporate governance* and *network industries literature*. Finally, the paper results in discussing the link back of the categories to the TEF as well as their explanatory value for other incumbents in the energy sector as well as other network based infrastructure sectors (Section 4).

2 Empirical evidence

This paper is based on the empirical analysis of urban utility companies (UUC) in Germany and Switzerland. Switzerland and Germany where selected as sources of empirical evidence because of their very similar federal organisation of the energy sector, which is reflected in the long tradition and key role of UUC, managing the municipal and regional level of the energy system. Furthermore, both countries differ regarding their political system, their relation to the European Union and the resource base of their national energy sectors, which enriches the conceptual understanding of UUC.

2.1 Object of research

In Germany as in Switzerland, UUC are mainly owned by cities and are thus public companies, located on the municipal level. Nonetheless, they belong to the biggest players in the national energy sector. Figure 1a-b shows the annual net sales of large German and Swiss energy companies. In both countries, the large producers (like EON, RWE or ALPIQ and axpo) build their own league due to historic structure of the sector. In the "second league" however, the UUC (like SWM Munich or SIG Geneva) have the largest annual net sales and thus a high system relevance, which makes them a particularly interesting object of research.

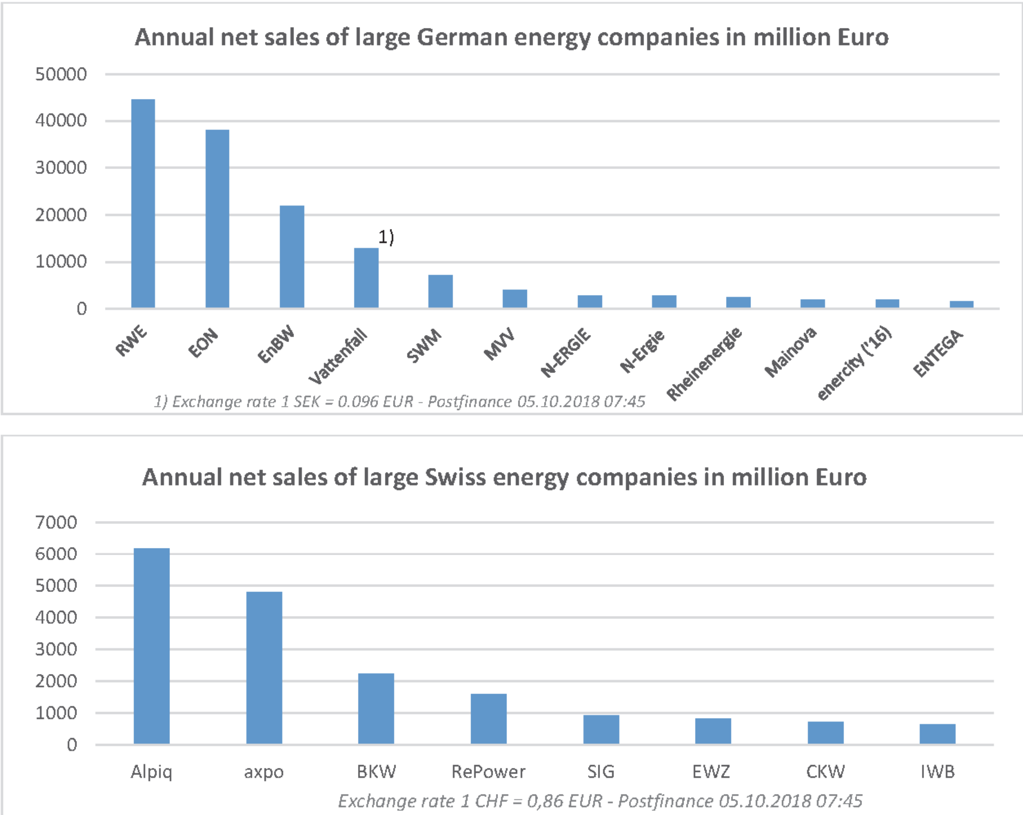

Figure 1a-b: Annual sales of large German and Swiss utility companies (author's own representation, based on annual reports)

The UUC's main task is the operation of all "critical" infrastructure networks of the city (e.g. the electricity grid, gas network, district heating networks, the water, telecommunication and often also the public transport network) (Rentsch, 2017; Schedler, Gulde, & Suter, 2007). Consequently, they are not mere energy suppliers, but are also in charge of other public services for the city (water, waste, public transport etc.) and have a large breadth of value creation. Additionally, they are also not mere grid operators, but they are in charge of the energy production, trade, retail and services to the customers. In their energy division, they operate along the whole energy value chain – in EU countries like Germany with a separate (unbundled) division for the grid operation. Consequently, they act at the same time in market-based competition in the area of production, trade, retail and services, but also in a monopoly and heavily regulated for grid operation.

In comparison to the regional and the cantonal utilities, their value creation is traditionally broader and can also comprise waste, telecommunication and public transport. However, the differences between the UUC might be higher than in comparison to the regional utility companies, since the cities organise their infrastructure management differently (see table 1). In comparison to small municipal utility companies, they are decisively larger and cover the full depth of the energy value chain (also production and trade) for which the municipal utilities often are too small. However, all UUC share the two main characteristics of being a public company and operating critical network infrastructures with all other regional incumbents as the regional, cantonal or municipal utility companies. Hence, they are employed as case study for investigating the particularities of this actor group.

2.2 Empirical examples

The UUC – analysed for this paper – were selected according to the following criteria: their size (the largest UUC in the two countries), their long history (established before World War II) and their ownership structure (min. 75 % ownership of the city, respectively a city canton, where the city area corresponds to the cantonal area) (see Table 1.

Table 1: Overview on selected UUC in Germany and Switzerland (based on the UUC's annual reports and homepages)

UUC	Annual turnover	Foundation year	Ownership structure	Organisational form	Business areas
Stadtwerke München SWM (GER)	6675 million Euro (without public transport and swimming pools) (2017)	1899 Städtische Elektrizitäts- und Gaswerke, 1939 Stadtwerke München, 1998 corporatisation.	100% city of Munich	Limited Company	Electricity, gas, district heating, services (water, telecommunication, public transport)
Rheinenergie AG and Rheinenergie group (including e.g. trade) (GER)	3647 million euro (2016)	1873 Gas- und Wasserwerke Stadt Köln, 1960 corporatisation, 2002 Rheinenergie AG	80% City of Cologne, 20 % Innogy	Listed corporation	Electricity, gas, district heating, services (water)
Enercity AG (GER)	2101 million Euro (2017)	1922 Städtische Betriebswerke, 1970 corporatisation, 1996 enercity AG	75 % city of Hannover, 24 % Thüga, 1 % region of Hannover	Listed corporation	Electricity, gas, district heating, services (water)
Services Industriels de Genève SIG (CH)	1065 million CHF (2017)	1896 as municipal company of the city of Geneva, 1931 public company of the city, the canton and the other municipalities of the canton	55 % canton of Geneva, 30% city of Geneva, 15% municipalities of the Canton	Independent public company	Electricity, gas, district heating, services (water, waste management, telecommunication)
Elektrizitätswerke Zürich EWZ (CH)	0.859 million CHF (2016)	1890 as department of the city administration	100 % City of Zurich	City administration department	Electricity, services, (telecommunication)

Industrielle Betriebe Basel IWB (CH)	0.727 million CHF (2016)	1868 municipalisation of the gas supply, 1899 establishment of the electricity supply, 1908 separation of the electricity supply from water and gas, 1978 re-fusion in IWB,	100% Canton of Basel	Independent public company	Electricity, Gas, district heating, services (water, telecommunication)

2.3 The national context in Germany and Switzerland

UUC in Germany and Switzerland share many characteristics which are mainly related to the federal structure of the national energy sectors, a long tradition of urban self-governance and the concept of public services. The national context in which they are embedded, however, differs in some key domains. While Germany is a full member of the EU and therewith followed the EU energy sector liberalisation directives (market opening, unbundling, international unification of technical standards). Switzerland is not member of the EU and has yet no overarching legal agreement with the EU on the energy sector. Switzerland only partly liberalised its electricity sector (in retail only for key accounts, households are bound to tariffs in territorial monopolies) and unbundling was only implemented on the Transmission Grid Level (establishment of the TSO Swissgrid). The gas sector is not yet liberalised at all. The UUC therefore operate energy production, distribution and retail in the same organisation. Latest with the liberalisation in 1998, in Germany all UUC were transformed in an independent company (many German UUC had been independent already before, see table 1). In Switzerland however, there are still some large UUC operating as department of the city administration (e.g. ewz Zürich and Lausanne), while others are independent public firms (e.g. Geneva or Basel) or listed (private) corporations (e.g. Energie360 Zürich or ewl Lucerne).

Regarding the national energy production mix and the energy production resource base respectively, the two countries also differ decisively. Switzerland has about 60 % share of hydro power, about 30 % share of nuclear power and only minor shares of new renewables in its electricity production. Germany indeed went through an enormous increase of renewable energies, they however represent only a share of 33 % in the national electricity production since 50 % are still produced based on gas, coal or oil and about 12 % on based on nuclear power (Bundesamt für Energie BFE, 2017; Statistisches Bundesamt Destatis). Despite these differences regarding the initial situation, both countries fixed political goals for transitioning their energy sector towards more sustainability, by phasing-out nuclear power, reducing CO2 emissions and setting energy efficiency goals (Bundesamt für Energie BFE; Bundesministerium für Wirtschaft und Energie).

Beyond the diverging national context, however, table 1 and empirical findings from this study published in (Mühlemeier, 2018c, 2018b), showed that the differences among UUC in the same country are higher than differences among German and Swiss UUC. In both countries some utility companies focus more on the investment in renewables abroad (e.g. ewz Zurich or SWM Munich), while others focus more on the local and regional context (e.g. SIG Geneva or enercity Hannover). Regarding the organisational structure, there is the full range in both countries: from fully integrated firms (IWB Basel and SIG) with subsidiaries (SWM) to listed companies, focussing on the energy department – but are still part of the city Holding (Rheinenergie). The only exception is ewz Zurich, which is still part of the city administration. Ewz tried already two times to become an independent firm, however the citizens voted against this corporatisation. In both countries, the establishment of innovation departments as well as a firm culture which promotes innovation and entrepreneurship was mentioned by some firms as current key task. The influence of policy makers on their strategy (via the administrative board) was also perceived differently, however not related to the firm's organisational form.

This short glimpse on the empirical details exemplifies that every UUC is a unique case. Nonetheless, they share many communalities on the meta-level. These communalities built the basis for the development of the analytical categories, explained in section 4. The analytical categories aim at a conceptual contribution of cross-national validity for the analysis of actor specific aspects. A more detailed description of the study's empirical findings in both countries can be found in (Mühlemeier, 2018c, 2018b).

3 Research design and methodology

This paper is based on an iterative research design, combining theoretical considerations and empirical evidence in a cross-fertilising manner (see Figure 2 In order to support an iterative theory-building procedure, the empirical results from a case study, based on the TEF, are discussed against the background of the complementary theoretical considerations from *public corporate governance* and *network industries*. Subsequently, they are validated again by the empirical data and finally linked back to the TEF and the theoretical discourse on incumbent behaviour. This approach is inspired by grounded theory (Glaser & Strauss, 1999), respectively iterative theory building and triangulation (Eisenhardt, 1989; Kerssens-van Drongelen, 2001; Lewis, 1998).

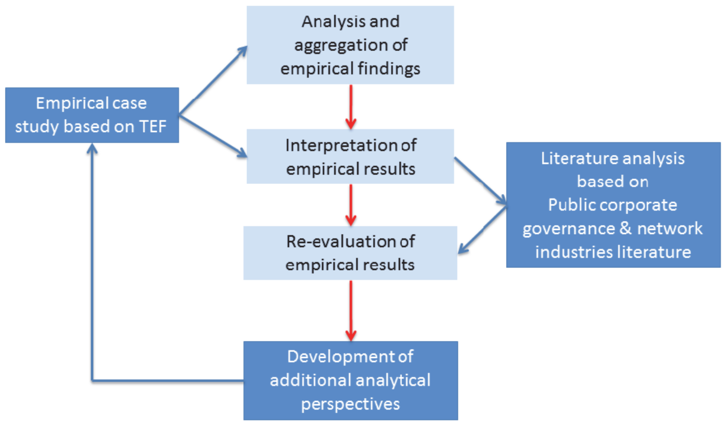

Figure 2: Overview on the iterative research design (author's own representation)

2.3 Empirical data collection

The data collection for the empirical study was structured by the analytical dimensions of the TEF and based on the analysis of sector reports and annual reports of the UUC in 2017. This secondary data was complemented by 38 expert interviews conducted in Summer 2017 in Germany and Switzerland. The interviews were designed as semi-structured interviews, they were held, based on an interview guideline, face-to-face, in German or French, enrolled through a snowball sampling (Flick et al., 2004: 125; Flick, 2009: 168) and recorded in agreement with the interviewees. During the interviews, the topics of main interest were: "structural and cultural characteristics" of UUC, "relations to other players", "past, current and future challenges" as well as "strategic responses" and finally their "role in the transition".

To generate a broad body of knowledge and gain a comprehensive understanding of the UUC - from inside but also outside of the organisation - the sampling of the interview partners aimed at a broad diversity of backgrounds: research, consultancies, administration, associations and CEOs or members of the strategic department of the UUC (see Table 2) They were all considered experts, working on, with or within UUC for a long time. At the end of every interview, the interviewee was asked for further contacts to persons he or she considers experts in the context of UUC (snowball sampling). This explorative study consequently did not aim at a representative share of interview partners per sector, but for their profound expertise with UUC and results in a varying number of interview partner per sector (see Table 2)

Table 2: Overview on the interviewees from Germany(GER) and Switzerland(CH)

	Large UUC	Middle-sized UUC	Research	Consultancies, service provider	Industry association	Environmental association	Politics
GER	4	1	5	7	2	1	
CH	4	3	4	4	3		1

2.4 Data analysis

For data analysis, the interview records were anonymised, transcribed and analysed, using the software MAXQDA (www.maxqda.de). The content analysis of the transcripts (Mayring, 1991, 2014) was based on a semi-structured procedure: the texts were sorted according to pre-defined codes "structural and cultural characteristics", "past, current and future challenges" as well as "strategic responses" and "role in the transition" and afterwards further sorted and aggregated according to emerging structures (e.g. in structural characteristics "depth" and "breadth of value creation", "market" and "monopoly" regime etc.).

Following the iterative research design, the results of these structured transcripts (codes and codings) were discussed with peers and senior researchers against the background of contributions in *public corporate governance* and *network industries* and resulted in the analytical categories presented below. For a comprehensive presentation of the empirical results see (Mühlemeier, 2018c, 2018a)

3 Analytical categories for UUC as public incumbents in infrastructure network industries

In the subsequent section, I first present the theoretical considerations of the TEF and explain how they are particularly valuable for the case of UUC, based on the empirical evidence from the case study analysis. Subsequently, I present the analytical categories for the analysis of UUC in detail, based on theoretical considerations from *public corporate governance* and *network industries* literature and the empirical evidence from the UUC in Germany and Switzerland. To conclude, Table 3 provides a comprehensive overview on the six analytical categories, summarising their theoretical foundation and the empirical evidence.

3.1 The triple embeddedness framework (TEF)

The TEF provides a systematic framework how to analyse firms as embedded organisations and investigate their role in the socio-technical transition (Geels, 2014). Additionally, it provides theoretical considerations how to interpret the findings on influencing factors and the firms' behaviour (strategic answers). The TEF, thus, explicitly elaborates on the interaction between the institutions (social structure), the systemic context (social system) and the agency of firms in transitions (see Figure 3.

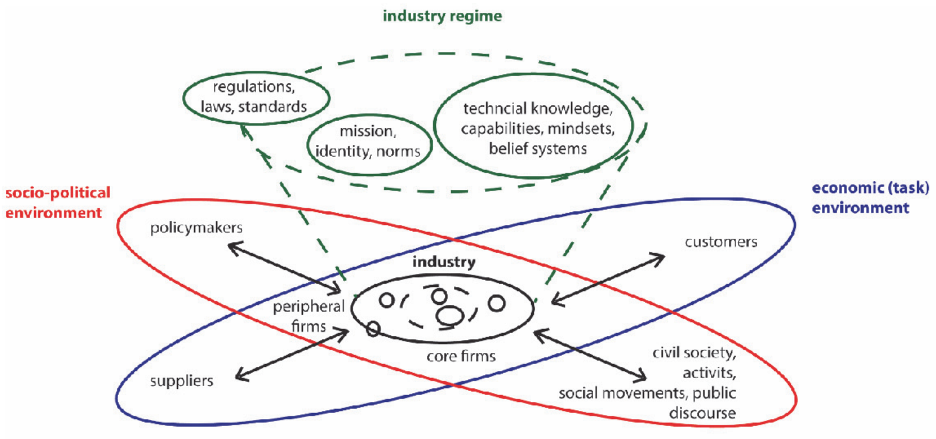

Figure 3: The Triple Embeddedness Framework – influences on the firms from different levels (author's own representation, based on Geels, 2014)

The TEF is based on insights from evolutionary economics (e.g. the concept of firm behaviour as reaction to selection pressure from the economic environment or the concept of corporative learning as incremental and path dependent process (Dosi, 1982, 2000; Dosi & Grazzi, 2006)), neo-institutional theory (e.g. the concept of an organisational field (industry) or the importance and selection pressure from institutions which shape this organisational field (industry regime) (DiMaggio & Powell, 1983; Scott, 1995), and economic sociology (e.g. the embeddedness of the economy in a wider societal context (Granovetter, 1985; Krippner, 2002) or the questioning of a neutral state and the concept of core actors which dominate an industry (Fligstein, 1996; Lindblom, 2002).

The TEF conceptualises companies as *firms-in-industries* which are embedded in three different layers. Firstly, their industry is shaped by a particular *industry regime*, which encompasses all types of institutions typical for the industry (specific types of knowledge, mind-sets and worldviews, values and norms as well as formal regulations). Secondly, the firms-in-industries are embedded in their direct *economic task environment*, which encompasses relations to customers, suppliers, competitors or administrative bodies who are directly linked to the sector but also all the assets they operate for their business. Thirdly, the firms are embedded in the wider *socio-political environment*, represented by general administrative bodies, political parties, NGOs, citizens etc. (Geels, 2014). Hence, the TEF conceptualises two types of embeddedness: *vertical embeddedness* in the firms-in-industries regime (social structure) and *horizontal embeddedness* in the socio-political and economic interactions with other players (social system). From all these layers of embeddedness, there may occur changes and pressures, which affect the firms and to which they need to react (*strategic answers*).

In parallel to the two types of embeddedness, Geels (2014) develops two types of strategic answers: first, *externally-oriented strategies* to the "horizontal" environment e.g. through lobbying or framing towards the socio-political context as well as innovation strategies, investments or mergers in the economic context. Second, *internally-oriented strategies* to adapt the firm through learning, organisational change, the incorporation of new knowledge and mind-sets in the "vertical" regime (see Figure 4). Geels (2014) conceptualises learning of firms as a mixed behavioural-cognitive process (trial-and-error as well as evaluation of it), which happens in reaction to external pressure on the firm and takes place in several loops: from small adjustments, to strategic reorientation and finally strategic recreation (see Geels 2014: 272).

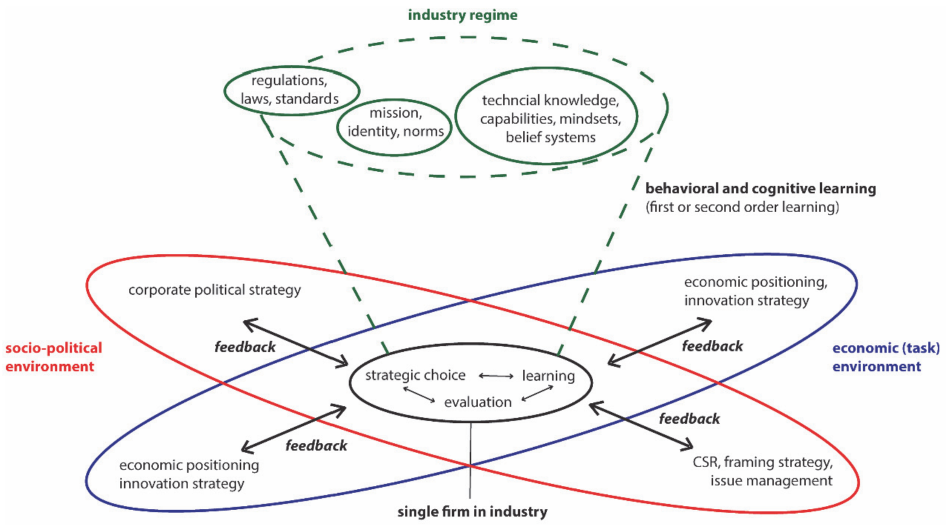

Figure 4: The Triple Embeddedness Framework – Strategic answers of the firms on the different levels (author's own representation, based on Geels, 2014)

Based on the TEF, the behaviour of UUC can be explained by major changes in the "industry regime" as well as in the "economic" or "socio-political environment" and their subsequent (strategic) reactions to these changes. For the analysis of UUC, the TEF concept of the "industry regime" is of particular importance, since it highlights one of the most relevant influence factors on the UUC: fundamental regime shifts – imposed from outside the sector - to which the UUC as incumbent regime players needed and still need to react. Firstly, from a public administration - monopoly regime to a liberalised, market-based, entrepreneurial regime (liberalisation). Secondly, from a centralised mainly non-renewable system to a decentralised and renewable energy system (decarbonisation, denuclearisation) and thirdly, from an analogue, wire-based system to a digital and smart system (digitalisation) ["Five years ago energy market design was not even a term in the discourse, so this shows how things change" DE8].

These fundamental changes in the regime of the UUC caused the actual emergence of an "economic task environment" with shareholders, customers, suppliers and competitors as well as a general exponential increase of new players in their economic environment. Furthermore, it resulted in fundamental changes of the political goals for the energy supply (still affordable and secure but also efficient and renewable), and most recently the emergence of a second resource layer (digital data) which opens new possibilities for smart grid management and decentral production in collaboration with prosumers (e.g. virtual power plants) but also further increases the amount competitors ["Start-ups, energy retail platforms (e.g. verivox) but also Google, Telecom, players who are able to deal with data" DE9]. Thus the changes in the energy sector regime caused an increasing complexity, regulatory openness, increasing speed of change and an accumulation of tasks for the UUC. The UUC strategically reacted through organisational and cultural changes (establishing of innovation management, new business areas and models, but also cultural changes and new job profiles), cooperation with other UUC and their customers, the establishment of lobbying agencies and international investments in renewable energies (for a more detailed analysis of the empirical findings see (Mühlemeier, 2018c, 2018a)).

The notion of the "industry regime" thus facilitates the investigation of fundamental changes in regulations but also mind-sets and required competences of the UUC as embedded firms in their industry.

Additionally, the notions of "economic" and "socio-political environment" allow to locate the related changes in the actor network, which surrounds the UUC. Finally, the overlap of the "economic task environment" and the "socio-political environment" (see Figure 3· also perfectly mirrors the position of UUC at the intersection of societal, political and economic performance expectations, e.g. creating revenues for the shareholder while implementing political goals through investments in renewable energies and energy efficiency. This alludes to another major challenge for incumbents like the UUC: certain key societal values remain constant (e.g. the democratic control on the firm, the service public expectations) while others change fundamentally (e.g. economic efficiency of the firm or revenue generation). These particular aspects of public companies in infrastructure network industries are evidently not explicitly conceptualised in the generic TEF and thus further developed in the subsequent section.

3.2 Public corporate governance

Public corporate governance literature (e.g. (Frentrup, 2008; Lienhard, 2009; Schedler et al., 2011) particularly focuses on questions of (good) governance of publicly owned companies in liberalised contexts and thus proposes some typical challenges of public companies, which guided the development of the following analytical categories.

Public service vs. profitability

UUC provide a city with all critical public services, such as energy, water, and public transport. Their major task is the provision of these public services to the inhabitants and they are expected to offer them as accessible, affordable and qualitative services to all inhabitants, even though this might not be always profitable. At the same time - due to liberalisation and the resulting corporatisation - the UUC are also expected to be profitable and gain revenues for the city, mainly to finance other, non-profitable public services ["Cities are more than just owners, they are stakeholders – they have political expectations and they are in a double-role: owner and political player, so the claim political goals as owner" DE10; "earning money is the main expectation from the politics. Of course they always say please think also about the Energiewende but still the main claim is, it needs to be profitable" DE18].

This necessarily results in two conflicting logics and the related conflicting expectations: societal performance and market performance / profitability expectations (Schedler et al., 2007; Schedler et al., 2011; Schedler & Finger, 2008) (see Figure 5·

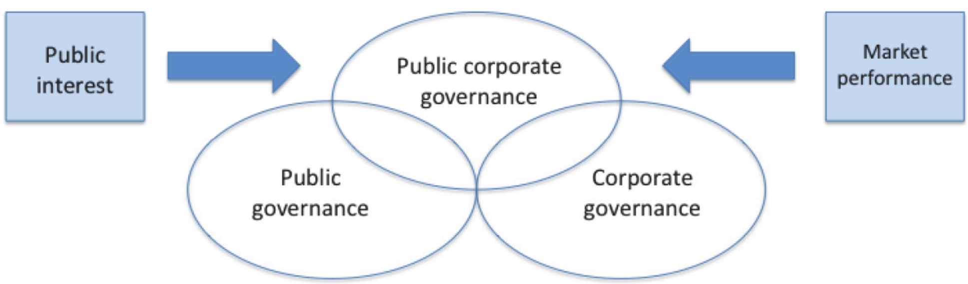

Figure 5: Public and private interest on public companies (author's own representation, based on Schedler et al. 2011: 19)

The political goals on decarbonisation of the electricity and heat supply and the required infrastructure investments are challenging particularly UUC whose business is still largely grounded on gas supply, as e.g. IWB, the UUC of Basel. Besides offering energy services, they mainly finance the expansion of "new" renewable energies (photovoltaic, solar heat or biomass) and the extension of e-mobility infrastructure based on their revenues from the gas supply (IWB is one of the largest gas suppliers in Switzerland). In so doing, they manage to implement the political goals mainly based on firm-internal financial resources – and generate revenue for the city of Basel so that they can finance the non-profitable public services. If they would additionally be pushed to reduce their gas business and even deconstruct the existing pipeline infrastructure (which is an ongoing political discussion), they could not finance this anymore from their corporate budget, but would need to rely on direct financial support from the city - which the city again would need to generate via taxes.

Thus, the particularity of public companies is that these conflicting societal expectations are not external to the company, as for a private company offering public services (e.g. a private gas supplier), but they are integral part of their owner strategy and thus internal to the company. Consequently, the city can directly steer its infrastructure services and can design a transition process based on public and "private" financial sources from the utility company. This leads directly to the second important aspect of public corporate governance: the democratic control.

Democratic control vs. competitiveness

The city administration as the public owner aims at exercising direct democratic control over the company. However, due to liberalisation and the corporatisation of the company, the city administration is not part of the operative business of the firm, but in charge of the definition of strategic goals and the control of their achievement. In this context, *public corporate governance* literature emphasises the challenge of the principal-agent problem. The principal (the city administration) wants to overcome the knowledge gap to the operative business of the agent (UUC) to exercise the democratic control (Jensen & Meckling, 1976; Rentsch, 2017). As a results of this gap in information, the principal sends policymakers to the advisory board of the company to ensure the direct democratic control (Gnan, Hinna, Monteduro, & Scarozza, 2011).

Additionally, the city exercises the democratic control also directly via the owner strategy and the respective owner goals. Figure 6 shows the political process of an owner strategy definition in public companies: the parliament defines the general public interest, the ministries (executive) operationalises the general public interest in an owner strategy with owner goals. These two political agencies form the outer controlling circle. Afterwards, the administrative board represents the owner goals and defines - together with the operative management - the firm strategy, which is then implemented by the operative management. These two entities are part of the public firm and thereby of the inner controlling circle. The administrative board ideally guarantees the translations of the owner goals from the outer to the inner controlling circle (marked with an overlap). This process is true for all political scales of a federal energy governance system.

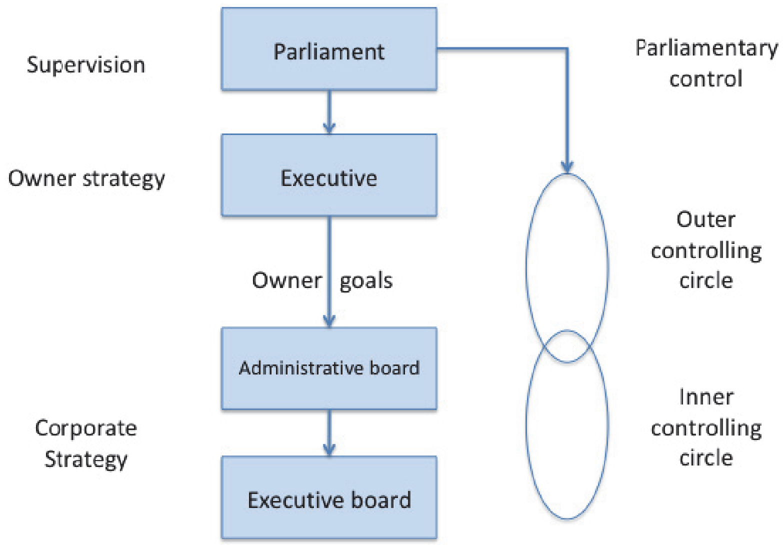

Figure 6: Democratic control of a public company (author's own representation, based on(Schedler et al., 2011)

However, as mentioned above, there are still the economic performance expectations from this same principal. The public company should act as successful and profitable as possible in a competitive setting – in production as well as in retail. However, competitiveness requires a certain amount of disclosure and rather widens the knowledge gap to the principal (e.g. offers of a public agency in a tendering process need to be accessible to any citizen, whereas corporatised public companies can keep them private – accessible only to the responsible representatives). Consequently, there are often target conflicts in the owner strategy or the constellation of the advisory board is questioned - whether to staff the board with democratic representatives or experts from the sector to match the owner goals best. ["Who is sitting in the administrative board of a UUC? Local politicians. And the minority has a profound understanding and knowledge of the energy sector – the rest has municipal political interests and basically wants money for the service public" DE3; "In the administrative board, who are the politicians? Are they experts in the energy field or in politics or are they more like knowledgeable citizen?" DE12]

Multidimensional roles of the owner

The principal-agent problem also alludes to another particularity of public companies: the owner is not only approaching them as an owner, but in a multitude of roles and "faces". Most prominently, the dichotomy of the classical owner and the democratic representative of the urban society, which results in the conflicts mentioned above. Moreover, the city administration as the public owner approaches the company simultaneously also as regulatory agency (judicative), different ministries e.g. the environmental, the financial and the social ministry (executive) and different political parties with diverging visions, representing the diversity of the urban society (legislative). In addition, the civil society can also directly influence the UUC – also "against" the parliament. The city of Zurich wanted to corporatise its UUC in 2015, however the citizens voted against it. The UUC of Munich had plans to quit coal power plants on the long run, Munich's citizens, however, voted for quitting coal power in 2022.

Finally, the temporal horizons and changes of personalities differ among the different political realms, too. Regulatory mismatches and strategic conflicts might be the effect on the public company (Lienhard, 2009).

Federal governance – multiple political goals and means

UUC are located and regulated on the municipal level of the federal governance system. The UUC therefore are part of a subsidiary and bottom-up type of regulation. However, the regime shifts mentioned above are mainly regulated on the national level (often following EU directives) and need to be implemented on all levels of the federal governance system (top-down). This can lead to regulatory mismatches and parallel or even contradictory targets and subsidy schemes among the different political layers (Rave, 2016; Schäfer & Otto, 2016).

The city of Munich has very ambitious decarbonisation targets, however, the Bundesland Bavaria has a very conservative distance regulation for wind power plants which basically makes it impossible to install any wind power plants in Bavaria. Therefore, the Stadtwerke Munich invest in the North Sea to match the cities goals. The city of Zurich aims at reaching the 2000-Watt society and included this goal in the municipal regulation (the overall energy demand of every citizen must not exceed an equivalent of 2000 Watt per capita), whereas the Swiss federation aims at reducing the CO2 emission per capita. The municipal regulation was only recently complemented by the addition of an equivalent of 1 ton CO2 per capita.

These four additional analytical categories explain and exemplify why the overlap of the “economic” and the “socio-political environment” in the TEF are of particular relevance for public companies, as the UUC.

Corporatisation and public entrepreneurship

Finally, the *public corporate governance* literature particularly elaborates on the mentioned regime shift in infrastructure sectors from a public administration towards a market-based regime. In theory, the role of the public agencies on all federal levels should have changed from the actual provider of the public service to the mere guarantor of it (Schedler et al., 2011).

In reality, path dependencies, fundamental values (as e.g. democratic control over critical infrastructures) led to the corporatisation of the formerly administration agencies to public companies which still produce and supply energy. The UUC consequently needed to develop competencies and knowledge types which are necessary in a liberalised market-based regime, while still meeting the public expectations of their owner on the public services and acting under direct democratic control.

Thus, keeping the old competences while establishing new competences might be one of the most challenging tasks for the UUC [“we are characterised by a particular type of employee: an engineer, oriented towards technology, who at the same time thinks in societal dimensions and doesn’t focus on the profit for the city administration, but who aims at the functionality of the whole city” DE16, “we are of course conservative, which matched our business for a long time – we install pipelines and wires, they last for hundred years. There one did not need a very flexible mind. But this is changing rapidly right now and this process demands a lot of cultural change from our side” DE10, “it doesn’t depend on the structures but on the people’s mind set and this one won’t change over a few months” DE3]

In the *public corporate governance* literature, therefore, the concept of *public entrepreneurship* was developed (Bernier & Hafsi, 2007; Greiling, Eichhorn, & Macdonald, 2013). It conceptualises and discusses the development of necessary competences for the development of entrepreneurship in the public sector and e.g. the development of new business models for public companies.

3.3 Network Industries

Infrastructure network operation: natural monopolies and re-regulation

One additional aspect, which is not yet considered explicitly in *public corporate governance* literature is the fact that most of the public companies in the energy sector are not only operating in a market-based competitive regime, produce and deliver energy, but they also operate "critical" network infrastructures to ensure the quality, accessibility and affordability of the public services (e.g. the electricity grid, the gas and the district heating networks) (see Figure 7

Market	Production, Trade
Monopoly	Network operation
Market	Retail, Services

Figure 7: Market and monopoly based business areas in the energy division of public companies (author's own representation, based on (Brunekreeft et al., 2015)

It is the raison d'être of these networks that a competing parallel network infrastructure, providing the same service, does not make any economic sense. Consequently, network infrastructures tend to be "natural monopolies", which is further elaborated in the network industries literature (Finger & Jaag, 2015; Finger & Künneke, 2011; Künneke, 2009). The combination of this physical logic and the societal public service expectations causes either public ownership and operation of the network infrastructure (which is the case in Switzerland), or a heavily regulated concession system, where private players can compete for concession rights (German energy sector). Consequently, public companies act in heavily regulated contexts, even though they are labelled as "liberalised". This is often neglected in the *public corporate governance* literature, since it's background lies in new public management and the introduction of corporate governance mechanisms in the realm of public companies. Hence, network industries literature draws not only attention to the physical reality of infrastructure sectors but also to the influence of regulation on them, even though they have been liberalised (Finger, Groenewegen, & Künneke, 2005).

On the one hand, Germany only recently regulated the installation of reserve capacities for the grid balancing – the network operators are allowed to install two GWh through a tendering procedure and are compensated by public money. On the other hand, UUC are more and more discovering the opportunities of smart grid balancing by actively including prosumers in virtual power plants (e.g. SWM and Rheinenergie). Digitalisation thus provides new solutions, which questions the initial separation of network operation, production and supply of energy. ["The whole unbundling regulation was made before the energy transition and the digitalisation and it hinders it right now. The utility companies get no feedback on the needs and the reaction of the customers – this is still designed for the uni-directional system and need to be revised in the future" DE3; "if somebody has the responsibility, he should also have the possibility to interfere" DE12]

In the Swiss governance system, it is still discussed, whether and if so which capacity mechanism scheme should be implemented. So far the UUC play a highly important role for the balancing of the grid, since they operate production and distribution still in the same organisation, so that they can directly react to grid instabilities. ["Integrated resource planning is really complicated with unbundling

- even when there are contracts of data exchange, so the classical full integrated firm works, they can decide: do we want to install LED or do we want to build a new plant" CH10].

Table 3 summarises the proposed analytical categories, their related theoretical references and alludes to empirical evidence from the analysis of the UUC in Germany and Switzerland.

Table 3: Overview on analytical categories for public companies in network industries (based on (Mühlemeier, 2018a)

Analytical category	**Theoretical reference**	**Empirical evidence**
1. Public service vs. profitability	(Schedler et al., 2007; Schedler et al., 2011; Schedler & Finger, 2008)	The city administration as owner and political player has diverging expectations on profitability of the UUC and its compliance with energy transition goals, e.g. the investment in renewable energies, energy efficiency measures or the divestment from non-renewable energies.
2. Democratic control vs. competitiveness	(Jensen & Meckling, 1976; Rentsch, 2017)	The city administration wants to execute as much democratic control as possible but wants the UUC to be as competitive and profitable as possible. Thus, there are e.g. discussions on the composition of the administrative board (share of policymakers, engineers or business experts).
3. Multidimensional roles of the owner	(Lienhard, 2009)	The city administration encounters the UUC in many different roles which might have different interests: as owner, legislative (different parties), executive (different ministries) and judicative (different regulations e.g. for nature protection or housing renovation).
4. Federal governance – multiple political goals and means	(Rave, 2016; Schäfer & Otto, 2016).	Due to the bottom-up subsidiary organisation of the sector, UUC are traditionally regulated on the municipal level, however liberalisation, energy transition and digitalisation are regulated top-down on a European and national level, which causes mismatching regulations.
5. Corporatisation and public entrepreneurship	(Bernier & Hafsi, 2007; Greiling et al., 2013)	The liberalisation entailed the corporatisation of many UUC and still causes their adaptation to market-based logics, including organisational change (e.g. establishment of innovation management) and cultural change (e.g. developing new competences).
6. Infrastructure network operation: natural monopolies and re-regulation	(Finger & Jaag, 2015; Finger & Künneke, 2011; Künneke, 2009)	The natural monopoly of networks results in public ownership and in the analysed cases the network operation by UUC. The UUC operate in market and monopoly, influenced by strong regulations. A recent example: renewable energies and digitalisation trigger the discussion on how to manage and finance grid balancing (e.g. with strategic reserves or smart steering measures like virtual power plants).

4 Discussion

The previous sections elaborated on the question, “Which analytical categories can be derived for incumbents in the energy sector through the analysis and conceptualisation of urban utility companies (UUC) as public companies in network industries?” (RQ1). The following section discusses first, “how these analytical categories can be linked to the TEF and therewith linked to transition studies in general” (RQ2). Subsequently, the section concludes by kicking off the discussion on “How can the analytical dimensions enrich the understanding of other incumbents in the energy sector and other network based infrastructure sectors?” (RQ3).

4.1 Linking the analytical categories to key conceptual building blocks of the TEF

The subsequent section explains, how the six analytical categories developed above, can be linked to the conceptual building blocks of the TEF: i) *vertical embeddedness – general and specific institutions*, ii) *horizontal embeddedness – economic and socio-political environment*, iii) *core vs. peripheral position of the firms* and iv) *strategical answers – learning*. This linkage has thereby two qualitative levels, which structure the subsequent section. First, *exemplifying:* the analytical categories can *exemplify* the building blocks through a further operationalisation of the existing conceptualisation of the TEF for the case of UUC. Second, *complementary*: the analytical categories can *complement* the TEF through adding further aspects to the conceptualisation of the TEF, which are of key relevance for the understanding of UUC. Table 4 (in annex) provides and overview on the linkage of the analytical categories to core conceptual building blocks of the TEF.

Vertical embeddedness – general and specific institutions in the industry regime

Exemplifying:

The institutions, which shape the industry regime of the energy sector in general and influence the UUC in particular are both, internal and external to the energy industry (e.g. regulation and societal expectations on the decarbonisation of energy production or data security in the context of the digitalisation are external but highly relevant). The energy sector, however, is highly politicised and it becomes difficult to separate internal from external institutions in questions like, is the concept of public service (affordability and accessibility of energy supply) an internal or external institution? The energy industry regime blurs the border between external and internal - which might be clearer for other industries like car manufacturing or consumer goods. A wider “industry regime” understanding is thus expediently. Category 1 exemplifies this further and shows e.g. that performance indicators for UUC are different from other actors in the sector - e.g. technology providers for smart metering are not expected to operate under direct democratic control, act as social employer and be committed to the urban society. Category 5 adds the historical component to it, where these institutions are rooted as well as why they changed over time and illustrates their path dependency (e.g. knowledge and mind-sets have long been influenced by engineering and are still relevant today, where they overlap with knowledge and mind-sets from economics)

Complementary:

Moreover, external institutions, influencing the industry regime of UUC are not only external because the stem from other societal areas (as e.g. data policy) but also because they can be located on a different scale in the federal energy governance system. Category 4 elaborates this further in alluding to the fact that in federal energy governance systems, municipal, cantonal/regional and federal regulations and values can differ (e.g. on the local level climate protection might be of first priority, however on the national level, economic aspects are seen more important - e.g. in the discussion on the coal phase-out in Germany).

Horizontal embeddedness – economic and socio-political environment

Exemplifying:

The TEF conceptualises different selection criteria for firms in the economic task environment (competitiveness, efficiency, financial performance) and in the socio-political environment (legitimacy and social performance). In line with the wider "industry regime" understanding argued above, category 1 exemplifies that for UUC as for all public incumbents with service public obligations, these selection criteria (or performance indicators) are not part of two separate environments, but located in the intersection of the two environments (see Figure 3) Category 3 further exemplifies the importance of the intersection by showing that they UUC's owner (the city administration) represents at the same time different stakeholders, which again interact in different manners with the UUC (e.g. judicative, executive and legislative).

Complementary:

Category 2 complements the conceptualisation of the intersection of the two environments in the TEF by showing how this intersection is not only external to the firm but also internal. Through public ownership and the fact that their owner represents at the same time several stakeholders, the UUC's owner strategy encompasses both, economic and socio-political targets – often contradictory (e.g. profitability of the firm vs. investment in renewables, withdrawal from (profitable but unsustainable) energy sources, maintenance of the quality of (non-profitable) public service, or: organisational change towards more efficiency vs. restrictive personnel policy). This intersection ranges up to the composition of the administrative board, resulting in the question whether to political or economic competences should be given more weight. Category 1-3 thus exemplify the intersection of the two environments and emphasis its importance for the analysis of UUC.

Core vs. peripheral position of the firms in the industry

Exemplifying:

UUC as any other public incumbents are per definition core firms, since the sectors' regulation was made with and for them, they have key responsibilities and mandates for the functionality of the sector. However, their position at the core of the industry is not only shaped by the social system and its institutions, but also by the "physical reality", the "particularities" and "logics" of the technological basis of the sector. Category 6 elaborates on the fact that the energy sector is a network industry, with natural monopolies on network infrastructures for different energy carriers and therefore creates a different technological reality as e.g. manufacturing sectors. This additionally explains the core position of UUC (as monopolist distribution grid operator) and it also points out that current technology-based developments (as e.g. decentralisation and digitalisation) challenge the network-based regime and thus the core position of UUC.

Complementary:

Moreover, category 4 complements the "core-periphery" typology of the TEF by alluding to the particularities of federal energy governance systems: UUC are indeed core firms, but only on their municipal level. Category 4 helps to further investigate this specific multi-scalar situation in federal energy governance systems, e.g. how liberalisation changed the core position of UUC: Nowadays, UUC as other public incumbents are in competition on all federal scales in the areas of energy production and retail, reversely, they also expanded their radius of action on the national and even European level.

Strategical answers – learning

Exemplifying:

Category 5 enriches the understanding of the UUC's strategic answers by exemplifying the historical components and path-dependencies of their behaviour. The UUC so far only gradually changed their strategies (reorientation) and adapted to external pressures like liberalisation and decarbonisation. However, with the kicking-in of digitalisation, their role is fundamentally questioned (see section *core vs. peripheral position of the firms*). Thus, they need to recreate their business and their owners as well as the wider society needs to decide on their future roles - e.g. should they become pure network operators and leave maximum room for private companies or should they remain fully integrated energy supply and distribution company which allow for a maximum of direct democratic control on critical infrastructures (see also (Finger & Mühlemeier, 2018) for possible future roles of the UUC in the energy sector).

Additionally, category 6 deepens the understanding of the UUC behaviour by exemplifying that the physical reality influences and bounds the UUC's behaviour. It explains path-dependencies due to sunk costs in existing assets (e.g. the high voltage grid) and high costs of infrastructure replacement (e.g. new decentralised micro-grids). Finally, categories 2 and 3 add another explanatory variable for the UUC strategic behaviour by alluding to their particular situation, as their owner also represents several stakeholders at the same time (policymakers are part of their administrative board and the local society can directly influence their strategies through their political representatives or referendums). UUC as well as public incumbents, thus, do not act in the same way as private companies, to which public authorities are "only" external stakeholders. Considering these analytical categories while investigating the strategic behaviour of UUC and other public incumbents will broaden the analytical horizon and deepen insights.

Complementary:

The TEF mainly focusses on changing pressures and a generally changing environment during a sustainability transition, however, in a critical infrastructure sectors like the energy sector, a certain level of stability is societally desired and politically defined (supply security, affordability of energy). Due to their incumbent position and their specific mandates and responsibilities (see section *core vs. peripheral position of the firms*), UUC need to react to driving forces towards stability as well as towards change, while the fundamental transition of the energy sector is underway. Category 1 points to this discrepancy, which need to be particularly considered for the analysis of public incumbents in the energy sector.

Finally, the analytical categories can be used as a guide for empirical analyses and enrich the interpretation of results in addition to the TEF in order for the analysis to cover not only particularities of the actor but also the transitions' and the rich embeddedness category which is elaborated in the TEF. The analytical categories, however, can also be applied individually, based on their theoretical background in *public corporate governance* and *network industries* studies. This would be appropriate for studies which want to develop a general understanding of the actor or investigate their situation without a particular transition focus (see also (Mühlemeier, 2018c, 2018a)

4.2 Exploring the explanatory value of the analytical categories for other public incumbents in energy and other infrastructure network sectors

The proposed analytical categories have their biggest explanatory value for public companies in infrastructure network industries and can also be applied to other public and larger incumbents in the energy sector e.g. EON or EnBW. They are also independent firms with public owners and consequently, they also act as publicly owned companies in a market-based environment, facing the discrepancy of democratic control vs. competitiveness (category 2). The recent discussion on the splitting and re-merging among EON and RWE, thus, can be interpreted as a strategic bit on the profits in renewable energies (RWE) versus the future profits in the regulated network business (EON). The parallel existence and overlap of the market-based and the monopoly logic apparently still shapes their business models (category 6). And, although they have been corporatised and appear as competitive and innovative companies, they also have their roots and historical development in the former monopoly, centralised and analogue regime (category 5). These considerations enrich the understanding, why and how their behaviour is shaped by path-dependencies as well as why they struggle to adapt to regime shifts, to develop the necessary competences and to implement related organisational change – as finally all incumbents do.

The proposed analytical categories can also be applied to incumbents in other infrastructure network industries like the railway or the communication sector. Both have been liberalised in the context of the European integration and are based on network infrastructure, which is often publicly owned or highly regulated (category 6). Incumbents in these sectors provide critical public services and are still public (national) companies acting in a market-based regime (e.g. deutsche Bahn, Telecom, Swisscom) (category 1) (Finger, 2014; Lang, Laperrouza, & Finger, 2013; Welfens & Yarrow, 2012). Incumbents in the telecommunication, railway and energy sector therefore share communalities, which are due to their underlying network infrastructure. They act between the two extremes of "economies of density" (denser areas are more profitable) and "public service obligation" (less dense areas need to be served nonetheless) (category 1), their investments are capital intensive and have a high share of sunk costs, since assets are hardly transferable (category 6). In the European context, they act in different forms of competition: "in the market" between train operators, based on regulated access to the network infrastructure and "for the market", e.g. via concessions (category 2) (Laperrouza, 2011, p. 219).

The telecom sector – as an early mover in the European liberalisation – could thereby function as an example to study how incumbents (re)act in the context of a maturing liberalisation. Although the liberalisation of the European telecommunication sector was already decided in 1998, the market is still dominated by an oligopoly and regulatory questions like the unbundling of network operation and service provision as well as the reduction of the barriers for new entrants are ongoing debates (Melody, 2011, pp. 117–120). In the context of the telecommunication sector, the radical technology change over the last 30 years is particularly interesting, since the ascent of mobile telecommunication and the (mobile) internet caused a true technical revolution, the incumbents had to deal with. However, "even though the internet was born liberalised", it will become more regulated since society is becoming more and more dependent on it (Mueller & Lemstra, 2011, p. 159). Debates on equal access, speed and price as well as network neutrality will enter into relation.

The railway sector is considered a laggard in European liberalisation. Only in 2007 the European freight transport was liberalised and according to the forth European "railway package" the full liberalisation of the passenger market will follow in 2020 (European Parliament, 2016; Laperrouza, 2011). Historically, the railway sector has a strong national focus and culture with national technology standards and regulations as well as high political sensitiveness and e.g. strong unions. Until today, this national heritage causes challenges in the European integration, interoperability, harmonisation of regulation and establishment of European authorities (Laperrouza, 2011). Laperrouza (2011) states with a smirk "it should not be a surprise to have an airline company operating a high-speed passenger train across

Europe…" (Laperrouza, 2011, p. 230). Due to similar national path-dependencies and the political sensitiveness, the study of incumbents in the railway sector could definitively contribute to a more complex understanding of incumbents in the energy sector.

The analytical categories proposed in this paper could therefore be transferred to other network industry sectors in which public enterprises play a major role and could facilitate comparative studies which enhance the understanding of their behaviour as incumbents in times of fundamental change.

This strength of the categories, however, represents at the same time one of their limitations: the categories were especially developed for public companies and do not answer the question whether public companies act differently than private or public-private incumbents. Moreover, this paper necessarily remained conceptual and did not analyse e.g. whether the UUC's behaviours influenced the course of the energy transition process differently than those of other public incumbents. Finally, the proposed analytical categories were developed based on the thoroughly selected case of urban utility companies, however, the further empirical application of the proposed analytical categories to other UUC (e.g. of smaller size, or with a larger share of private shareholders) or to other public incumbents (e.g. regional and cantonal utility companies) would definitively enrich future theory building.

5 Concluding remarks

Based on an iterative theory building process, this paper developed six analytical categories for the study of public incumbents in infrastructure network industries and discussed how they can be linked to key building blocks of the triple embeddedness framework (TEF). The paper thus shows how the proposed analytical categories can be used in the broader context of transition studies, while emphasising their complementarity to the TEF and individual applicability. Finally, the paper opened up a debate on the potential explanatory power of the analytical cetegories for other public incumbents in the energy sector as well as in other infrastructure network sectors, as e.g. telecommunication or the railway sector.

Urban utility companies (UUC) are integral part of federal energy governance systems, as e.g. in Germany and Switzerland, which are organised in a bottom-up structure. The UUCs' key responsibility is it therefore to supply "their city" with all critical infrastructure services (also with electricity and heat) and the management of the necessary local infrastructures. They are mostly owned by the city to ensure direct democratic control over these "critical infrastructures". In the energy sector, UUC are experiencing more and more fundamental technological and regulatory changes, such as the European integration, liberalisation, decarbonisation and digitalisation with which they need to cope. Due to their key (often monopoly) position on the local level, they play a key role for the implementation of the politically defined energy transition goals and become key actors in a decentralised energy system.

This paper proposes to conceptualise the urban utility companies as local public incumbents in infrastructure network industries and works out six key analytical categories to understand the UUC's behaviour. Category 1 *public service vs. profitability* highlights that UUC are balancing the different expectations of their owner. Traditionally, the energy division of UUC generated the revenues for the city to finance other, less profitable public services. In the context of the energy transition, however, the energy division itself needs more and more investments and becomes less profitable, which causes new challenges of the local infrastructure financing. Category 2 *democratic control vs. competitiveness* highlights the fact that UUC are public companies, acting in a market-based environment. They balance expectations on their transparency, public control over them and the cautious spending of tax payer money on the one hand and on the other hand requirements for disclosure, quick "non-democratic" decisions and risk taking in a competitive environment. Thereby, category 3 *multidimensional roles of the owner* points out that their owner, the city administration, encounters them in diverse roles with different goals and means: as shareholder and several stakeholders, such as regulatory and administrative agencies but also societal representatives, mirroring the social diversity of their owner, the city. Category 4 *federal governance – multiple political goals and means* alludes to the fact that the UUC are municipal firms. In federal energy governance systems, however, responsibilities are allocated on the different levels. UUC face diverging goals and means, which increases the complexity of their regulatory environment. Category 5 *Corporatisation and public entrepreneurship* shows the path dependencies of UUC due to their strong administrative and engineering culture heritage. As public firms in a liberalised energy sector, UUC change their organisational structure and develop a public entrepreneurship culture to keep up with the ongoing changes in the sector. However, category 6 *Infrastructure network operation: natural monopolies and re-regulation* emphasises that in their key role as local network operator they operate in heavily regulated "natural monopolies", which is often ignored if considering UUC as independent firms.

This paper finally proposes to link these analytical categories to the main building blocks of the TEF to exemplify and complement it for the specific analysis of local public incumbents in network industries. The *overlap of the socio-political and the economic task environment*, for example, is very important for the study of UUC, since the energy sector is highly political. Category 1 – 3 exemplify that UUC are public firms, balancing different socio-political and economic expectations and tasks as well as the multiple roles of their owner and positions in the two environments of the TEF respectively. Their owner strategies also comprise political goals (such as the investment in renewables energies or energy efficiency measures) and their administrative board is formed by policymakers. The TEF also conceptualises *core- and periphery-firms* in the sector, with more or less powerful positions. Category 6 exemplifies the core position of the UUC due to their monopoly position as network operator. Category 4, however, complements that they are only core firms on the local level of the federal energy governance system. Finally, the TEF conceptualises different *strategic behaviours* and types of learning in the context of a changing environment. Category 5 exemplifies by alluding to the path dependencies in the UUC strategic reactions, e.g. their administrative heritage. Category 2 and 3 further deepen the historic understanding of the UUC's strategic behaviour being torn between socio-political and economic forces and open up the debate on their future role and possible future strategic behaviour.

To sum up, the proposed analytical categories enrich empirical studies on local incumbents in the context of the energy transition on the one hand, and on the other hand they draw the transition studies' attention to the particular case of federal energy governance systems and the UUC as specific actors. In doing so, they decisively contribute to a more nuanced picture and deepened understanding of incumbents in transition studies, showing their particular characteristics and diversity beyond the widely spread image of "national champions" and "chief lobbyists" against transition. Finally, the elaboration of the analytical categories based on the theoretical background of *public corporate governance* and *network industries* literature also opens up the possibility, to link transition studies to these bodies of literature and thereby supports the closing of the persistent agency gap in transition studies.

Further research on incumbents in transitions of infrastructure sectors should definitively consider the particularities of public companies as well as network industries to enhance the general understanding of incumbent behaviour. An intra-sectoral comparison among private and public incumbents, as well as local, regional and national incumbents could be very fruitful. Likewise, the inter-sectoral comparison among infrastructure network sectors as telecommunication or public transport would contribute to a refined understanding of parallels between different incumbent actors and thereby of the technical regimes in general. Finally, employing empirical evidence from other federal energy governance systems, like Austria or the U.S.A. or states with a strong tradition of municipal self-governance (e.g. Sweden and Norway) could also add interesting insights to the discourse of incumbent behaviour in transition studies.

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Annex

Table 4: Overview on the link of the analytical categories to core building blocks of the TEF

Analytical Category	Theoretical concept in the TEF	Function	Explanation
1. Public service vs. market performance	*Vertical embeddedness – internal and external institutions*	Exempl.	Blurred boundaries between external and internal institutions and related performance indicators for the UUC, broader understanding of the technology regime for the (public) energy sector
	Horizontal embeddedness – economic and socio-political environment	Exempl.	Importance of the intersection between economic and socio-political environment – broader set of selection criteria and expectations for UUC
	Strategical answers - learning	Compl.	Parallelism of societal expectations in stability and change during the transition of a critical infrastructure sector – act for change but also fulfil supply security and public service mandate
2. Democratic control vs. competitiveness	*Horizontal embeddedness – economic and socio-political environment*	Compl.	Intersection of economic and socio-political environment is also internal to the firm – UUC's owner strategy, composition of administrative board
	Strategical answers - learning	Exempl.	The Shareholder represents several stakeholders at the same time, UUC act differently, policymakers are part of their administrative board - direct democratic control.
3. Multidimensional roles of the owner	*Horizontal embeddedness – economic and socio-political environment*	Exempl.	Importance of the intersection of economic and socio-political environment – shareholder represents at the same time stakeholders in various forms
	Strategical answers - learning	Exempl.	Shareholder represents several stakeholders at the same time, UUC act differently e.g. since the society can directly influence them through policymaking or referendums
4. Federal governance – multiple political goals and means	*Vertical embeddedness – internal and external institutions*	Compl.	External institutions in federal energy governance systems stem also from other federal scales
	Core vs. periphery position of the firm	Compl.	Federal energy governance systems needs multi-scalar view on core vs. periphery position of incumbents
5. Corporatisation and public entrepreneurship	*Vertical embeddedness – internal and external institutions*	Exempl.	Historical perspective on internal and external institutions, path-dependencies (e.g. in knowledge forms)
	Strategical answers - learning	Exempl.	Historical perspective on particularities of UUC's strategic answers – liberalisation caused adaptation and reorientation, digitalisation requests recreation of business strategies.
6. Infrastructure network operation	*Core vs. periphery position of the firm*	Compl.	Physical reality and particular logics of network industries – explanatory variable for core position of UUC
	Strategical answers - learning	Exempl.	Physical reality and particular logics of network industries – explanatory variable for strategic answers of UUC.

APPENDIX

A - Supplementary empirical material

A.1 Module 1 (publication 1)

A.1.1 Structural data on energy regions

ÖkoEnergieland

Biomasseanlagen	**Standort**	**Inbe-trieb-nahme**	**Instal-lierte Leistung [kW_{th}]**	**Instal-lierte Leistung [kW_{el}]**	**Trassen-länge [m]***	**Angeschl. Objekte**	**Brennstoff**	**Wärme ab Anlage [MWh/a]**	**Strom ab Anlage [MWh/a]**	**Gesamt-ener-gie ab Anlage [MWh/a]**	**Wir-kungs-grad$_{th}$ [%]**
Heizwerk Güssing I	Güssing	1997	8.000		30.000	400	Waldhackgut, Spreissel	12.000		12.000	66%
Heizwerk Güssing II	Güssing	2002	3.000			100	Sägespäne	12.555		12.555	75%
Heizwerk Urbersdorf	Güssing	1996	650		2.700	47	Waldhackgut	1.800		1.800	89%
Heizwerk Glasing	Güssing	1992	300		1.900	24	Waldhackgut	662		662	65%
Heizwerk Gärtnerei Pomper	Güssing	2010	1.000		0	1	Waldhackgut	2.000		2.000	90%
Heizwerk Kr. Tschantschendorf	Tobaj	1993	350		650	19	Waldhackgut	800		800	81%
Heizwerk Dt. Tschantschendorf	Tobaj	1996	600		1.100	45	Waldhackgut	1.600		1.600	58%
Heizwerk St. Michael	St. Michael	2001	1.700		8.200	100	Waldhackgut	4.421		4.421	70%
Heizwerk Eberau	Eberau	2001	1.000		5.700	84	Waldhackgut	3.149		3.149	71%
Heizwerk Güttenbach	Güttenbach	1997	2.500		12.023	242	Waldhackgut	6.880		6.880	95%
Heizwerk Deutsch Schützen	Deutsch Schützen	2005	850		4.580	67	Waldhackgut	2.063		2.063	81%
Heizwerk Strem	Strem	2004	1.000		5.000	100	Waldhackgut	860		860	77%
Heizwerk Bildein	Bildein	1995	1.000		5.200	90	Waldhackgut	2.373		2.373	82%
Biomassekraftwerk Güssing	Güssing	2001	4.500	2.000			Waldhackgut	31.500	14.000	45.500	50%
Biostrom Güssing	Güssing	2006	3.500	1.700			Sägespäne	1.400	10.400	11.800	2%
Biogasanlage Wolf	Güssing	2010	550	500	0	1	Hühnergülle, Mais, Roggen	1.500	3.250	4.750	17%
Biogasanlage Strem	Strem	2004	600	500			Mais, Gras	1.735	4.350	6.085	14%
Gesamt			31.100	4.700	77.053	1.320		87.298	32.000	119.298	

Source: Regionales Energiekonzept ökoEnergieland (2011)

Solarthermieanlagen	**Standort**	**Inbetrieb-nahme**	**Installierte Leistung [kW_{th}]**	**Kollektor-fläche [m²]**	**Tatsächliche Wärmeproduktion [MWh/a]**		
					vor Anlage	Wirkungsgrad	ab Anlage
Solarthermieanlage Urbersdorf	Güssing	1996	238	340	391	70%	274
Solarthermieanlage Dt. Tschantschendorf	Tobaj	1996	315	450	518	70%	363
Solarthermieanlage Bildein	Bildein	1995	228	325	374	70%	262
Solarthermie-Demoanlage BORG Güssing	Güssing	2003	28	40	46	30%	14
Gesamt			809	1.155	1.328		913

Source: Regionales Energiekonzept ökoEnergieland (2011) + Energieautarker Bezirk Güssing (2006) + Tabellenblatt Energie

Photovoltaikanlagen	**Standort**	**Inbetrieb-nahme**	**Installierte Leistung [kW_{el}]**	**Kollektor-fläche [m²]**	**Tatsächliche Stromproduktion [MWh/a]**		
					vor Anlage	Wirkungsgrad	ab Anlage
Photovoltaikanlage Güssing	Güssing	2004	28	241	277	10%	27
Photovoltaik-Demoanlage BORG Güssing	Güssing	2003	10	92	106	9%	9
Gesamt			38	333	383		36

Source: Regionales Energiekonzept ökoEnergieland (2011) + Tabellenblatt Energie

Wasserkraftwerke	**Standort**	**Inbetrieb-nahme**	**Installierte Leistung [kW_{el}]**	**Fluss**	**Tatsächliche Stromproduktion [MWh/a]**		
					vor Anlage	Wirkungsgrad	ab Anlage
Kleinwasserkraftanlage Gerfried Schultheis	Deutsch Schützen	1900	50	Pinka	438	46%	200
Kleinwasserkraftanlage Anton Schwarz	Bildein	1978	110	Pinka	964	47%	450
Kleinwasserkraftanlage Josef Perl	Eberau	1921	80	Pinka	701	46%	325
Gesamt			240		2.102		975

Source: Das ökoEnergieland, http://www.oekoenergieland.at/index.php/erzeugungsanlagen [23.5.2013], Stand: 2011 + Persönliche Mitteilung Josef Perl und Anton Schwarz [17.6.2013] + Tabellenblatt Energie

Energieregion Weiz-Gleisdorf

Biomasseanlagen	Standort	Inbetrieb-nahme	Installierte Leistung [kW_{th}]	Installierte Leistung [kW_{el}]	Trassen-länge [m]*	Angeschl. Objekte	Brennstoff	Wärme ab An-lage [MWh/a]	Strom ab An-lage [MWh/a]	Gesamt-energie ab Anlage [MWh/a]	Wirkungs-grad$_{th}$ [%]
Heizwerk Ungerdorf Mari-enhof	Gleisdorf	1993	250		875	24	Waldhackgut	525		525	89%
Heizwerk Ungerdorf Fran-kenberg Eichengrund	Gleisdorf	2000	150		252	24	Waldhackgut	315		315	89%
Heizwerk Lassnitzthal	Gleisdorf	2001	110		900	7	Waldhackgut	231		231	89%
Heizwerk Ludersdorf	Gleisdorf	2003	100		280	5	Waldhackgut	210		210	89%
Heizwerk Pirching	Gleisdorf	2005	450		1.064	13	Waldhackgut	945		945	89%
Heizwerk Pirching	Gleisdorf	2005	50		120	2	Waldhackgut	105		105	89%
Heizwerk Gleisdorf	Gleisdorf	2008	800		1.000	10	Waldhackgut	1.680		1.680	89%
Heizwerk Gleisdorf B	Gleisdorf	2009	220		0	3	Waldhackgut	462		462	89%
Heizwerk Pirching	Gleisdorf	2009	100		220	6	Waldhackgut	210		210	89%
Heizwerk Ungerdorf	Gleisdorf	2009	200		0	1	Waldhackgut	420		420	89%
Heizwerk Ungerdorf	Gleisdorf	2009	150		280	46	Waldhackgut	315		315	89%
Heizwerk Wetzawinkel	Gleisdorf	2002	80		200	12	Waldhackgut	168		168	89%
Heizwerk Puchbach	Puch bei Weiz	2008	80		80	2	Waldhackgut	168		168	89%
Heizwerk Puch bei Weiz	Puch bei Weiz	2009	800		1.484	19	Waldhackgut	1.680		1.680	89%
Heizwerk Oberdorf	St.Rupr./Raab	2000	160		269	9	Waldhackgut	336		336	89%
Heizwerk Breitegg	St.Rupr./Raab	1997	100		400	7	Waldhackgut	210		210	89%
Heizwerk Wollsdorferegg	St.Rupr./Raab	1998	60		100	5	Waldhackgut	126		126	89%
HeizwerkSt.Ruprecht/Raab	St.Rupr./Raab	2003	500		800	10	Waldhackgut	1.050		1.050	89%
Heizwerk Kühlwiesen	St.Rupr./Raab	2004	80		133	4	Waldhackgut	168		168	89%
Heizwerk Unterfladnitz	St.Rupr./Raab	2006	500		874	9	Waldhackgut	1.050		1.050	89%
Heizwerk Gutenberg	Weiz	1989	800		1.353	25	Waldhackgut	1.680		1.680	89%
Heizwerk Göttelsberg	Weiz	1998	150		34	2	Waldhackgut	315		315	89%
Heizwerk Weiz, Werk Süd	Weiz	1999	10.800		31.000	280	Waldhackgut	22.680		22.680	89%
Heizwerk Weizberg	Weiz	1999	800		760	14	Waldhackgut	1.680		1.680	89%

Heizwerk Naas b. Weiz	Weiz	2004	300		50	3	Waldhackgut	630		630	89%
Heizwerk Weiz	Weiz	2004	220		200	5	Waldhackgut	462		462	89%
Heizwerk Dürntal	Weiz	2005	80		100	3	Waldhackgut	168		168	89%
KWK Mortantsch	Weiz	2005	300	15	297	11	Waldhackgut	2.415	121	2.536	46%
Heizwerk Sturmberg	Weiz	2006	130		78	2	Waldhackgut	273		273	89%
KWK Weitzer Ökoenergie	Weiz	2006	11.000	940	0	1.700	Waldhackgut	88.550	7.567	96.117	46%
Heizwerk Thannhausen	Weiz	2007	300		250	5	Waldhackgut	630		630	89%
Heizwerk Preding	Weiz	2008	130		250	6	Waldhackgut	273		273	89%
Biogasanlage Gleisdorf	Gleisdorf	1997	600	0	0	1	Abwasser Fruchtverar-beitung	5.360	0	5.360	46%
Biogasanlage Prebuch	Albersdorf-Pre-buch	2002	350	200	50	6	Speisereste	3.063	1.750	4.813	46%
Gesamt			30.900	1.155	43.753	2.281		138.553	9.438	147.990	

Source: LEV Steiermark + Persönliche Auskünfte

Wasserkraftwerke	**Standort**	**Inbetriebnahme**	**Installierte Leistung [kW_{el}]**	**Theoretische Stromproduktion [MWh/a]**		
				vor Anlage	Wirkungsgrad	ab Anlage
Wasserkraftanlage KW Edelsee a. d. Feistritz	Gleisdorf	1955	90	788	85%	670
Wasserkraftanlage KW Neudörfl a. d. Feistritz	Gleisdorf	1980	350	3.066	85%	2.606
Wasserkraftanlage Stegmühl a. d. Feistritz	Weiz	1985	790	6.920	85%	5.882
Wasserkraftanlage Ridlmüller a. d. Feistritz	Weiz	1983	464	4.065	85%	3.455
Wasserkraftanlage Raabklamm a. d. Raab	Weiz	1911	1.385	12.133	85%	10.313
Wasserkraftanlage KW Alte Säge a. d. Raab/Mühlbach	St. Ruprecht an der Raab	*1922*	24	210	85%	179
Wasserkraftanlage KW Mühle a. d. Raab/Mühlbach	St. Ruprecht an der Raab	*1990*	26	228	85%	194
Wasserkraftanlage KW Fladnitzmühle a. d. Unterfladnitz	St. Ruprecht an der Raab	*1912*	22	193	85%	164
Wasserkraftanlage Kraftwerk Glieder a. d. Raab	Gleisdorf	*1973*	180	1.577	85%	1.340
Kleinwasserkraftanlage an der Raab	St. Margarethen an der Raab	*1919*	80	701	85%	596
Kleinwasserkraftwerksanlage an der Raab in Gleisdorf	Gleisdorf	*1968*	69	604	85%	514
Gesamt			3.480	30.485		25.912

Source: Land Steiermark, Fachabteilung Energie und Wohnbau

A.1.2 Interview outline (in German)

ENAC / IIE

Laboratory on Human-Environment Relations in Urban Systems
Swiss Mobilier Chair in urban ecology and sustainable living

Experteninterview – Konnektivität in regionalen Energiesystemen

Im Rahmen unserer bisherigen Forschungsarbeit zur **Resilienz regionaler Energiesysteme** haben wir **Diversität und Konnektivität** als zentrale Systemeigenschaften für resiliente Energiesysteme herausgearbeitet. Diese gelten sowohl für den technischen als auch für den sozialen Bereich des Energiesystems. Erste Analysen der sozialen und technischen Diversität sowie Konnektivität des sozialen Netzwerks der der Region Weiz-Gleisdorf waren bereits erfolgreich.

Bei der Analyse der **Konnektivität des technischen Energiesystems** fehlt uns jedoch bisher ein entsprechender Zugang, wie die Konnektivität hier verstanden und welche Datengrundlage verwendet werden könnte, um diese zu quantifizieren oder zumindest qualitativ abzuschätzen.

Wir möchten mit Ihnen im Rahmen unseres Interviews daher unsere theoretisch erarbeiteten Konnektivitätsindikatoren diskutieren und Sie um eine Einschätzung zur Entwicklung der Konnektivität der Energienetze in der Region bitten.

Indikatoren zur Analyse der Konnektivität, Definition & vorgeschlagene Anwendung:

Indikator	Definition für das technische System	Vorgeschlagene Anwendung auf die Entwicklung der Energienetze (Strom und Wärme!)
Durchschnittliche Pfadlänge	Durchschnittliche Länge der Verbindung von einer Produktions- bzw. Verteilereinheit zum Abnehmer	Stromnetz: Sich verändernde Systemlänge– auf den unterschiedlichen Spannungsebenen Wärmenetze: • Sich verändernde Systemlänge des Gasnetzes (unterschiedliche Druckebenen) • Ausbau Fernwärmenetze?
Relative Zentralität	Anzahl der Abnehmer, die von einer Produktions- bzw. Verteilereinheit versorgt werden	Stromnetz: • Netzebene, auf der eine Produktionsstätte einspeist (je höher, desto höhere Zentralität) • Veränderung mit erneuerbaren Energien? Niedrigere Netzebenen? Dezentralisierung? Wärmenetze: • Fossil: Anzahl der Abnehmer, die z.B. von einem Gaskraftwerk / Ölraffinerie oder Verteiler versorgt werden (hypothetisch) • Erneuerbar: Zunahme der dezentraleren Versorgung (kleine Fernwärmenetze, Solarthermie, Wärmepumpen), mit weniger Abnehmern pro Produktions- bzw. Verteileinheit
Modularität	Subnetze mit Produktions- bzw. Verteilereinheiten und Abnehmern, höhere Anzahl an Verbindungen innerhalb des Moduls als zum restlichen Netzwerk	Stromnetz: • Bisher nicht möglich, untere Netzebenen nur zur Fehlerverbreitung abkoppelbar • mit erneuerbaren Energien: Eigenverbrauchsgemeinschaften, Microgrids (nach wie vor an das Netz gebunden) Wärmenetze: • Bisher: zentralisierte Gas- oder große Fernwärmenetze (in Städten) • Mit erneuerbaren Energien: Zunahme kleinerer Module, dezentrale Fernwärme, bzw. Nahwärme (Insellösungen)

1

Unsere Fragen

1. Ist unsere **Anwendung des Indikators „durchschnittliche Pfadlänge (= Systemlänge)"** Ihrer Meinung nach für das Strom- und die Wärmenetze passend? Haben Sie Verbesserungsvorschläge?
2. Wie hat sich das Strom- und die Wärmnetze in der Region Weiz-Gleisdorf von 1996 bis 2016 bezüglich der durchschnittlichen Pfadlänge entwickelt? (Hier ist einerseits Ihre qualitative Expertenmeinung gefragt. Sollten Sie Daten dazu haben, die diese belegen, wäre dies sehr schön aber nicht zwingend.)

3. Ist unsere **Anwendung des Indikators „relative Zentralität"** Ihrer Meinung nach für das Strom- und die Wärmenetze passend? Kann dieser Indikator evtl. auch mit der Vermaschung des Stromnetzes in Bezug gebracht werden? Haben Sie Verbesserungsvorschläge?
4. Wie hat sich das Strom- und die Wärmnetze in der Region Weiz-Gleisdorf von 1996 bis 2016 bezüglich der relativen Zentralität entwickelt?

5. Ist unsere **Anwendung des Indikators „Modularität"** Ihrer Meinung nach für das Strom- und die Wärmenetze passend? Haben Sie Verbesserungsvorschläge?
6. Wie hat sich das Strom- und die Wärmnetze in der Region Weiz-Gleisdorf von 1996 bis 2016 bezüglich der Modularität entwickelt?

7. Mit welchen **Daten** könnte man diese Indikatoren - Ihrer Meinung und Erfahrung nach - quantifizieren?

Kontakt:

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2

Interviews with grid-operators (conducted per telephone in Mai 2017 by Susan Mühlemeier and Claudia R. Binder)

A.1.3 Interviewee list – anonymised

Abbreviation	Sector	Position	Situation	Date	Duration
G1	Energy industry (Grid operator)	Director	Telephone	10.05.2017	00:48
G2	Energy industry (Grid operator)	Collaborator	Telephone	31.05.2017	00:32

A.2 Module 2 (publication 2 and publication 3)

A.2.1 Interview outline (in German) – publication 2

Interviewleitfaden Weiz-Gleisdorf (7.11 – 11.11)

Vorgehen zum Interview

Erste Einführung der Forschungsinteressen:

Wir möchten die Entwicklung der Energietransformation in der Region nachvollziehen, in Bezug auf a) die Akteure und ihr Netzwerk und b) die technischen Aspekte. Für das aktuelle Interview konzentrieren wir uns dabei auf das soziale/technische System.

Soziales System:

1. Wer sind aus Ihrer Sicht die prägenden Akteure in der Region in Bezug auf die (Weiter-)Entwicklung des Energiesystems in der Region?
   > Konzept der sozialen Arenen erklären
2. Welche Arenen sind aus Ihrer Sicht besonders wichtig für die Gestaltung der Energiewende in der Region?
3. *Welche Arenen unterscheiden sich besonders, sind besonders unterschiedlich in der Art wie sie funktionieren?*
4. Wie sind diese Arenen untereinander vernetzt, welche Arenen arbeiten besonders eng miteinander zusammen?
5. Gibt es spezifische Subgruppen/Interessensgruppen im Netzwerk?
6. Können Sie die Grösse der Arenen abschätzen (% der Akteure pro Arena)

   > wer ist für die Gouvernanz/Steuerung/Management/Lenken des Systems wichtig?

Technisches System:

1. Tabelle Technologien / Technologiegruppen (Übersicht zur «technical disparity»), qualitative Differenzierung zwischen Technologiegruppen - Tabelle durchgehen

Fragen zu Daten:

2. Übertragungsnetz zwischen Produzenten und Konsumenten (direkt, regionale Mittelspannung) - gibt es eine Übersicht/Karte über das Stromnetzwerk, inkl. Umwandlungswerke?
3. Wärme-Versorgungssystems (Fernwärme) in Weiz und Gleisdorf (lokale Fernwärmenetze: wie viele Netzwerke gibt es? Wie gross, wie viele Produzenten und Konsumenten sind angeschlossen?
4. Wie ist der Anteil der Selbstversorger an den Gesamthaushalten (Elektrizität / Wärme) im Vergleich zum Gesamtbestand? Wie sieht es im Industriesektor aus?

Einschätzung durch die Experten:

5. *Wenn keine Daten vorhanden, Einschätzung zu Frage 4 & 5: Übertragungsnetz zwischen Produzenten und Konsumenten für Strom und Wärme: wie lange ist das Netz, wer ist angeschlossen und wie ist der Anteil der Selbstversorger am Gesamtbestand der Haushalte/Unternehmen?*
6. Was sind zentrale Interventionspunkte (Centrality) bei Störungen?
7. Können Teile des Systems abgekoppelt werden (Modularity), gibt es regionale Teilnetzwerke, oder sind die Leute in erster Linie Direktabnehmer?

Zusätzliche Fragen:

1. Kann man Erdgas regional durch Biogas ersetzen?
2. Rolle der Speicherung von Energie in der Region: wie kann die (erneuerbare) Energie gespeichert werden, was gibt es regional für Infrastruktur hierzu?

Arena / Disparity attribute	Industry	Associations	Research	Government
Structure / actor types	Enterprises, cooperatives	Local associations, LEADER groups,	Universities, research institutions	Communes, provinces, federal state
Communication/ rationality?	tbd	tbd	tbd	tbd
Coordination	Market	Network	Network	Hierarchy
operation type	investing, providing energy and energy-related products	Intra- and interregional networking	Developing and testing of new technologies	Regulating, subsidizing, investing in energy plants / research projects
Time horizon	Medium-term	Long-term	Medium-term	short-term
Scale	Local - international	Local - regional	Regional - National	Local – national

Tabelle 1: Social Disparity

Technology / Disparity attribute	Hydropower	Biogas	Biomass power plant (CHP)	Photovoltaic
Energy conversion efficiency (η)	0.85		0.85	0.08-0.16
Resource base	Water	Biomass	Biomass	Sunlight
Direct CO_2 emissions	No	Yes	Yes	No
Land consumption	Low	High	High	High
Dependency on weather events	Low	Medium	Medium	High
Costs (cent/kWh)	15.6-17.8	13.5-21-5	12.2	7.8-14.2

Tabelle 2: Technical Disparity

Interview-Outline for Interviews in the Energy Region Weiz-Gleisdorf (conducted in November 2016 by Romano Wyss)

A.2.2 Interviewee list – anonymised

Abbreviation	Sector	Position	Situation	Date	Duration
I1	Politics	Mayor	Face-to-face	08.11.2016	00:23
I2	Energy provider	Collaborator	Face-to-face	08.11.2016	00:57
I3	Research/foundation	Director	Face-to-face	09.11.2016	01:05
I4	Politics	Mayor	Face-to-face	09.11.2016	00:21
I5	Research/foundation	Director	Face-to-face	10.11.2016	00:46
I6	Research/foundation	Collaborator	Face-to-face	11.11.2016	00:42
I7	Association	Collaborator	Face-to-face	11.11.2016	00:16

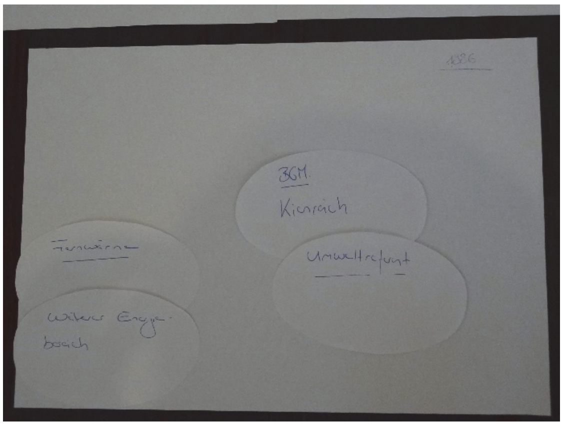
A.2.3 Code scheme

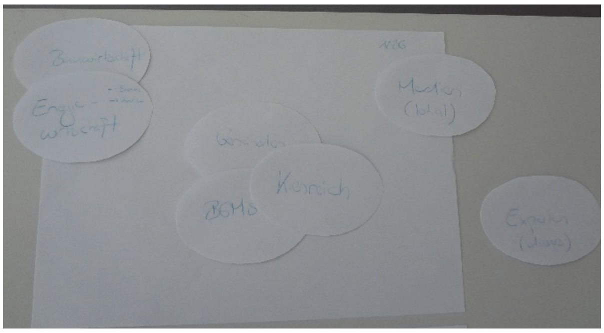
Code scheme	Memo
affiliation of interviewee	only self-information of the interviewee about his or her affiliation
politics	administration and or parliament, activity in party
local	
external	
industry	
energy	energy production
energy related	energy related services (e.g electricians)
others	
association	any kind of associations, foundations, etc.
research / education	research, university, schools
media	
proposed arenas	information on important entities or actors from specific arenas
politics	
local	communes, local politicians
external	national level, european level
industry	
energy - producing / distributing	energy companies, grid etc. industries producing and distributing energy
energy related	related like electricians, construction firms etc.
others	like tourism etc. seen as important for the energy transition
associations	
research / education	
media	
society	
interactions	
operative work	interaction in daily life, exchange, like for the production of a certain good in this coding only the "who with whom question" is answered later the "on which topic" and in "which way" do they interact, will be answered

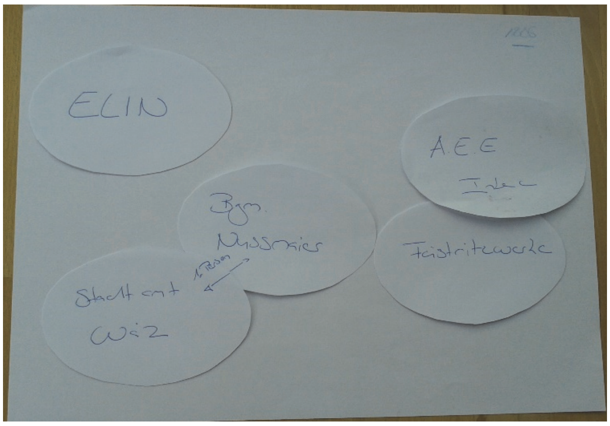
politics - industry	
industry - research	
politics - research	
associations - research	
associations - industry	
associations - politics	
policy - media	
associations - media	
relation to society	
creating new / innovation	cooperation or exchange for the creation of the new, innovations etc in this coding only the "who with whom question" is answered later the "on which topic" and in "which way" do they interact, will be answered
politics - industry	
politics - research	
industry - research	
associations - politics	
associations - industry	
associations - research	
associations - media	
relation to society	
ownership	who owns which assets (plants, etc.)
additional findings	

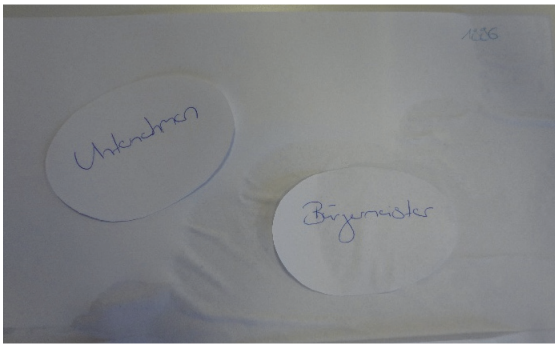
A.2.4 Mental model analysis data (in German) – publication 2

Mental models 1996

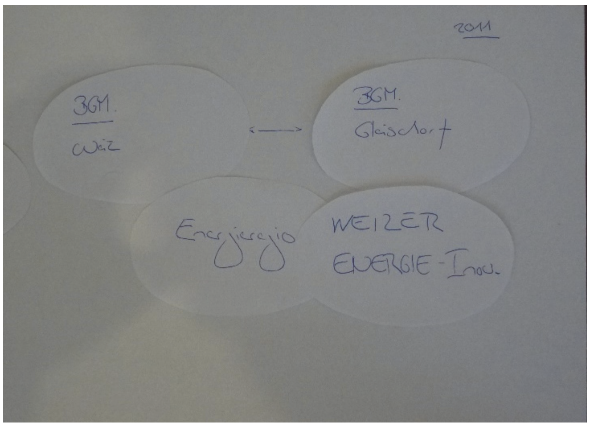


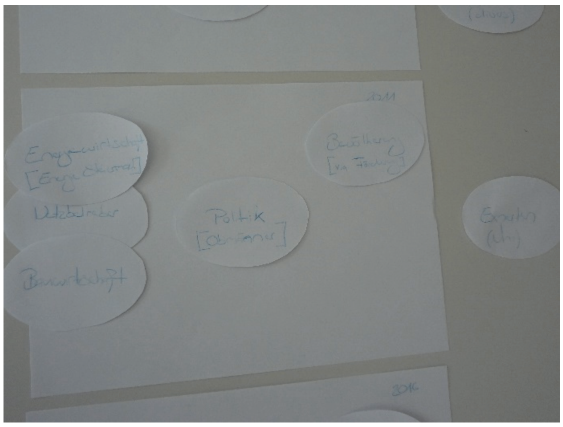


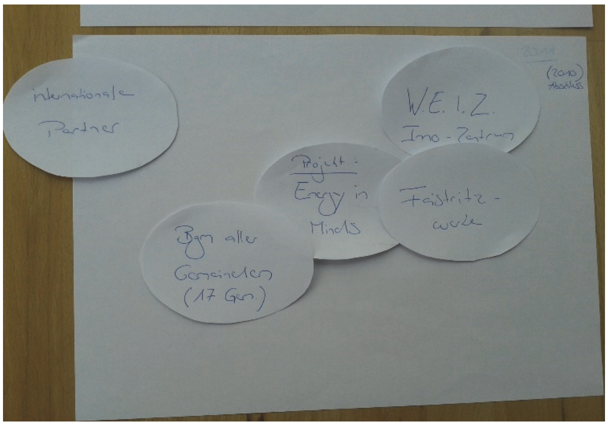


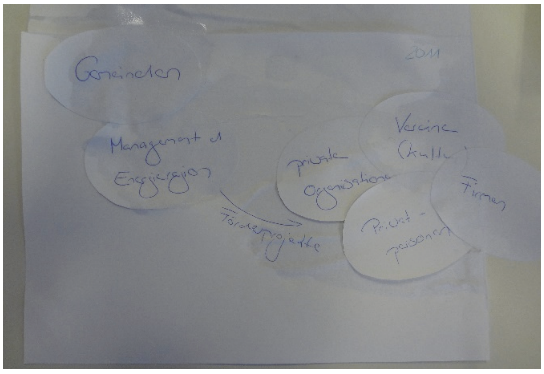


Mental models 2011

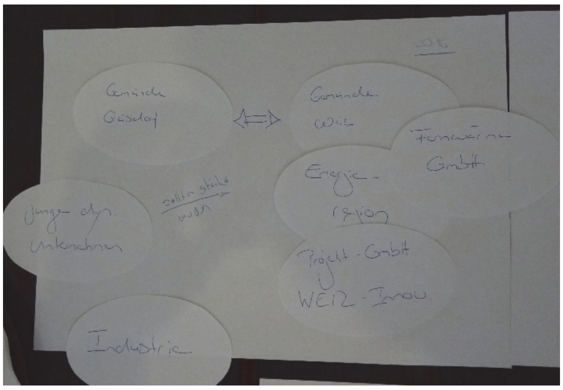


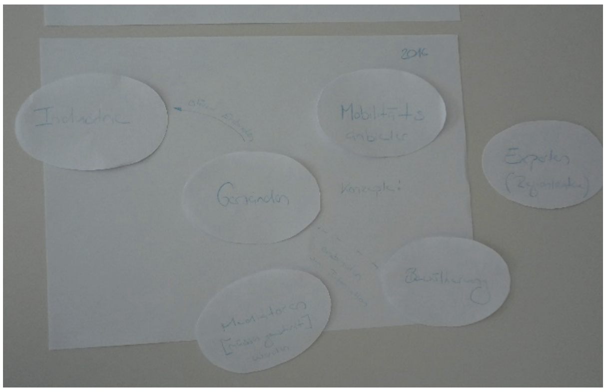


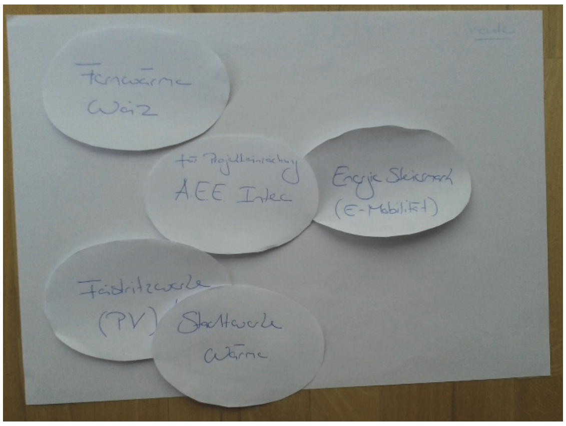


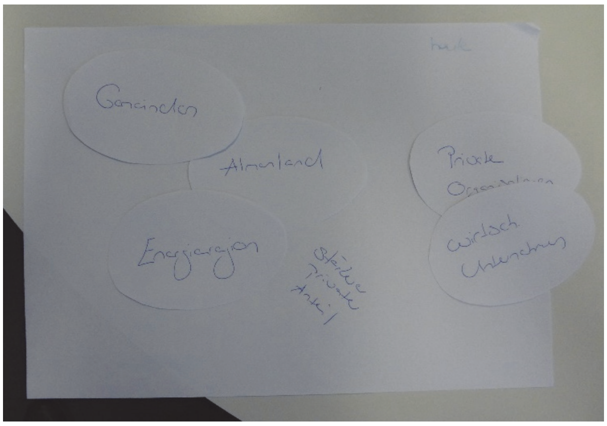


Mental models 2016

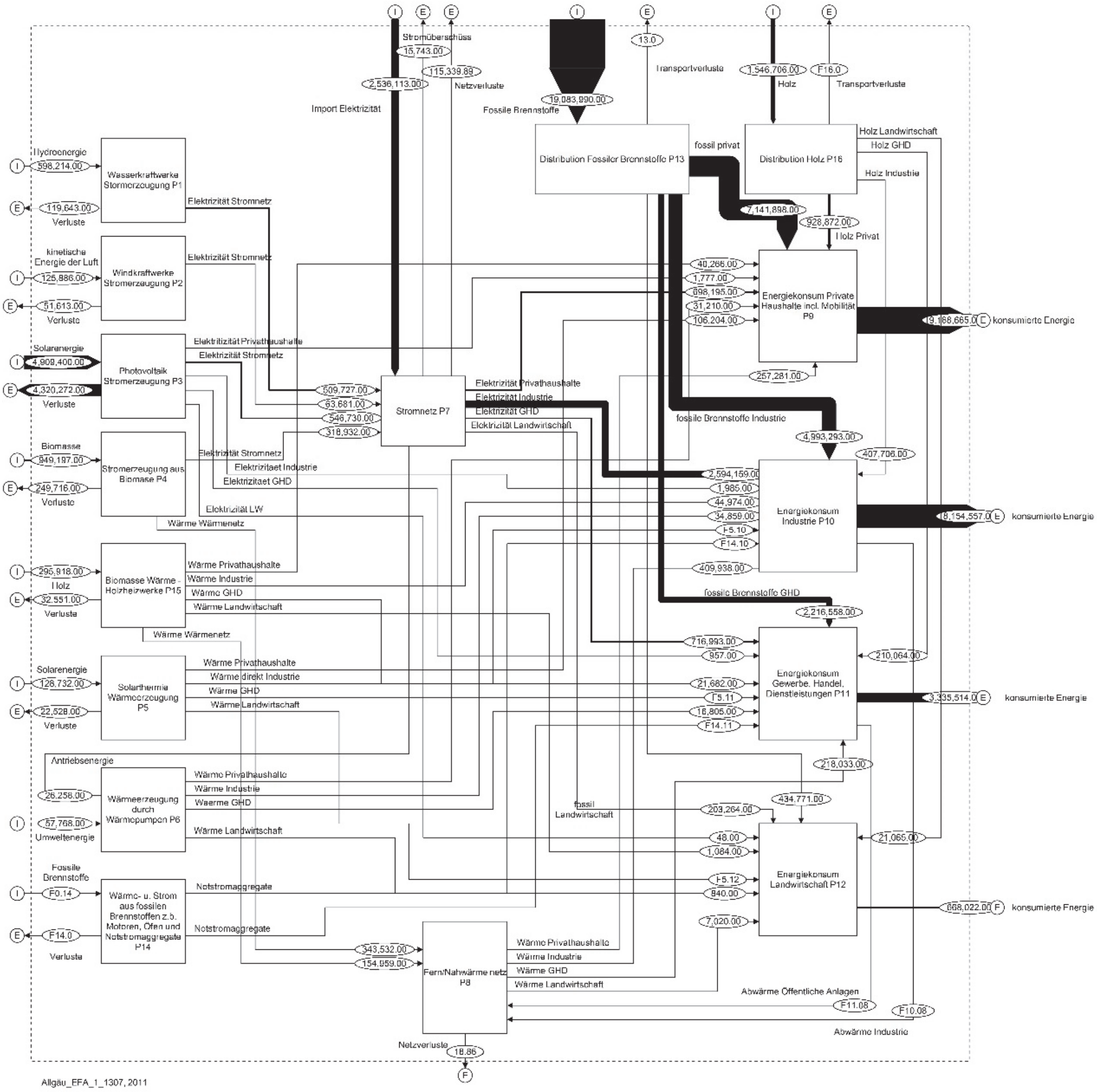








A.2.5 Energy flow analysis graph - publication 3



Energy flow analysis on the the region *bayerisches Allgäu,* conducted by Bärbel Hinterberger in 2016 (Master Student at LMU)

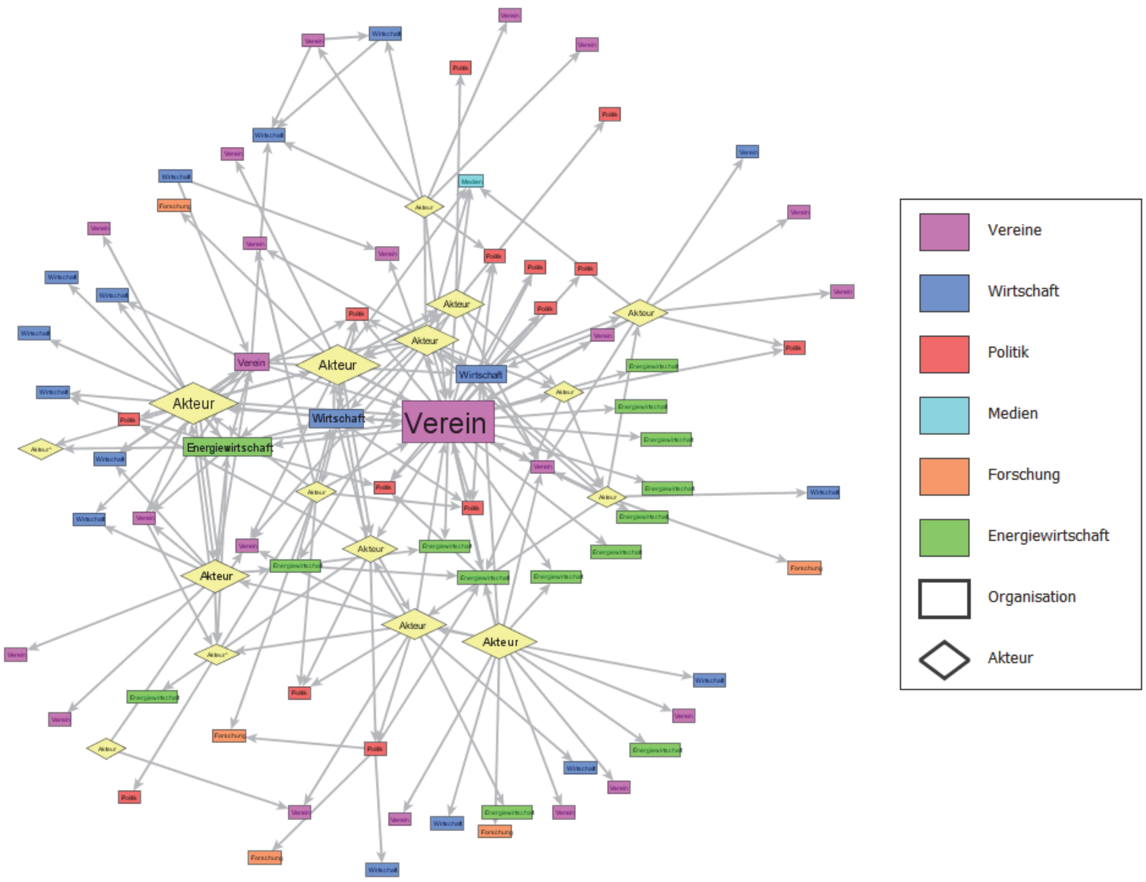
A.2.6 Social network analysis data - publication 3

Code Scheme

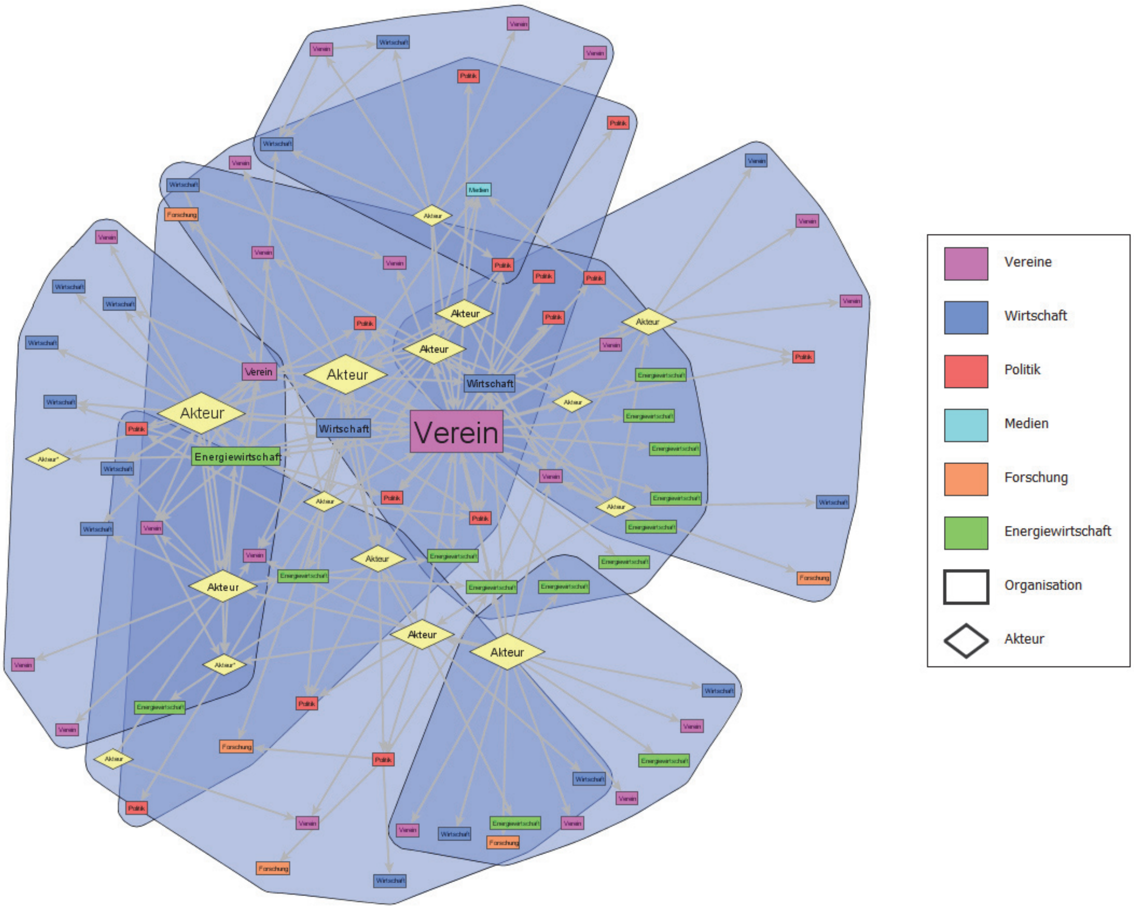
Code system	Memos
individual positions of the change agent	individual story, steps, positions
regional network of the change agent	connections to other actors
mentioned actors	actors mentioned by the change agent as being im portant for the regional energy governance system
mentioned organisations	mentioned names of networks, organisations, firms important for the regional energy governance system

Network graphs (VISONE) – in German

Degree centrality



Modularity


Verein
Akteur
Wirtschaft
Energiewirtschaft
Vereine
Wirtschaft
Politik
Medien
Forschung
Energiewirtschaft
Organisation
Akteur

A.3 Module 3 (publication 4)

A.3.1 Interview outline (in German)

Interview mit LMU Projekt „Transformationsprozesse zu einem nachhaltigen Energiesystem“

Interviewerin: Suse Mühlemeier (Doktorandin)

Verlauf der Energiewende

1. Wann begann Ihrer Meinung nach die **regionale Energiewende im Allgäu** (Auslöser, Rahmenbedingungen, besondere Ereignisse, regional und extern, Meilensteine)
2. Was zeichnet die **Energiewende im Allgäu** im Vergleich zu anderen Regionen besonders aus? positiv wie negativ?
3. Welches sind Ihrer Meinung nach, **DIE zentralen Akteure/Pioniere der Energiewende im Allgäu?**

Ihre Rolle

4. Wie würden Sie Ihre **eigene Rolle** im Rahmen der Energiewende beschreiben? (Zeitverlauf, Aktivitäten, Funktionen, Ämter)
5. Was waren ihre **drei Hauptmotive, bzw. Beweggründe** sich für die Energiewende in der Region zu engagieren und was hält sie bis heute dabei?
6. Welchen **Stellenwert** hat das Engagement für die Energiewende für sie? Eher Ehrenamtlich nebenher oder verdienen Sie damit auch Ihren Lebensunterhalt? Hobby? Beruf? Berufung?
7. Was waren die **größten Schwierigkeiten** bei der Durchsetzung ihrer Vorhaben und wie haben Sie sie überwunden?

Einflüsse aus dem Umfeld

8. **Förderliches**
   a. Welche **allgemeinen Einflüsse** (Gesetze, Fördergelder, Klimaereignisse..)
   b. welche **individuellen Akteure** und
   c. welche **Netzwerke**, bzw. Organisationen waren in diesem Prozess fördernd, **begünstigend?** (Parteien, Unternehmensnetzwerke, Fördervereine, Medien)
9. **Hinderliches:**
   a. Welche **allgemeinen Einflüsse** (Gesetze, Fördergelder, Klimaereignisse..)
   b. welche **individuellen Akteure** und
   c. welche **Netzwerke**, bzw. Organisationen waren in diesem Prozess hinderlich, bzw. **hemmend?** (Parteien, Unternehmensnetzwerke, Fördervereine, Medien)

Zukunft

10. Welche Faktoren werden für die **zukünftige Entwicklung** der Energiewende im Allgäu entscheidend sein?
11. Abschließend: Was haben Sie in all den Jahren **gelernt**?

Interviews were conducted from November 2014 – August 2015 by Holger Sauter, Thomas Knöpfle and Susan Mühlemeier

A.3.2 Interviewee lists – anonymised

Name	Sector	Position	Situation	Date	Duration
A1	Politics	Head of district administration	Face-to-face	11.08.2015	01:19
A2	Service provider/consulting	Director	Face-to-face	02.07.2015	01:15
A3	Industry / Research	Electrician	Face-to-face	20.01.2015	01:10
A4	Association / Industry	Director	Face-to-face	08.07.2015	01:15
A5	Service provider/consulting	Group leader	Face-to-face	02.03.2014	01:30
A6	Association	Director	Face-to-face	19.12.2014	01:00
A7	Energy industry	Windpower plant operator	Face-to-face	11.08.2015	00:55
A8	Industry	Director	Face-to-face	02.07.2015	01:40
A9	Industry	Senior manager	Face-to-face	21.11.2014	01:35
A10	Politics	Head of district administration	Face-to-face	08.07.2015	01:06
A11	Service provider/consulting	Senior consultant	Face-to-face	Without date	01:17
A12	Energy industry	Director	Face-to-face	08.07.2015	01:18
A13	Association / industry	Director	Face-to-face	20.11.2014	01:40
A14	Politics	Mayor	Face-to-face	12.03.2015	01:14

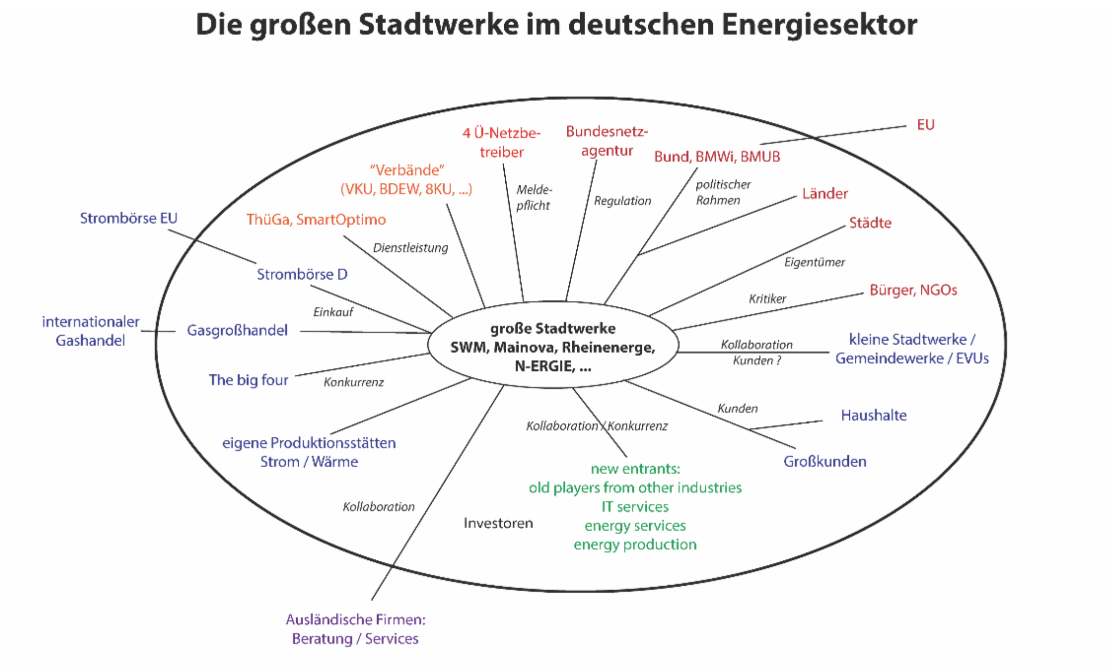
A.3.3 Code scheme

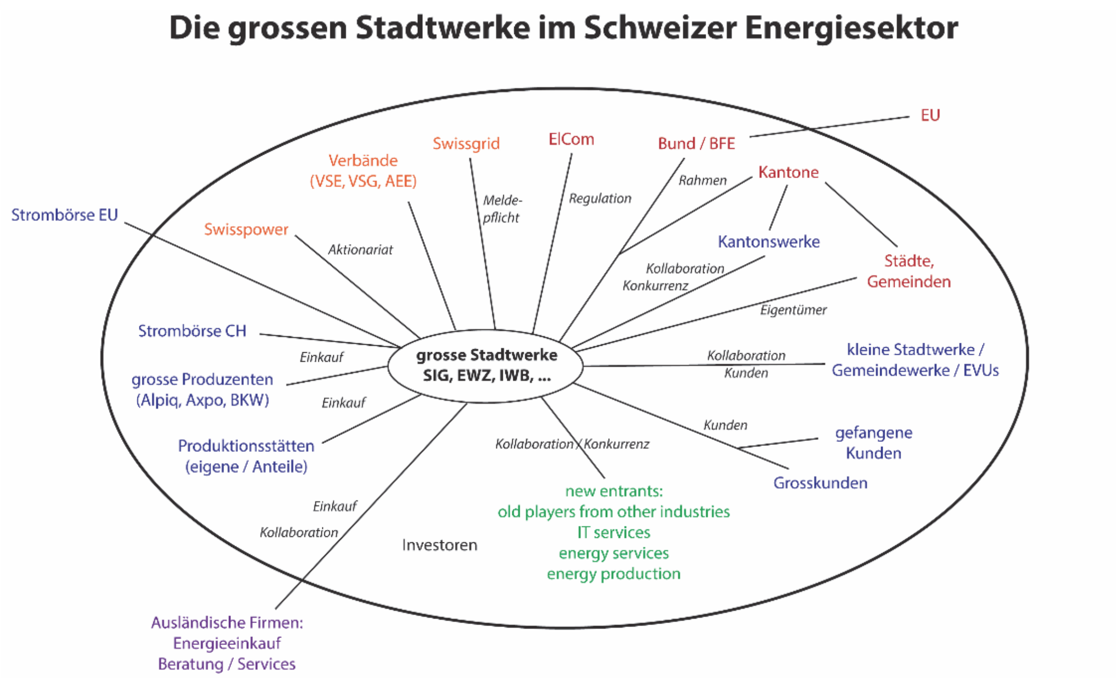
Code System	**Memos**
positions of the change agent	career path, individual steps, roled
Individual ressources	what the interviewees mentioned as their ressources e.g. personal network
individual motivation	their individual motivation, why do they engage themselves
individual values and beliefs	what are their individual beliefs and values, mentioned throughout the interview?
individual strategies	which strategies do their mention in the context of their engagement?
hindering factors for the energy transition	which hindering factors for the energy transition do they evaluate, regional
positive factors for the energy transition	which positive factors for the energy transition do they evaluate, regional
evaluation of the energy transition external to the region	how do they evaluate the energy region beyond the region
influence of politics	how do they evluate the influence of politics ?
influence of energy companies	how do they evaluate the influence of energy companies
influence of citizen initiatives	how do they evaluate the influence of citizen organisations
influence of society	how do they evaluate the influence of the wider society?
influence of cooperatives	how do the evaluate the influence of cooperatives
institutionalisation of energy transition	aspects mentioned in the context of institutionalisation, effects of their engagement
strategies of incumbents	which strategies do they observe?
personal learning processes	what are their personal lessons learnt from their engagement?
mentality of the regional actors (the Allgäuer)	apsects related to the regional mentality
regional path dependencies, influece of the area	aspects related to the influence of the region, the landscape etc.
strategies	which strategies do they mention for their engagement in the energy transition
additional findings	are there interesting additionoal findings?

A.4 Module 4 (publication 5 and publication 6)

A.4.1 Interview material and outlines (in German and French)

Actor Network Maps for Germany and Switzerland – which were discussed at the beginning of the interviews (see outline)





Interview-Leitfaden für Experteninterviews – Dissertation Mühlemeier

Der Energiesektor

1) Aus der Sicht der großen Stadtwerke: Wer sind die **wichtigsten Player im Energiesektor** in Deutschland? *(Diskussion der vorgelegten Akteurslandkarte)*

2) Wie ist hier die **Position der großen Stadtwerke** zu sehen und wie **interagieren** die großen Stadtwerke mit den anderen Akteursgruppen?

Charakteristika der großen Stadtwerke

3) Welche **strukturellen Besonderheiten** (innerhalb der Firmen) zeichnen die großen Stadtwerke in Deutschland im Vergleich zu anderen Energieversorgungsunternehmen aus?

4) Welche **firmenkulturellen Besonderheiten** zeichnen die großen Stadtwerke in Deutschland im Vergleich zu anderen Energieversorgungsunternehmen aus?

5) Wie verhalten sich die großen Stadtwerke in der **Energiewende**? Welche Rolle übernehmen sie und wie positionieren sie sich?

Herausforderungen und strategische Antworten

6) Was sind die **größten Herausforderungen** für die großen Stadtwerke im Kontext der Energiewende seit dem Jahr 2000 auf folgenden Ebenen:

- **Innerhalb des Energiesektors** mit Wettbewerbern, Kunden, Zulieferern
- Von **politischer Seite** (von lokaler bis nationaler Ebene)
- **Zivilgesellschaftlich** z.B. durch NGOs aber auch generelle Veränderungen in der Gesellschaft
- Hinsichtlich der **physischen Infrastruktur** (Netz, Leitungen, Kraftwerke...)
- Und letztlich **in den Stadtwerken** selbst (Umstrukturierungen, Personalien...)

7) Gab es unter diesen Herausforderungen **echte Schocks** für die großen Stadtwerke in Deutschland in den letzten 15 Jahren?

8) Wie haben die Stadtwerke auf diese Herausforderungen im Einzelnen **reagiert**?

- **Innerhalb des Energiesektors** (z.B. neue Produkte, Aufkäufe, strategische Allianzen)
- Von **politischer Seite**: Lobbyismus auf unterschiedlichen Ebenen,
- **Zivilgesellschaftlich** (z.B. CSR, gezielter Austausch oder bewusstes Ignorieren?)
- Hinsichtlich der **physischen Infrastruktur** (Investition in Erneuerbare, Kauf oder Verkauf von assets, Konzessionen)
- Und letztlich **in den Stadtwerken** selbst (Umstrukturierungen, Personalien...)

(Diskussion der vorgelegten Challenges and strategic answers map)

Zukunft der Stadtwerke

9) Wie schätzen Sie die **Zukunft der Stadtwerke** ein? Was sind **zukünftige Herausforderungen** der großen Stadtwerke im Vergleich zu anderen Energieversorgern?

10) Haben die Stadtwerke Ihrer Meinung nach **besondere Stärken** im Vergleich zu anderen Energieversorgern?

Stadtwerke und die Resilienz des Energiesystems

11) Wie schätzen Sie die **Rolle der Stadtwerke für die Stabilität und Anpassungsfähigkeit des Energiesystems** ein – auf politischer, wirtschaftlicher und technischer Ebene.

11.1) Tragen die großen Stadtwerke - mehr als andere Akteure – zur **Stabilität des Energiesystems** bei (z.B. Versorgungssicherheit, Preisstabilität, ...)?

11.2) Tragen die großen Stadtwerke – mehr als andere Akteure – zur **Anpassungsfähigkeit des Energiesystems** bei (z.B. Netzumbau, Ausbau der Erneuerbaren, DSM, neue Produkte etc.)?

12) Können Sie mir jeweils drei bis vier Punkte nennen, die Ihrer Meinung nach die **Stabilität** einerseits und andererseits die **Anpassungsfähigkeit der Stadtwerke an sich als Organisation** auszeichnen?

Weitere Kontakte

13) Haben Sie Hinweise für mich, welche Experten ich weiterhin interviewen sollte, die einen guten Überblick über den Energiesektor im Allgemeinen haben und sich spezifisch zu den Stadtwerken auskennen.

Kontakt

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(for the Interviews in Switzerland, I asked exactly the same questions, I only changed "Deutschland" into "die Schweiz" – see also french translation)

Guide d'entretien – Thèse doctorale - Susan Mühlemeier

Le secteur de l'énergie

1) Quels **acteurs** sont **les plus importants** dans le secteur de l'énergie en Suisse ? (Discussion du plan des acteurs)

2) Comment est-ce que les services industriels **interagissent** avec les autres acteurs du secteur de l'énergie en Suisse ?

Caractéristiques des grands services industriels

3) Quelles **particularités structurelles** distinguent les grands services industriels d'autres entreprises de production et de distribution d'énergie en Suisse ?

4) Quelles **particularités de la culture d'entreprise** distinguent les grands services industriels d'autres entreprises de production et de distribution d'énergie en Suisse ?

5) Comment est-ce que les grands services industriels se comportent dans **la transition énergétique en Suisse** ? Comment se positionnent-ils et quel rôle prennent-ils dans ce processus ?

Défis et réponses stratégiques

6) Quels sont **les plus grands défis** pour les grands services industriels en Suisse dans le contexte de la transition énergétique **depuis l'année 2000** :

- Sur le plan **économique** (le secteur de l' énergie) *(p. ex. les concurrents, les consommateurs, les producteurs)*
- Sur le plan **politique** (de la municipalité, le canton, … global)
- Avec **la société civile** *(p. ex. ONGs ou changements généraux dans la société)*
- Sur le plan du contexte physiques *(p. ex. les réseaux, les centrales, les ressources)*
- Et finalement au niveau des **services industriels** eux-mêmes *(p. ex. leur structure, tradition, …)*

7) Est-ce qu'il y a eu des **véritables bouleversements ou crises** pour les grands services industriels en suisse, depuis l'année 2000 ?

8) Comment est-ce que les grands services industriels ont **réagi à ces défis** ?

- Sur le plan **économique** *(p. ex. nouveaux produits, acquisition, alliances stratégiques)*
- Sur le plan **politique** *(p. ex. lobbyisme)*
- Avec **la société civile** *(p. ex. RSE, échange avec des ONGs)*
- Sur le plan du contexte physique *(p. ex. investissements, achat ou vente de centrales)*
- Et finalement au niveau des **services industriels** eux-mêmes *(p. ex. changements d'organisation ou de personnel)*

(Discussion sur « le plan des défis et réponses stratégiques »)

Le futur des grands services industriels

9) Quels sont **les défis futurs** pour les grands services industriels comparés aux autres entreprises de production et de distribution d'énergie en Suisse ?

10) Quels sont les points forts/avantages des grands services industriels comparés aux autres entreprises de production et de distribution d'énergie en Suisse ?

Les grands services industriels et la résilience du système énergétique

11) Qu'est-ce que vous pensez du rôle des grands services industriels pour **la résilience et la performance future du système énergétique** en Suisse – techniquement et socialement ?

11.1) Est-ce que les services industriels contribuent particulièrement **à la stabilité** du système énergétique (techniquement et socialement) ?

11.2) Est-ce que les services industriels contribuent particulièrement **à l'adaptabilité** du système énergétique (techniquement et socialement) ?

12) Qu'est-ce que vous pensez de **la résilience des services industriels** eux-mêmes ? Pouvez-vous citer trois aspects qui caractérisent d'une part la stabilité et d'autre part l'adaptabilité des services industriels en tant qu'organisations ?

Recommandations pour d'autres contacts

13) Pourriez-vous me recommander d'autres experts que je pourrais interviewer (qui ont un point de vue global sur le secteur énergétique et qui connaissent les services industriels en particulier) ?

Contact

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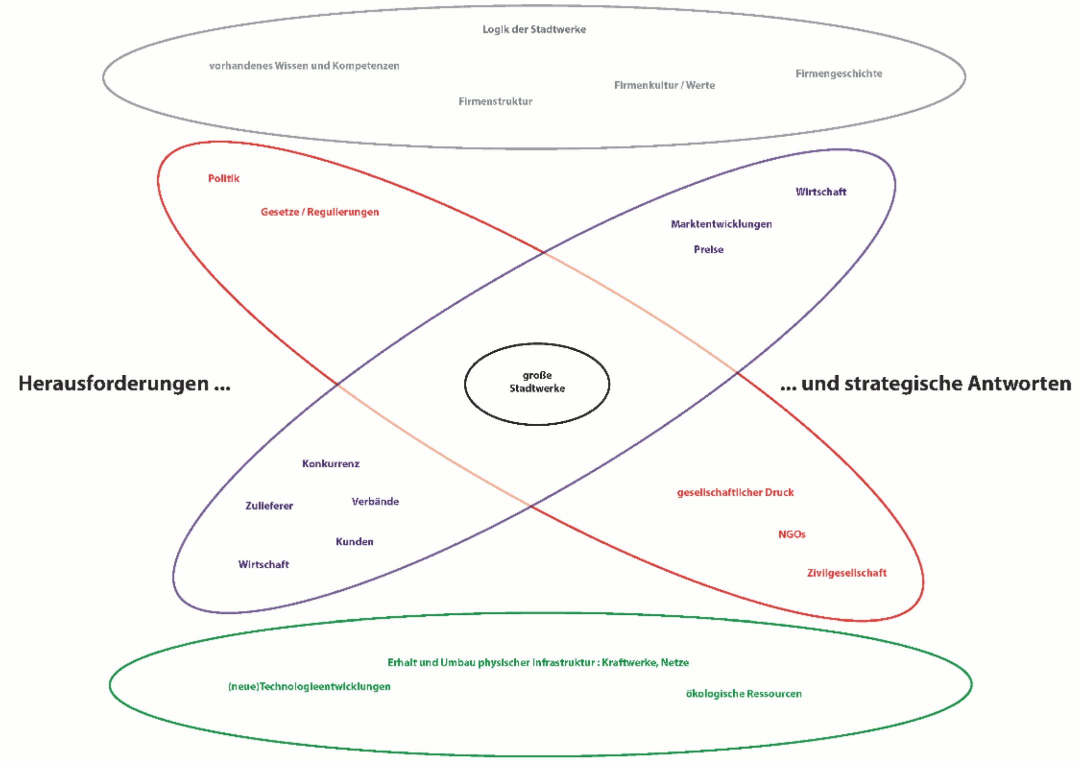
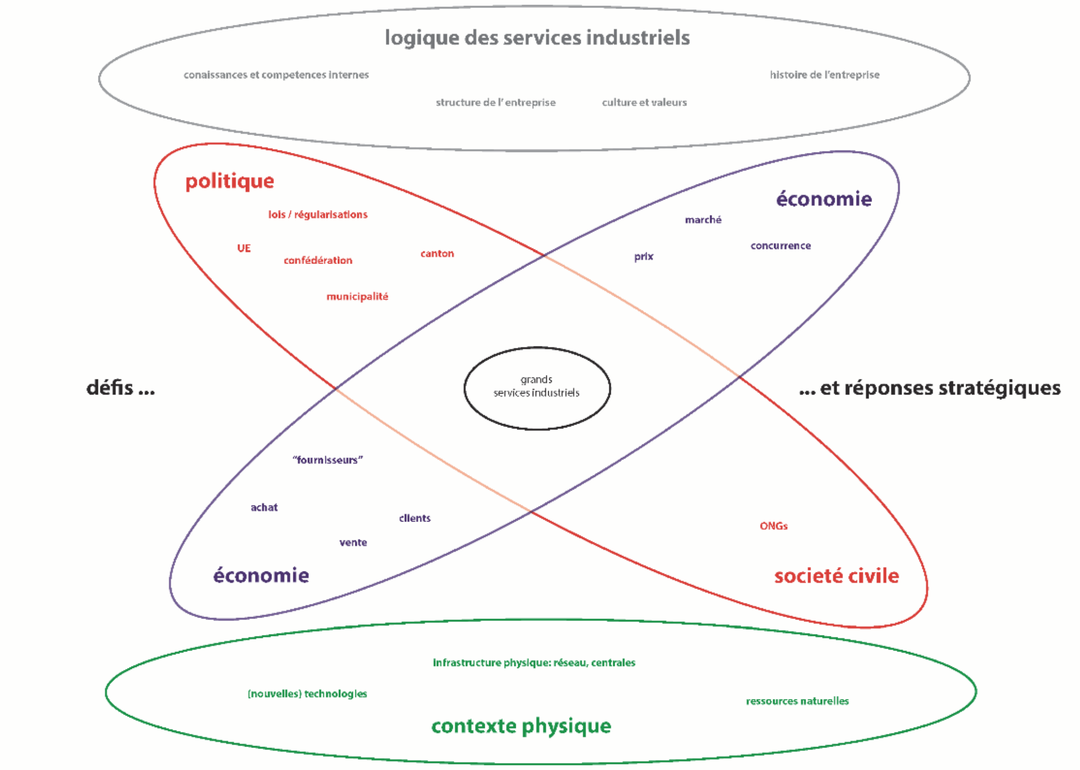
Challenges and opportunities maps (same for Germany and Switzerland)


Logik der Stadtwerke
vorhandenes Wissen und Kompetenzen
Firmenstruktur
Firmenkultur / Werte
Firmengeschichte
Politik
Gesetze / Regulierungen
Wirtschaft
Marktentwicklungen
Preise
Herausforderungen ...
große Stadtwerke
... und strategische Antworten
Konkurrenz
Zulieferer
Verbände
Kunden
Wirtschaft
gesellschaftlicher Druck
NGOs
Zivilgesellschaft
Erhalt und Umbau physischer Infrastruktur : Kraftwerke, Netze
(neue)Technologieentwicklungen
ökologische Ressourcen


logique des services industriels
conaissances et competences internes
structure de l' entreprise
culture et valeurs
histoire de l'entreprise
politique
lois / régularisations
UE
confédération
canton
municipalité
économie
marché
prix
concurrence
défis ...
grands services industriels
... et réponses stratégiques
"fournisseurs"
achat
clients
vente
économie
ONGs
societé civile
infrastructure physique: réseau, centrales
(nouvelles) technologies
ressources naturelles
contexte physique

A.4.2 Interviewee lists - anonymised

Switzerland

Abbreviation	Sector	Position	Situation	Date	Duration
CH1	Research/foundation	Professor	Face-to-face	02.03.17	01:00
CH2	Association	Collaborator	Face-to-face	09.03.17	01:16
CH3	Research/foundation	Research assistant	Face-to-face	09.03.17	01:13
CH4	Research/foundation	Professor	Face-to-face	09.03.17	00:54
CH5	Research/foundation	Director	Face-to-face	10.03.17	01:05
CH6	Association	Group leader	Face-to-face	10.03.17	01:08
CH7	Service provider/Consulting	Director	Face-to-face	10.03.17	01:26
CH8	UUC	Collaborator strategy department	Face-to-face	17.03.17	02:36
CH9	Association	Director	Face-to-face	20.03.17	00:39
CH10	Service provider/Consulting	Senior manager	Face-to-face	20.03.17	01:38
CH11	UUC	Collaborator strategy department	Face-to-face	20.03.17	00:55
CH12	Research/foundation	Director	Face-to-face	23.03.17	01:12
CH13	Administration (federal)	Group leader	Face-to-face	24.03.17	01:13
CH14	Middle-sized UUC	CEO	Face-to-face	27.03.17	01:08
CH15	Middle-sized UUC	Member of the executive board	Face-to-face	31.03.17	00:49
CH16	UUC	CEO	Face-to-face	04.04.17	01:16
CH17	Middle-sized UUC	CEO	Face-to-face	07.04.17	01:52
CH18	UUC	CEO	Telephone	19.04.17	00:18
CH19	Service provider/Consulting	Senior manager	Skype	19.05.17	00:53
CH20	Association	Director	Face-to-face	21.05.17	01:07

Germany

Abbreviation	**Sector**	**Position**	**Situation**	**Date**	**Duration**
DE1	Service provider/Consulting	Freelancer	Face-to-face	02.05.17	01:22
DE2	Service provider/Consulting	Senior manager	Telephone	02.05.17	00:51
DE3	Research/foundation	Professor	Skype	02.05.17	01:25
DE4	Research/foundation	Post-Doc	Face-to-face	05.05.17	01:01
DE5	Association	Senior manager	Face-to-face	05.05.17	01:30
DE6	Service provider/Consulting	Director	Face-to-face	19.05.17	00:57
DE7	UUC	CEO	Face-to-face	07.06.17	00:50
DE8	Research/foundation	2 Post-docs	Face-to-face	08.06.17	01:51
DE9	UUC	Collaborator strategy department	Face-to-face	08.06.17	00:56
DE10	UUC	2 Collaborators strategy department	Face-to-face	12.06.17	01:02
DE11	Service provider/Consulting	Director	Face-to-face	13.06.17	00:50
DE12	Service provider/Consulting	Senior manager	Face-to-face	14.06.17	01:52
DE13	Service provider/Consulting	CEO	Face-to-face	15.06.17	00:53
DE14	Research/foundation	Professor	Face-to-face	16.06.17	01:03
DE15	Association	Director	Face-to-face	16.06.17	01:20
DE16	Association	Director	Face-to-face	16.06.17	01:06
DE17	Service provider/Consulting	CEO	Face-to-face	07.07.17	00:51
DE18	Middle-sized UUC	CEO	Telephone	10.07.17	00:50

A.4.3 Code scheme

Code System			Memo
characteristics of UUC			mentioned structural and cultural characteristics
	structural		everything which is related to the "hard facts", size, portfolio,
		commonalities	what all UUC have in common
		differences	where there are differences among the UUC
	cultural		aspects related to the "soft facts", company culture, mind sets, belief systems - for the regime
		differences	what all UUC have in common
		commonalities	where there are differences among the UUC
position in the energy sector			mentioned important actors and relations of UUC to these actors
challenges			every aspect mentioned in the context of challenges
	past		challenges which the UUC faced in the past
		socio-policial	everything which is related to NGOs, politics, society, regulation
		economic	everything which is related to the business, competition etc.
		organisational	everything which is related to the organisation itself, the cultural aspects, the regime
	present		challenges in the present
		socio-policial	everything which is related to NGOs, politics, society, regulation
		economic	everything which is related to the business, competition etc.
		organisational	everything which is related to the organisation itself, the cultural aspects, the regime
	future		future challenges for the UUC
		socio-policial	everything which is related to NGOs, politics, society, regulation
		economic	everything which is related to the business, competition etc.
		organisational	everything which is related to the organisation itself, the cultural aspects, the regime
strategic answers			mentioned reactions oft he UUC tot he challanges, not necessarily any specific challenge, also general strategic answers
	in the past		
		socio-policial	everything which is related to NGOs, politics, society, regulation
		economic	everything which is related to the business, competition etc.
		organisational	everything which is related to the organisation itself, the cultural aspects, the regime

	present		
		socio-policial	everything which is related to NGOs, politics, society, regulation
		economic	everything which is related to the business, competition etc.
		organisational	everything which is related to the organisation itself, the cultural aspects, the regime
role for transition			answers and aspects related to the role of UUC for the energy transition or for the energy sector
	Transition		aspects related to the role of the UUC for the energy transition
		potential role	potential roles, where interviewees mentioned possibilities
		Current role	actual roles, where the interviewees mentioned exisiting contributions
	System		aspects related to the role of UUC for the current energy system / Systemdienstleistungen
		potential role	potential roles, where interviewees mentioned possibilities
		current role	actual roles, where the interviewees mentioned exisiting contributions
strenghts & weaknesses			answers and aspects related to strenghts and weaknesses of UUC
	strenghts		mentioned strenghts
	weaknesses		mentioned weaknesse
resilience			open collection of aspects mentioned in the context of resilience related questions
additional findings			additional interesting findings, open code

A.4.4 Workshop programme (in German and French)

ENAC / IIE

Laboratory on Human-Environment Relations in Urban Systems
Swiss Mobiliar Chair in urban ecology and sustainable living

Workshop-Einladung

„Die Rolle grosser Stadtwerke für Resilienz und Transition des Schweizer Energiesektors"

8. Juni 2018 | 09.00 – 12.00 Uhr (mit anschliessendem Lunch)

ETH Zürich, Tannenstr. 3, Gebäude CLA, Geschoss J, Raum 1

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Hintergrund und zentrale Fragestellungen

Liberalisierung, Decarbonisierung, Digitalisierung. Drei grosse Wellen fundamentaler Veränderungen dynamisieren seit 20 Jahren den vormals für lange Zeit statischen Schweizer Energiesektor.

Sie evozieren technische Veränderungen: neue Produktions- oder Speichermöglichkeiten entstehen. Darüber hinaus bieten digitale Daten neue Steuerungsmöglichkeiten und können als zusätzliche Ressourcenebene gesehen werden. Diese Veränderungen betreffen auch die soziale Seite des Energiesektors, das Gouvernanzsystem. Es treten neue Akteure auf bzw. alte Akteure aus anderen Industrien treten in den Sektor ein.

Es entstehen neue Aufgaben und Regulierungen bzw. befinden sich noch in der Aushandlung und es stellen sich **grundsätzliche Fragen nach Verantwortlichkeiten und den «Design-Prinzipien» des Sektors**.

Diese Fragen sind für die grossen Stadtwerke von besonderer Relevanz, da sie seit jeher zentrale Akteure des föderal organisierten Schweizer Energiesektors sind:

- Welche ihrer traditionellen **Verantwortlichkeiten** können und sollen die grossen Stadtwerke auch in Zukunft übernehmen? Welche Verantwortlichkeiten sollen sie abgeben, welche zusätzlich übernehmen? Zugespitzt gefragt: Wie stellt sich ihre Existenzberichtigung in Zukunft dar?
- Welche Verantwortung(en) übernehmen die grossen Stadtwerke dabei für die **Transformation** des Energiesektors und welche sollen sie in Zukunft übernehmen?

Diese grosse Transformation fordert vermehrt auch **die Resilienz des Energiesystems heraus** und stellt Politik, Wirtschaft und Technologieentwicklung vor die Herausforderung eine Transformation zu gestalten ohne die technologische und soziale Resilienz des Energiesystems zu gefährden.

<u>Technisch:</u> Einspeisevolatilitäten und politisch geförderte Überkapazitäten fordern z.B. die Netzstabilität heraus, die weitere Netzintegration erhöht auch die potenzielle Vulnerabilität der Netze,

<u>Sozial:</u> volkswirtschaftliche Kosten der Transformation schiessen z.B. in die Höhe, bisherige Geschäftsmodelle scheitern, der Service Public muss sichergestellt werden.

Für die grossen Stadtwerke stellen sich die Fragen:

- Welche Rolle spielen die grossen Stadtwerke aktuell für die **Resilienz** des Systems hinsichtlich dessen sozialer und technologischer Funktionalität?
- Welche Rolle(n) sollen sie für die **Resilienz des Energiesystems in Zukunft** übernehmen?

Ziele und erwartete Ergebnisse

Die zuvor erwähnten Fragen stellen das **Kernforschungsinteresse** meines Dissertationsprojektes dar und sollen in diesem Workshop mit Ihnen, Experten der Branche, in offener und kritisch-konstruktiver Weise diskutiert werden.

Als Diskussionsgrundlage präsentiere ich die **Ergebnisse meines Dissertationsprojektes**, die sowohl auf intensiver theoretisch-konzeptioneller Arbeit, als auch vertieften empirischen Analysen im deutschen und Schweizer Energiesektor basieren. Neben der Lektüre von Branchenberichten, Geschäftsberichten und wissenschaftlicher Literatur stütze ich meine Ergebnisse auch auf 40 Interviews mit Experten aus Forschung, Politik, Verbänden und der strategischen Leitung der Stadtwerke in beiden Ländern.

Der Workshop stellt dabei die letzte Etappe meines Dissertationsprojektes dar und ich erhoffe mir neben einer **kritischen Reflexion meiner Arbeit** vor allem eine **offene und in die Zukunft gerichtete Diskussion** mit Ihnen.

Die **Ergebnisse dieser Diskussion** sollen einerseits zurück in den akademischen Diskurs getragen werden und das Verständnis des Akteurs «grosses Stadtwerk» in föderalen Energiesystemen bereichern. Andererseits sollen sie auch von Ihnen in die Praxis mitgenommen werden können. Das präsentierte Resilienzdenken soll Ihnen dabei konkret eine weitere Perspektive zur Verfügung stellen, die Ihre Arbeit bereichern und Ihr Expertenwissen in einen anderen (neuen) Kontext stellen kann.

Ablauf und Inhalt

Zeit	Inhalt
08.45 – 09.00	**Ankunft und Kaffee**
09.00 – 09.10	**Einführung** *Claudia R. Binder, Susan Mühlemeier* - Begrüssung, Vorstellung der Teilnehmer - Ziele und Aufbau des Workshops
09.10 – 09.30	**Ergebnispräsentation** „Mögliche Verantwortlichkeiten der grossen Stadtwerke in der Schweizer Energietransition“ *Susan Mühlemeier* - Kausalmodelle zu mögl. Verantwortlichkeiten in Abhängigkeit von Transitionszielen (Liberalisierung, Decarbonisierung, Digitalisierung) und grundlegende Werten (Föderalismus, demokratische Kontrolle, service Public) - Mögliche Verantwortlichkeiten sind z.B. *pure grid manager, international producer of renewables, smart aggregator,* etc. - Potenzieller Beitrag der grossen Stadtwerke zur Transformation des Energiesystems unter Berücksichtigung der Kausalmodelle
09.30 – 10.15	**Expertendiskussion „**Verantwortlichkeiten in der Schweizer Energietransition“ Moderation: *Susan Mühlemeier* - Inhaltliches Feedback zur Weiterentwicklung der Kausalmodelle - Diskussion: Welches Modell wollen wir für die Zukunft?
10.15 – 10.30	Kaffee-Pause
10.30 – 11.00	**Ergebnispräsentation** „Soziale und technologische Resilienz regionaler Energiesystem in Transition“ *Susan Mühlemeier* - Konnektivität und Diversität, zentrale Bausteine des Konzepts sozialer und technologischer Resilienz in Transitionen - Anwendung des Konzepts auf Akteursebene: welche Rolle spielen die Grossen Stadtwerke für die soziale und technologische Resilienz des lokalen und (inter)nationalen Energiesystems
11.00 – 11.45	**Expertendiskussion** „Welchen Beitrag leisten die grossen Stadtwerke zur Resilienz des Energiesystems und seiner Transition“ Moderation: *Susan Mühlemeier* - Inhaltliches Feedback zur Weiterentwicklung der Resilienzperspektive - Diskussion: Wie tragen die möglichen Verantwortlichkeiten der Stadtwerke (Kausalmodelle) zur Resilienz des Energiesystems bei?
11.45 – 12.00	**Zusammenfassung, Ausblick und Praxisimplikationen** «Wie kann Resilienzdenken helfen, zukünftige Verantwortlichkeiten der Stadtwerke neu zu denken und in der Praxis zu gestalten?
12.00 – 13.00	Gemeinsamer Lunch im «Dozentenfoyer» der ETH Zürich

ENAC / IIE

Laboratory on Human-Environment Relations in Urban Systems
Swiss Mobiliar Chair in urban ecology and sustainable living

Invitation au workshop

„Le rôle des grands services industriels pour la résilience et la transition du secteur énergétique suisse »

5 Juin 2018 | 09h00 – 12h00 (suivi par un Lunch)

EPFL Campus Lausanne | **Salle CO 216**

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Contexte et questions clés

Libéralisation, décarbonisation et digitalisation. Pendant 20 ans, trois vagues de changement fondamental dynamisent le secteur énergétique suisse, qui était très statique les décennies précédentes. Ces vagues évoquent des changements technologiques : de nouvelles technologies de production et de stockage émergent, les données digitales offrent de nouvelles possibilités de gestion des réseaux et constituent une nouvelle base des ressources. Ces changements influencent également le côté social du secteur énergétique, à savoir le système de gouvernance. De nouveaux acteurs émergent, et acteurs d'autres secteurs entrent dans le secteur énergétique.

Des nouvelles tâches et règles sont développées ou sont en train d'être discutées et des questions fondamentales **sur les responsabilités et les « design principles » du secteur** se posent.

Pour les grands services industriels, ces questions sont particulièrement importantes, car ils sont depuis des décennies des acteurs clés du secteur énergétique en Suisse, qui est organisé d'une manière fédérale :

- **Quelles responsabilités** traditionnelles les grands services industriels, pourraient-ils continuer à assumer dans le futur? Quelles responsabilités devraient-ils céder aux autres acteurs et lesquelles devraient-ils assumer en plus ? Dit autrement, comment justifier leur existence dans le futur?
  - Quelle(s) **responsabilité(s) les grands services industriels assument-ils dans la transition énergétique** et lesquelles devraient-ils assumer dans le futur?

Dans cette large transformation du secteur se pose aussi de plus en plus la question de **la résilience du système énergétique. La** politique, l'économie et les développements technologiques doivent relever le défi de réaliser cette transformation sans compromettre la résilience technologique et sociale du système.

Technologiquement : les volatilités des rachats et la surproduction des énergies renouvelables mettent p.ex. à rude épreuve la stabilité des réseaux, l'intégration continue des réseaux augmente leur vulnérabilité potentielle.

Socialement : p.ex. les coûts économiques de la transition montent, les modèles économiques des fournisseurs traditionnels ne fonctionnent plus, le service public doit être assuré.

Pour les grands services industriels, les questions suivantes se posent :

- Quel est-**leur rôle pour la résilience du système énergétique** en Suisse – technologiquement et socialement. ?
- Quel(s) rôle(s) est-ce que les grands services industriels devraient assumer à l'avenir pour la résilience du système énergétique ?

Objectifs et résultats attendus

Les questions mentionnées ci-dessus représentent les sujets clés de ma thèse. Le but de ce workshop est de démarrer une discussion à propos de ces questions de manière ouverte et critique avec vous, experts du secteur énergétique.

Comme base de discussion, je présenterai **les résultats de mon travail doctoral**. Il est basé sur un travail conceptuel-théorique ainsi que sur les analyses empiriques du secteur énergétique en Suisse et en Allemagne. L'étude des rapports du secteur, des rapports annuels et la littérature scientifique ont été enrichis avec 40 entretiens d'experts tels que les représentants politiques, les associations, de la recherche, le conseil et les grands services industriels en Suisse et en Allemagne.

Le workshop représente la dernière étape de ma thèse et j'attends non seulement des réflexions critiques sur mon travail mais surtout une discussion ouverte sur le futur du secteur énergétique en Suisse.

Les résultats de cette discussion seront utiles d'un coté au domaine académique, dans le but de faciliter la compréhension d'acteurs « grands services industriels » dans les systèmes fédéraux; d'autre part, vous devriez pouvoir les appliquer dans le but d'enrichir votre travail. Finalement, les résultats et surtout la perspective de résilience devraient vous offrir concrètement une **perspective supplémentaire**, qui pourra enrichir votre travail et situer vos connaissances dans un autre (nouveau) contexte.

Déroulement et contenu

Horaire	Contenu
08.45 – 09.00	**Accueil et café**
09.00 – 09.15	**Introduction** *Claudia R. Binder, Susan Mühlemeier* - « Mot de bienvenue », présentation des participants - Déroulement et objectifs du workshop
09.15 – 09.30	**Présentation des résultats** „Les responsabilités possibles des grands services industriels dans la transition énergétique suisse " *Susan Mühlemeier* - Présentation des modèles de causalité en fonction des objectifs de la transition (libéralisation, décarbonisation, digitalisation) et des valeurs fondamentales (fédéralisme, contrôle démocratique, service public) - Responsabilités possibles : ex : *pure grid manager, international producer of renewables, smart aggregator*, etc. - Contribution potentielle des grands services industriels à la transition énergétique (sur la base des modèles)
09.30 – 10.15	**Discussion d'experts « Les responsabilités dans la transition énergétique suisse »** - Feedback au contenu des modèles de causalité - Discussion : Quel modèle que voulons-nous pour le futur ?
10.15 – 10.30	**Pause-Café**
10.30 – 10.50	**Présentation des résultats** „La résilience technologique et sociale des systèmes énergétiques en transition " *Claudia R. Binder & Susan Mühlemeier* - Diversité et Connectivité, composantes clés du concept « résilience technologique et sociale dans les transitions » - Application du concept au niveau des acteurs : Quel est-ce le rôle des grands services industriels dans la résilience technologique et sociale des systèmes énergétiques locaux et (inter)nationaux ?
10.50 – 11.30	**Discussion d'experts** „Comment est-ce que les grands services industriels contribuent à la résilience du système énergétique (en transition) ? » Modération : *Susan Mühlemeier* - Feedback sur la perspective de résilience et les opérationnalisations - Discussion : Comment est-ce que les possibles responsabilités (modelés de causalité) contribueraient à la résilience du système énergétique futur?
11.30 – 12.00	**Conclusion, perspectives et implications pour la pratique** « Comment la perspective de résilience peut-elle faciliter la réflexion sur et le design en pratique des responsabilités futures des grands services industriels ? »
12.00 – 13.00	**Lunch** au «Ristorante Gina» (Metro Station EPFL)

A.4.5 List of workshop participants (anonymised)

Workshop in Lausanne (05.06.2018)

Sector	Position
Research / foundation	Director
Urban utility company	Member of the administrative board
Middles sized urban utility company	Director
Consulting / service provider	Freelancer
Politics / administration (federal)	Group leader
Politics / administration (cantonal)	Director
Politics/ administration (municipal)	Director

Workshop in Zurich (08.06.2018)

Sector	Position
Research / foundation	Director
Urban utility company	Member of the administrative board
Middles sized urban utility company	Director
Consulting / service provider	Freelancer
Consulting / service provider	Director
Association	Director
Politics/Administration (municipal)	Director

A.4.6 Summary of workshop results (in German and French)

Präsentation: die Aktuelle Situation des Energiesektors und der grossen Stadtwerke Deutschlands und der Schweiz

Ausgangslage: Die Energiesektoren Deutschlands und der Schweiz durchleben seit 20 Jahren fundamentale Wandlungsprozesse. Europäische Integration, fortschreitenden Liberalisierung, politisch gesteuerten Dekarbonisierung und Denuklearisierung der Energieproduktion sowie Dezentralisierung und Digitalisierung durch fortschreitenden technologischen Wandel (Folie 9).

Gleichzeitig, basieren die Energiesysteme in beiden Ländern auf unveränderlichen Grundeigenschaften, die trotz des Wandels gewahrt werden (sollen): die Versorgungssicherheit und Wirtschaftlichkeit der Energieversorgung, ihre föderale und basisdemokratische Grundordnung, die mit direkter demokratischer Kontrolle über kritische Infrastrukturen einhergeht, sowie die Idee des Service Publics, der eine zuverlässige, gleichmässige und qualitativ hochwertige Energieversorgung in allen Landesteilen zu fairen Preisen verlangt (Folie 12).

Die Energiesysteme müssen sich daher fundamental wandeln und gleichzeitig stabil bleiben. Diese Ausgangslage verursacht vielfache Herausforderungen für traditionelle Akteure, wie die grossen Stadtwerke, deren Mandat das Garantieren von Stabilität umfasst, von denen aber gleichzeitig verlangt wird, sich an die grundlegenden Veränderungen anzupassen.

Charakteristika der grossen Stadtwerke: Die grossen Stadtwerke Deutschlands und der Schweiz, können trotz individueller Verschiedenheit durch folgende Gemeinsamkeiten charakterisiert werden:

- sie sind in öffentlicher Eigentümerschaft (der Stadt oder des Stadtkantons),
- sie versorgen die Endkunden im städtischen Gebiet,
- sie sind in mehreren Bereichen des Service Publics tätig und dabei
- auch in mehreren Energieformen (Strom, Gas, Fernwärme/kälte).

Sie agieren zudem alle als voll integrierte Energiekonzerne, die alle Wertschöpfungsstufen im Energiesektor abdecken und gehören trotz ihrer kommunalen Verankerung zu den grössten Energiekonzernen des Landes (Folie 17).

Die erwähnte Ausgangslage des Energiesektors, zusammen mit den aufgeführten Eigenschaften der grossen Stadtwerke, führen zu einer **steigenden Anzahl und Komplexität** ihrer **Rolle(n) im Energiesystem** (Folie 21), und haben **diverse spezifische Herausforderungen** zur Folge (Folie 20).

Die im Anschluss diskutierten Modelle zeigen mögliche Szenarien auf, welche Rollen die Schweizer Stadtwerke in Zukunft übernehmen könnten. Die hier zusammengefassten Ergebnisse spiegeln dabei ausschliesslich die Inhalte der Gruppendiskussionen wider.

Gruppendiskussion: Modelle über mögliche zukünftige Verantwortungen der grossen Stadtwerke

Modell 1: «Voll integrierter Energiekonzern»

Beschreibung: « business as usual » Die grossen Stadtwerke agieren weiterhin als voll integrierte Energiekonzerne in allen Bereichen (multi-energy und multi-utility) entlang der gesamten Wertschöpfungskette. Sie sind dabei nicht auf die Energiewirtschaft allein fokussiert, sondern bieten auch Services in allen Wertschöpfungsstufen an (incl. Datenmanagement). Ausser im Bereich des Netzbetriebs, befinden sie sich überall im Wettbewerb mit anderen grossen Stadtwerken und anderen öffentlichen und privaten Akteuren.

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Feedback

- **Versorgungssicherheit:** positiv, da Kontrolle über alle Teile der Wertschöpfungskette.
- **Föderalismus:** neutral, erhält status quo.
- **Wirtschaftlichkeit:** eher negativ, kann «genug Energie für den besten Preis» so garantiert werden? Eher hohe gesellschaftliche Kosten, die Wettbewerbsintensität nimmt zu.
- **Service Public:** positiv, starke direkte politische Kontrolle und wichtige Rolle der Politik in allen Wertschöpfungsbereichen, Stärkung des Service Publics.
- **Liberalisierung:** negativ, Modell wirkt sich Wettbewerbshemmend auf der Produktionsseite aus, Schwächung der Liberalisierung.
- **Dekarbonisierung:** positiv, politische Ziele können direkt durch- und umgesetzt werden.
- **Digitalisierung:** eher negativ, da grosse Stadtwerke eher analoge Unternehmenskultur haben, Modell kann sich zusammen mit Dekarbonisierung auch positiv auf Digitalisierung auswirken.

Gewinner dieses Modell wären die grossen Stadtwerke, Städte und Aktionäre. **Verlierer** des Modells wären die Kunden, da das Modell hohe Kosten für die öffentliche Hand verursacht (Dekarbonisierung, Speicherausbau).

Das Fortbestehen dieses Modells wurde als **sehr wahrscheinlich** eingeschätzt, es hängt jedoch von politischen Entwicklungen ab, wie z.B. dem Stromabkommen mit der EU, sowie dem Willen der Kunden, die Kosten dieses Modells zu tragen.

Modell 2: «Produzent und Netzbetreiber»

Beschreibung: Die grossen Stadtwerke verkaufen den Endkunden-"retail", da dieser in einem voll liberalisierten Markt nicht mehr profitabel ist. (Dieses Modell ist inspiriert bei dem norwegischen Fall Trønder Energie, die genau diesen Schritt unternommen haben.) Grosse Online-Plattformen übernehmen das Endkundenmanagement und die grossen Stadtwerke bieten keine Servces mehr für Endkunden an. Davon abgesehen bleiben die Aufgaben und Funktionen der grossen Stadtwerke jedoch die gleichen.

Feedback

- **Versorgungssicherheit:** eher negativ, da dezentrale Produktion schwieriger aufbaubar und ohne direkte Verbindung zwischen Produktion und Verbrauch mehr Volatilitäten im System.
- **Föderalismus:** negativ, es werden nicht mehr die föderalen Grundeinheiten betreut, sondern andere marktbasierte Einheiten.
- **Wirtschaftlichkeit:** positiv, das System funktioniert nur noch über Preissignale, allerdings auch negativ, da lokale Synergien nicht mehr nutzbar, Externalitäten müssen von der Gesellschaft gezahlt werden («wenn's keiner mehr zahlt, zahlt's der Steuerzahler» Beispiel alpiq und die Kernenergie, «Kernenergie war auch nie Kundengetrieben»).
- **Service Public:** negativ, Kunde steht zwischen mehreren Anbietern, hat mehr Risiko, höhere Bürokratie, aber auch gesamtsystemisch: Schuld an Fehlern wird zwischen verschiedenen Akteuren hin- und hergeschoben, unklare Verantwortungen.
- **Liberalisierung:** positiv, fördert konsequente Durchsetzung, freien Markt, kleine Retailer können in den Markt einsteigen, unabhängig von Asset-Grundlage.
- **Dekarbonisierung:** positiv und negativ: positiv, da Energiepolitik auf Systemebene direkt umgesetzt würde und auf der anderen Seite die Kunden/Bürger direkt aktiv werden könnten, dennoch schwierig da keine Gesamtlösungen und Sektorkopplung mehr, Verlust des direkten Bezugs zu den Bürgern, daher soziale Akzeptanz schwieriger.
- **Digitalisierung:** positiv für die Energiewirtschaft - es bilden sich Plattformen / negativ für die smart city, kein Kundenkontakt mehr, die für Verbesserung des service public genutzt werden müsste.

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Das Modell erschien während der Diskussion **schwer vorstellbar bis unvorstellbar**. Stadtwerke würden im Netzbereich nach wie vor die Endkunden betreuen, sonst aber Grosshandel machen und hätten keinen Anreiz mehr in eigene Produktion zu investieren, wenn sie sie nicht mehr direkt absetzen könnten (würde zu Modell 4 führen oder zu alpiq/axpo nahen Strukturen, aufspalten von Netz, guter und schlechter Produktion - was jedoch auf lokaler Ebene nicht sinnvoll ist)

Verlierer wären die Querverbundsstadtwerke sowie die Kommunen selbst, die die Gesamtsicht auf das städtische System verlieren würden (die Stadtwerke würden den Bezug zu «ihrem» Raum verlieren). Gewinner müsste der Kunde sein, der einen günstigeren Energiepreis bekommt, empirische Beispiele aus Deutschland zeigen aber das Gegenteil. Der Steuerzahler verliert am Ende, da die Gesamtkosten des Systems steigen. Am Ende gewinnen hier wahrscheinlich nur die (privaten) Retailer.

Modell 3: «Netzbetreiber und Versorger»

Beschreibung: Die grossen Stadtwerke verkaufen ihre Produktion, da die zentrale Produktion nur noch rentabel betrieben werden kann, wenn sie von zentralen Akteuren gemanagt wird (Skaleneffekte). Die dezentrale Produktion hingegen wird von den Prosumern übernommen. Die grossen Stadtwerke konzentrieren sich daher auf das Netzmanagement und das Kundengeschäft (wie heute die kleinen EVUs). Sie bieten zwar keine Services im Bereich der Produktion mehr an (Projektierung etc.), bauen jedoch ihr Serviceangebot im Kundenbereich aus (z.B. Prosumermanagement). Abgesehen vom Netzbetrieb, befinden sich die Stadtwerke im Wettbewerb mit anderen öffentlichen und privaten Akteuren.

Feedback

- **Versorgungssicherheit**: neutral, Netzseitig /auf Netzstabilität kein Einfluss, für Produktion ebenfalls neutral, wenn sonst im System genug Energie vorhanden, Verantwortung für produktionsseitige Versorgungssicherheit muss dann neu definiert werden, ebenso wie Systemgrenzen (lokale, nationale oder europäische Versorgungssicherheit?).
- **Föderalismus:** kein Einfluss, wird nur beeinflusst, wenn die Grösse der Werke beeinflusst wird (z.B. Zusammenschlüsse).
- **Wirtschaftlichkeit:** neutral, Denuklearisierungsproblem dann z.B. ein nationales Problem aber dennoch nicht gelöst, «gute» wie «schlechte» Produktion wäre dann auf anderer Ebene zu finanzieren (ob privat oder öffentlich bleibt fraglich).
- **Service Public:** neutral, Grundversorgungsauftrag bleibt gleich, fraglich wie neuer service public der digitalen Vernetztheit gemanagt wird.
- **Liberalisierung:** positiv unterstützend, Stadtwerke kaufen dann auf dem Markt und verkaufen mit geringer Marge, eventuell neue (private) Akteure in Produktion.
- **Dekarbonisierung:** positiv, Stadtwerke fördern Ausbau nicht mehr selbst, schaffen aber als Netzbetreiber Voraussetzungen für Netzkonvergenz und dezentrale Produktion, Prosumers, Genossenschaften etc., «wer Produktion hat, ist viel zu sehr auf die Produktion fokussiert das ist «Dinosaurierementalität». Fraglich, wie Anreize für weiteren Ausbau gestaltet werden müssen. Für Denuklearisierung ebenfalls positiv, da zum nationalen Thema erhoben.
- **Digitalisierung:** positiv, da Stadtwerke immer noch alle Netze haben und Gesamtsystemsicht.

Als Verlierer wurden die Stadtwerke selbst angesehen, da ihre wirtschaftliche Handlungsfähigkeit ohne eigene Produktion eingeschränkt würde und eine stärkere Abhängigkeit von Marktpreisen bestünde. Gleichzeitig seien sie aber auch **Gewinner**, da sie nach wie vor als Querverbünde die integrative Wirkung für ihren städtischen Raum hätten. Das Modell wurde als **wahrscheinlich** eingeschätzt.

Modell 4: «Smart Aggregator»

Beschreibung: Die grossen Stadtwerke verkaufen sowohl Produktion als auch den Endkunden"retail" und sind nur noch im regulierten Monopolbereich des Netzbetriebes aktiv. Allerdings ist das Monopol

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auch auf das Gebiet des Flexibilitätenmanagements und der Netzservices ausgeweitet (DSM, Aggregation). Damit einhergehend ist das Management privater Daten und Systemdaten zum Service Public deklariert und wird ausschliesslich von öffentlichen Entitäten - den grossen Stadtwerken und Kantonswerken - übernommen.

Feedback:

- **Versorgungssicherheit:** eher negativ, da Netzbetrieb nur ein Teil der Versorgungssicherheit, Produktion und Handel sind ebenso wichtig, Informationen aus Produktion und Handel fehlten so.
- **Föderalismus:** eigentlich positiv, im Energiebereich sei der Föderalismus aber sowieso fraglich, da Bund und Kantone unterschiedliche Ziele haben.
- **Wirtschaftlichkeit und Service Public:** eher negativ, Wirtschaftlichkeit sei das eigentliche Ziel des Modells (im Sinne von Unbundling etc.) jedoch stark abhängig von der Regulierung, es bedarf in jedem Falle sehr viel mehr Regulation um Funktionalität des Sektors zu garantieren. Für die zentrale Produktion (Skaleneffekte) ist es sicher positiv, für das Gesamtsystem wurde es jedoch negativ eingeschätzt.
- **Liberalisierung:** negativ für Netzbereich da das Monopol ausgeweitet / keine Liberalisierung im Netz. Für andere Wertschöpfungsbereiche positiv.
- **Dekarbonisierung:** negativ, da dezentrale (erneuerbare) Produktion erschwert, «man hat keinen Einfluss auf den Ausbau», «reine Netzbetreiber haben kein Interesse an erneuerbarer Produktion» (Regulierung wichtig!). Allerdings könnte sich block chain basiert auch ein «Aufschwung der dezentralen Erneuerbaren ergeben», das sei aber stark abhängig von den Bürgern..
- **Digitalisierung:** unklar, wie sich das Modell auswirkt.

Verlierer des Modells wären die Kunden (private und Industriekunden, bzw. Unternehmen), die höhere Energiepreise in Kauf nehmen müssten und für ihre Energieversorgung mit einer zunehmenden Anzahl an Akteuren interagieren müssten. Städte und Aktionäre wären ebenfalls Verlierer. **Gewinnen** würden dagegen die Händler und grossen Produzenten, aber auch die Netzbetreiber.

Offene Fragen bezüglich Modell 4: «Ist das Stadtwerk denn dann überhaupt noch ein nützliches Konstrukt?» Ein Stadtwerk zeichnet sich ja auch durch seine politische Rolle aus, z.B. ökologische Themen voranzutreiben. Es wäre besser, wenn überall alle Energieformen in einem Stadtwerk integriert wären. Wer übernimmt die anderen Aufgaben, aus denen sich die grossen Stadtwerke zurückziehen, wie wird das reguliert?

Aus Sicht der Gruppe **kein erstrebenswertes Modell**.

Offene Fragen und Feedback aus der gesamten Gruppendiskussion

- Die Modelle sind zu stark aus «Elektrizitätsperspektive» designt, stärkere Berücksichtigung des Wärmesektors nötig.
- Der Aufbau der Modelle in Produktion, Netz, Verteilung entspricht nur der zentralisierten Produktion, für dezentrale Produktion so nicht zutreffend.
- Modell 5 (Folie 30) ist unrealistisch.
- Zeit- und Raumdimensionen der Modelle müssten noch weiter ausdefiniert werden.
- Effekte der Modelle hängen stark an der (nationalen) Regulierung des Sektors.
- Handel ist nicht gut definiert, klarer differenzieren was gemeint ist: «Energiebeschaffung» oder «Handel» im Sinne von «Grosshandel».
- Rolle der Netze: Welche Ziele hat die Gesellschaft für die Netze und wer finanziert das?
- Unbundling war ursprünglich Werkzeug zur EU Integration und Aufbrechen zentralisierter Systeme, für dezentrale und digitalisierte Systeme nicht sinnvoll.

5

Präsentation: Resilienz soziotechnischer Systeme – theoretische Perspektive

Ein resilientes sozio-technisches System «kann externe und interne Schock dergestalt absorbieren, dass seine Funktionalität niemals gefährdet ist». Die nötigen Systemfähigkeiten sind dabei seine «Robustheit, Anpassungsfähigkeit und die Fähigkeit der Subsysteme sich zu transformieren, sodass die Resilienz des Systems erhalten bleibt» (Folie 39). Stabilität und Flexibilität können daher als Pole der Resilienz eines Systems festgehalten werden. Um die Resilienz eines Systems analysieren zu können, wurden sechs Indikatoren vorgeschlagen, die Kerncharakteristika eines resilienten Systems operationalisieren: Diversität und Konnektivität (Folie **41**).

Gruppendiskussion: Die Rolle der grossen Stadtwerke für die Resilienz des Schweizer Energiesystem

Es wurden verschiedene Vorschläge gemacht, wie die grossen Stadtwerke zur sozialen und technologischen Resilienz des Schweizer Energiesektors beitragen – z.B. ihre Investitionen in Erneuerbare Energien, die die technologische Diversität erhöhen oder ihre Funktion als lokale Koordinator der verschiedenen Energieformen und Service Public Bereiche, die ihnen Sektorkopplung und Netzkonvergenz erlauben, die wiederum die Konnektivität des Systems erhöhen (Folien **44 - 45**)

Feedback

Bürger = Kunde = Eigentümer: Die Identifizierung und Nähe zum Bürger hat grosse Auswirkungen auf das Handeln der Stadtwerke. Die **Vernetzerfunktion der Stadtwerke** ist daher ein wichtiger Beitrag zur Systemstabilität. Und je grösser der Veränderungsdruck, desto höher das Bedürfnis nach Stabilität. Jeder Stakeholder sieht dabei in den Stadtwerken etwas Anderes. Und da sie das „aushalten" und diese Vielfalt erlauben, tragen sie auch **durch Diversität zur Stabilität** des Systems bei.

Die vielen unterschiedlichen Anforderungen an die Werke hemmen dabei jedoch gleichzeitig ihre Flexibilität, und es ist fraglich ob sie so wirklich den entscheidenden Beitrag zur **Flexibilisierung des Systems** leisten (z.B. durch Investitionen in smartness) oder ob nicht hier andere Akteure die Führung übernehmen (z.B. Swisscom/tiko). Fraglich bleibt auch, ob die Stadtwerke mit dem Veränderungstempo mithalten können, ob ihre eigene Flexibilität dazu hoch genug ist.

Die Idee, alles im eigenen Haus selbst machen zu wollen (hohe Diversität, die für die Stabilität positiv eingeschätzt wurde), scheint für die Flexibilisierung wenig förderlich, stattdessen sollten die grossen Stadtwerke **klarer abstecken, welche Themen für sie wirklich relevant sind** und auf welche Ziele sie sich konzentrieren. Darauf aufbauend sollten sie vermehrt **Kooperationen untereinander** eingehen, Kräfte bündeln und die nötigen Kapazitäten schaffen, um mit dem Veränderungstempo mithalten zu können (Konnektivität erhöhen).

Weiterhin sollten sie die **Nähe zum Bürger** suchen und ihren Vertrauensvorsprung nutzen, um nicht „am Markt vorbei zu produzieren". Indem sie sich auf „ihre Stadt" konzentrieren, können sie auch in Zukunft in ihrer Vernetzerrolle agieren, indem sie z.B. eine bürgernahe Digitalisierung gestalten. Insgesamt tragen sie so zu einer stärkeren sozialen Vernetzung bei

Herausforderungen, die für Resilienz des Systems bleiben:

- **Zeitachsen:** unterschiedliche Themen haben sehr unterschiedlichen Zeithorizonte - langfristige Infrastrukturinvestitionen, Netzwartung etc. vs. kurzfristige Start-ups, sich ändernde politische Ziele, Kundenwünsche
- **Saisonalität** der Energieproduktion: stärkt man Autarkie oder internationale Vernetzung, ökologische Speicherlösungen?

6

- **EU-Integration vs. Robustheit durch Föderalismus und Dezentralität**: wie „verteidigt" man die wichtigen Stabilitätsfaktoren Föderalismus bzw. Dezentralität im Kontext der EU-Integration?
- **Rolle des Regulators:** Brauchen wir eine weiter gestärkte zentrale Regulationsinstanz, oder sind wir lokal stark genug? Wer ist der Architekt und Schiedsrichter der neuen Rollen?
- **Nationale Vernetzung:** Welche nationalen Organe können die grossen Stadtwerke in Zukunft nutzen? Welche Rolle spielt z.B. der Städteverband in Zukunft?
- **Zieldefinition(en):** Divergierende Ziele auf unterschiedlichen Governance Ebenen - wie schafft man Klarheit, ohne die städtischen Ziele (oft ökologischer ausgerichtet) zu kompromittieren?

Welche Aspekte können in die Praxis getragen werden?

Die Rolle der grossen Stadtwerke kommunizieren und aktiv gestalten:

- Das Selbstbewusstsein der Energieversorger stärken,
- Chancen sehen, nicht nur Gefahren & Mut Dinge zu tun,
- auf die städtischen Wurzeln stützen: „auf städtischer Ebene kann man etwas tun, die nationale Ebene ist viel zu träge",
- die Nähe zum Bürger suchen und Akzeptanz schaffen, um aus der Stabilitätsblase herauskommen und an Flexibilität zu arbeiten.

Das Resilienzkonzept nutzen, um ...

- robuste und intelligente Systeme zu entwickeln,
- das Saisonalitätsproblem neu anzugehen (neu über Autarkie nachdenken, ökologischere, kleinere und dezentralere Lösungen andenken um mehr Autarkie zu schaffen),
- die Systeme auch ohne Schocks resilient zu machen „create a sense of urgency" (z.B. Blackout Szenarios durchspielen),
- neue Kommunikationsform gegenüber der Politik zu entwickeln,
- auf Ebene der Mitarbeiter und Bürger neue Wahrnehmung zu schaffen,
- auch innerhalb der Organisation „Stadtwerk" zu nutzen, um eigene Stabilität und Flexibilität zu erhöhen, die dann wiederum erst die angesprochenen Systembeiträge ermöglicht.

7

Présentation : La situation actuelle du secteur énergétique et les grands services industriels urbains

Le secteur énergétique suisse éprouve trois **changements fondamentaux** :

- la rupture des monopoles nationaux et la libéralisation des marchés liées à la intégration européenne,
- la décarbonisation de la production et
- la digitalisation du secteur.

En même temps, des **bases stables perdures** qui doivent rester garanti malgré les grands changements mentionnés :

- la sécurité d'approvisionnement,
- la rentabilité du secteur (les coûts sociétaux) ainsi que
- les principes du service public, du fédéralisme et de la propriété publique des infrastructures critiques.

Le secteur énergétique doit donc se transformer en restant stable. Cela cause des défis pour les acteurs historiques du secteur qui sont en charge de garantir la stabilité pendant qu'ils s'adaptent aux changements fondamentaux.

Les caractéristiques des GSIs : en considérant la diversité des GSIs suisses et allemands, ils partagent néanmoins des **caractéristiques communes** :

- de fournir de l'énergie à des clients finaux,
- appartenir à des grandes villes,
- d'être constitué comme des entités/ entreprises publiques,
- de travailler dans plusieurs domaines de l'énergie et des services publics (ce qui fait la différence entre eux et les SI cantonaux),
- d'être des entreprises entièrement intégrés – couvrants l'ensemble de la chaîne de valeur – qui font partie des plus grandes entreprises énergétiques du pays (ce qui fait la différence entre eux et les petits SI municipales).

La situation actuelle du secteur (changements et stabilité) et les caractéristiques particulières des GSIs se traduisent d´un côté par une **augmentation du nombre et de la complexité des rôles des GSIs** (slide 17). D'autre côté, ils causent des **défis particuliers pour les GSIs**.

- Ils sont des gérants d'infrastructures de réseaux (monopoles naturels, fortement régulé) dans un environnement libéralisé et marqué par la compétition.
- L'idée de la séparation du réseau et de la production est contradictoire à la digitalisation et à la production décentralisé qui demandent la connexion de production et demande.
- Au niveau de l'organisation, la volonté publique et le contrôle démocratique direct par les politiciens et les exigences correspondantes sont contradictoires aux exigences de la performance et de l'innovation.
- Cela pose des problèmes du genre « principal-agent » - comme la composition du conseil administratif.

2

Discussion de groupe : Modèles sur des responsabilités potentiels futures de GSIs

Pour discuter des responsabilités potentielles futures des GSIs et de leurs effets sur le secteur énergétique, cinq modèles ont été proposés, dont quatre ont été discutés en groupes.

Modèle 1

Description : « business as usual » les GSI restent actif dans tous les domaines (énergétiques et autres services publiques) de la chaîne de valeur. Ils offrent des services et gèrent les données dans tous les domaines. Sauf pour les réseaux, ils se trouvent partout dans la compétition avec d'autres GSIs ainsi qu'avec d'autres acteurs publics et privés.

Feedback :

- Le modèle 1 serait positif pour le **fédéralisme** (les monopoles locaux renforceraient l´autonomie de la ville et amèneraient plus de pouvoir au niveau local – mais il poserait des problèmes si la confédération voulait encore prendre des décisions centraliste) **et la sécurité d´approvisionnement** (les GSIs connaissent mieux le contexte local, ils peuvent garantir eux-mêmes la sécurité).
- Par contre, le modèle « ne pousse pas **la libéralisation** ». Au niveau de l'économie le modèle contribuerait á « l´économie de scope », pas à l´économie d´échelle. La valeur resterait en circuit dans la ville au fur et à mesure de la gestion de l´entreprise et des investissements à l´étranger.
- Pour **la décarbonisation, le modèle** montrerait des effets positifs (plus d'investissements dans les renouvelables, car la ville en est plus en faveur que les privés, ER financés par les subventions). Au niveau de la **digitalisation,** le modèle ne serait pas favorable.

Les gagnants seraient surtout « les conservateurs », les villes qui pourraient éliminer la compétition et les clients qui bénéficieraient de la même qualité et la stabilité du système. En même temps les clients seraient aussi **les perdants**, car le prix d'énergie augmenterait. Autrement, les « new entrants » seraient clairement les perdants clairs.

Modèle 2

Description : Les GSIs de débarasse du « retail » car dans un marché libéralisé ceci n'est plus profitable – voir l'exemple de Trønder Energie (Norvège). Les grandes plateformes en ligne prennent en main la gestion des clients finaux – les GSIs n'offrent plus de services pour les clients finaux. Autrement, les responsabilités resteraient les mêmes.

Feedback : Le modèle soutiendrait les plateformes de prosumers et les GSIs perdraient le lien avec les clients (« s'il n'y a plus il n'y a plus… »). Si les grands producteurs deviennent des retailers, ça ne changera pas grande chose. Les changements devraient s'appliquer pour tous les acteurs.

- Au niveau de **la sécurité d´approvisionnement,** le modèle entraîne un effet négatif, car la connexion entre la production et la vente serait rompu (plus de « prix service public »), ce qui garantit jusqu'à présent au GSI de financer la production en suisse. Le modèle pousserait les investissements à l'étranger et réduirait les dividendes des investissements en générale.
- **L'effet économique** serait à la fois positif et négatif : il se manifesterait par une baisse des prix (positif pour le client, négatif pour le GSI) et par la dépendance des prix européens.

3

- **Au niveau du libéralisme,** il y aurait plus de marché, des nouveaux acteurs, plus de choix pour le client, mais aussi plus de responsabilités et moins de protection contre les volatilités des prix et des jeux de pouvoir des grands acteurs (effets positifs et négatifs).
- Au niveau de **la digitalisation**, il aurait plus de place pour des start-ups et des innovateurs, en même temps le lien entre la vente et la production serait cassé, ce qui serait négatif pour la digitalisation.

Finalement, le client final va perdre et gagner en même temps : le prix augmenterait, mais il y aura plus de choix.
Le modèle 2 résulte en même temps dans le modèle 3, car il n´y aura plus de moyens financiers pour la production et donc les GSIs vendraient aussi les unités de production.

Modèle 3

Description : Les GSIs vendent les unités de production, car la production centralisée n'est que rentable quand elle est gérée par des acteurs centralisés (économies d'échelle) et la production décentralisée se base sur la présence de prosumers. Les GSIs se concentrent leurs activités sur la gestion des réseaux et la gestion des clients. Ils n'offrent plus de services pour la production (project management etc.), mais ils offrent encore des services pour les prosumers (contracting). Le GSIS se retrouve dans une situation de compétition.

- **Feedback** : **Sécurité d'approvisionnement** : Le modèle pousserait la production à l´ étranger, il augmenterait donc la distance entre la production et la consommation. Pour l'agrégation et le balancement de la demande, il serait important de gérer toute la chaîne de valeur pour garantir la sécurité (effet plutôt négatif)
- **L'effet économique** serait plus positif que pour le modèle 1 ; le prix basé sur le marché et la concurrence des producteurs laisserait baisser le prix de la production.
- En vue du **fédéralisme**, le modèle demanderait plus de liens internationaux au niveau de la confédération pour la planification et l'assurance de la sécurité d'approvisionnement (plus de gouvernance top-down, donc plutôt négatif pour le fédéralisme).
- Le modèle donnerait plus de responsabilité au client concernant **la décarbonisation** (de vendre de l'énergie au producteur durable), mais il soutiendrait la mentalité « not in my backyard » et le modèle serait moins efficace pour la décarbonisation que le modèle 1.
- Au niveau de **la digitalisation**, le modèle pousserait les GSIs au DSM, mais pour ça il faudrait renforcer le lien entre la production (décentralisé) et la consommation.

Modèle 4

Description : Les GSIs vendent la production et le « retail », ils sont uniquement actifs dans le monopole (réseaux), par contre le monopole est élargi et comprend aussi la gestion des flexibilités (DSM, agrégation) et donc les services pour le réseau. La gestion des données privées et du système est déclarée comme service public et gérée uniquement par les GSIs.

Feedback : Globalement, le modèle se montrait positif pour l'optimisation du système, mais les GSIs perdraient le lien direct avec le client. Ils risquent de devenir « comme une caisse maladie » et de perdre la vue globale du système. Le système énergétique deviendrait encore plus fragile, p.ex. toute la régulation serait concentrée auprès du régulateur.

4

- Au niveau de **la sécurité d´approvisionnement,** il y aurait une perte de contrôle local concernant la production et la vente. Par contre, au niveau du réseau, il y aurait un nouveau focus sur les infrastructures locales se manifesterait. Le régulateur deviendrait très important, les régulations augmenteraient (augmentant – tout à la fois –de la fragilité du système).
- **Niveau économique** : L´économie d´échelle augmenterait et des larges entités se développeraient. Ainsi, il y aurait une perte de **fédéralisme**, plus de dépendance du régulateur européen, plus de décisions top-down et un marché plus globalisé.
- **Le service public** serait réduit à l´infrastructure mais ça éviterait le « problème anglais » (le mauvais entretien des infrastructures).
- Pour **la libéralisation**, le modèle 4 serait positif, car il permettrait l'établissement d'une variété d'acteurs.
- Par contre, pour **la décarbonisation** le modèle se monterait négatif. Les GSIs (comme les autres acteurs) dépendraient des dynamiques du marché et le marché « fait pas de la politique énergétique », il n´inclurait pas les externalités négatives. Il faut donc définir des taxes environnementales, et « ça ne marcherait jamais. »
- Au niveau de **la digitalisation**, le modèle serait plutôt positif, l'accessibilité des donnés serait garantie et les GSIs deviendraient des acteurs importants pour le smart city développement.

Si ce modèle était vraiment réglé en faveur des consommateurs, c'est eux qui seraient **les gagnants** au niveau économique. Mais en tout cas, « **les perdants** seraient le climat et les renouvelables » (si des règlements forts n'étaient pas mis en place).

Questions ouvertes pendant toute la discussion

- Les modèles sont trop influencés par l'électricité, le défi principal c'est le chauffage.
- Est-ce qui dit libéralisation dit en même temps privatisation ?
- Où est-ce que se situe la limite entre le commerce et le retail ?
- Les effets des modèles dépendent fortement de la constellation des autres acteurs dans le système (est-ce qu´il aura encore d'autres SI publics ? etc.) et des développements technologiques et du développement des réglementations.
- L'horizon de temps n´est pas le même dans les différents domaines (production, commerce, vente).
- Le modèle 4 serait le statut minimum qu´on pourrait conserver avec une libéralisation complète.

Présentation : La résilience des systèmes sociotechniques – perspectives théorétiques

Un système sociotechnique résilient « peut absorber des chocs externes ou internes d'une telle manière que sa fonctionnalité n'est jamais mise en danger ». Les capacités nécessaires sont la robustesse, l'adaptabilité et la capacité des sous-systèmes de se transformer pour maintenir la résilience du système. La stabilité et la flexibilité sont donc les pôles de la résilience. Pour analyser la résilience d´un système sociotechnique, six indicateurs étaient proposés qui opérationnalisent les deux caractéristiques clés : la diversité et la connectivité.

5

Discussion : Le rôle des GSIs pour la résilience du système énergétique suisse

Différentes propositions concernant la contribution des GSIs à la diversité et la connectivité du système ont été présentées – par exemple leurs investissements dans les projets pilots augmente la diversité technologique du système, leur fonction comme coordinateur local des multi-dis et multi-énergie permet la convergence des secteurs et des réseaux, ce qui augmente la connectivité du système (slides 40 et 41).

Feedback

Les contributions clés des GSIs à la **connectivité sociale et technologique**

- La convergence des réseaux / énergies,
- l'arbitrage entre demande et « supply » et
- l'entretien de la cohérence dans le système pendant la transition autant que
- la proximité aux citoyens / l'identification des citoyens avec leurs SI.

Par contre, le savoir et les solutions locales étaient considérés comme points forts des GSIs pour **la diversité** du secteur.

Il restait la **question de la temporalité** : en fonction d'horizon temporel « à court-terme » ou « à long-terme », les GSIs contribueraient différemment aux indicateurs de référence.

La coopération entre les GSIs et donc la connectivité dans le système de gouvernance était un point controversé :

- d´un côté, les GSIs se sentent à l´aise dans la co-opétition entre eux, car ils ne sont pas des concurrents directs (identification au territoire),
- de l'autre côté, la coopération entre eux pourrait être démultipliée pour que les GSIs puissent utilisent mieux leurs diverses compétences.

Finalement, le concept de la résilience n´est pas encore vraiment établi dans le secteur, mais il serait très utile pour attirer l'attention public et mieux se préparer aux chocs potentiels.

À part de cela, le rôle important de **l'argent public pour les innovations** était discuté. Cela surtout dans le contexte de smart city, ou les GSIs jouent un rôle important pour le développement local de l'infrastructure pour la future.

Liée au point de l'argent public, l'orientation au long-terme des GSIs était considéré comme un point fort et important. Dans ce contexte, **l'investissement dans la recherche appliqué** et le retour d'expérience entre les GSIs devrait être augmenté. Finalement, l'ouverture du marché devrait elle aussi être vu comme une opportunité pour les GSI - à mieux valoriser leurs forces.

Au niveau des **actions concrètes** à l´avenir :

- l'amélioration de **la visibilité** et **la communication sur l'importance, les rôles et les actions des GSIs** et
- l'intensification de la relation avec les clients (flexibilisation des tarifs)
- la lutte contre les subventions cachées (des énergies non-renouvelables) étaient mentionnés.

Finalement, la question de **la propriété et l'accessibilité des données** et **la définition des indicateurs de performance** sociales et techniques pour les GSIs étaient considérées comme tâches clés pour la future (en collaboration avec le régulateur).

6

B - Additional book chapters

B.1 Ein indikatorengestützter Ansatz zur Analyse der Resilienz in Transitionen von Energiesystemen

Ein indikatorengestützter Ansatz zur Analyse der Resilienz in Transitionen von Energiesystemen: theoretische Konzeptualisierung und empirische Anwendung im bayerischen Allgäu.

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Zusammenfassung

Die soziale und technische Transition unseres Energiesystems mit dem Ziel einer größeren Nachhaltigkeit ist schon länger nicht mehr nur ein politisches Vorhaben, sondern befindet sich mitten in der Umsetzung. Während traditionelle Energieversorger und Energieproduktionstechnologien unter Druck geraten, treten neue Akteure auf den Plan und es werden fortlaufend neue Gesetzgebungen, Geschäftsmodelle und Technologien entwickelt. Mit diesen fundamentalen Umwälzungen stellt sich die Frage, wie ein sich transformierendes regionales Energiesystem entlang eines vorgegebenen Transitionspfades resilient gestaltet werden kann. In diesem Kapitel schlagen wir einen indikatorengestützten Ansatz zur Konzeptualisierung und Operationalisierung von Resilienz regionaler Energiesysteme in Transition vor. Wir basieren diesen Ansatz auf zwei Kernkonzepten der Resilienz - Diversität und Konnektivität - und zeigen in einem ersten Schritt, wie diese sowohl für die technischen als auch die sozialen Aspekte eines regionalen Energiesystems in jeweils drei Indikatoren ausdifferenziert werden können. Als Diversitätsindikatoren werden Varietät, Balance und Disparität verwendet; als Konnektivitätsindikatoren die durchschnittliche Pfadlänge, die Gradzentralität und die Modularität. In einem zweiten Schritt wenden wir das Indikatorenset auf das Fallbeispiel bayerisches Allgäu an und verwenden dazu empirisches Material, das aus Experteninterviews, Sekundärdaten und einer Energieflussanalyse zur Verfügung steht. Der Beitrag liefert damit nicht nur einen theoriegeleiteten Ansatz zur Analyse der Resilienz von regionalen Energiesystemen in Transition, sondern zeigt zugleich auch empirische Anwendungsmöglichkeiten auf und reflektiert Limitationen und weiteren Forschungsbedarf.

Schlagworte

Resilienz, Transition, Indikatoren, Diversität, Konnektivität, regionale Energiesysteme, Energiewende, Allgäu, sozio-technisches System

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1 Einführung

Die bevorstehende Transition[1] des Energiesystems hin zu größerer Nachhaltigkeit gilt als eine der größten Herausforderungen des 21. Jahrhunderts (Leipprand, Flachsland, & Pahle, 2016). Aus analytischer Perspektive kann der Energiewendeprozess dabei als eine Abfolge schockartiger Veränderungen und kleinschrittiger Anpassungsprozesse auf einem bestimmten Transitionspfad verstanden werden (Rotmans, Kemp, & Van Asselt, 2001). Während des gesamten Transitionsprozesses müssen Akteure sowohl bevorstehende Veränderungen antizipieren und sich an diese Veränderung anpassen, als auch aus völlig neuen Situationen lernen und die ihnen zur Verfügung stehenden technischen Möglichkeiten möglichst erfolgreich nutzen (Martens & Rotmans, 2005; Rotmans & Fischer-Kowalski, 2009). Nach Grin, Rotmans, & Schot (2010) sind Transitionsprozesse „tief in gesellschaftlichen Strukturen, Routinen und Kultur verwurzelt" (übersetzt nach Grin et al., 2010). Dies bedeutet, dass die Transition des Energiesystems integriert analysiert werden muss, d.h. unter Berücksichtigung der Koevolution technischer und gesellschaftlicher Faktoren (Hodbod & Adger, 2014; Minsch, Goldblatt, Flüeler, & Spreng, 2012). Ein wichtiger Aspekt ist dabei, dass Akteure die Transition einerseits kontinuierlich vorantreiben müssen, andererseits das technische System der Energieproduktion und -verteilung während des gesamten Transitionsprozesses fehlerfrei funktionieren muss. Dies ist nicht nur von ökonomischer Bedeutung, um eine konstante Energieversorgung zu gewährleisten, sondern auch von politischer Relevanz, um die gesellschaftliche Unterstützung für die Transition zu garantieren und ungewollte Störungen zu verhindern (Mühlemeier, Wyss, & Binder, submitted).

Im wissenschaftlichen Diskurs zur Energiewende wird dezentralisierten Energiesystemen eine entscheidende Rolle zugesprochen, um einen höheren Anteil der erneuerbaren Energien in der Energieversorgung und damit eine CO_2-Reduktion und den Wandel hin zu mehr Nachhaltigkeit zu erreichen (Johansson, Jonsson, Veibäck, & Sonnsjö, 2016). Der Bedeutungszuwachs der regionalen Ebene wurde auch von der Europäischen Union (EU) entsprechend bestätigt (Breidenich, Magraw, Rowley, & Rubin, 1998). Im weiteren Verlauf dieses Kapitels nehmen wir daher auf regionale Energiesysteme Bezug und definieren Regionen als territoriale Einheiten, die mehrere EU NUTS3 Regionen (Eurostat, 2015) umfassen. In Deutschland entspricht dies dem Zusammenschluss mehrerer Landkreise unterhalb des Regierungsbezirksebene. Was in diesem Kontext bisher kaum berücksichtigt wurde, ist die Analyse der Resilienz regionaler Energietransitionen gegenüber kurzfristigen Schocks und langfristig sich verändernden Rahmenbedingungen. Damit die Transition eines sozio-technischen Energiesystems erfolgreich sein kann, muss sowohl das fehlerfreie Funktionieren des technischen Teilsystems, als auch die soziale Akzeptanz dieses Prozesses entlang des gesamten Transitionspfades gewährleistet sein (O'Brien und Hope, 2010). Das Energiesystem muss daher in seiner Funktion resilient gegenüber externen und internen Schocks sowie unvorhergesehenen Störungen bleiben (Gailing und Röhring, 2015; Schilling, 2016; Schilling et al., Manuskript), während es die unterschiedlichen Phasen des Transitionsprozesses durchläuft (vgl. 1.1). Um dies zu erreichen, müssen sowohl die technischen Komponenten des Systems in Transition, als auch die Verbindungen zur sozialen Sphäre entlang des Transitionsprozesses berücksichtigt werden.

[1] Transition wird hier bewusst anstelle des im deutschen gebräuchlicheren Transformation verwendet, um die Einbettung des Kapitels in den Forschungsstrang der *socio-technical transitions towards sustainability* zu verdeutlichen (Chappin & Ligtvoet, 2014).

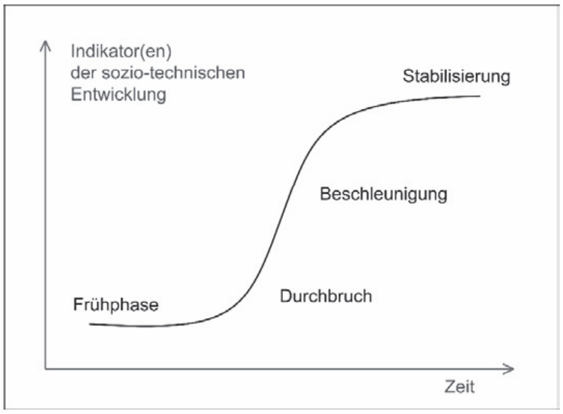

Abbildung 1.1: Die vier Phasen sozio-technischer Transitionen (übersetzt von Rotmans et al., 2001)

Binder, Mühlemeier, & Wyss (2017) schlagen vor, dass bei der Analyse der Resilienz von Energietransitionen der Koevolution von technischen und sozialen Subsystemen besondere Aufmerksamkeit gebührt. So ziehen neue Produktions- und Distributionstechnologien u.a. neue Institutionen und Akteurstypen nach sich, die zu einer grundlegenden Änderungen im regionalen Gouvernanzsystem führen können (Binder, Hecher, & Vilsmaier, 2014; Hecher, Vilsmaier, Akhavan, & Binder, 2016; Sovacool, 2016; Späth & Rohracher, 2012; Strunz, 2014).

Um die Resilienz eines soziotechnischen Energiesystems während des Transitionsprozesses zu konzeptualisieren und die Resilienz des Prozesses zu messen, haben Binder et al. (2017) ein Indikatorenset für die Analyse zweier Kernkonzepte der Resilienz entwickelt: Diversität und Konnektivität. Dieses Indikatorenset erlaubt die Analyse der Resilienz des regionalen Energiesystems während des Transitionsprozesses – sowohl von technologischer als auch sozialer Perspektive.

Im Rahmen dieses Kapitels wenden wir das Indikatorenset für das Fallbeispiel bayerisches Allgäu an und verfolgen dabei folgende Ziele: i) die Analyse der Resilienz der Energiewende im Allgäu unter Berücksichtigung technischer und sozialer Aspekte, ii) eine kritische Reflektion der Anwendbarkeit der Indikatoren zur Analyse der Resilienz von Energiesystemen während des Transitionsprozesses sowie iii) das Herausarbeiten weiterer Anwendungsmöglichkeiten des Indikatorensets für regionale Fallstudien.

Wir strukturieren dieses Kapitel dafür in folgende Abschnitte: in Abschnitt 2 erläutern wir zunächst die theoriegeleitete Konzeptualisierung und Operationalisierung des von Binder et al. (2017) vorgeschlagenen Indikatorensets für die Analyse der Resilienz von sozio-technischen Energiesystemen in Transition. Anschließend wenden wir in Abschnitt 3 diese Indikatoren auf das Fallbeispiel bayerisches Allgäu an und wir schließen in Abschnitt 4 mit zusammenfassenden Erkenntnissen und Vorschlägen für weitere Forschungsmöglichkeiten ab.

2 Konzeptualisierung und Operationalisierung des Resilienzbegriffs für Energiesysteme in Transition

Die Resilienz eines Systems kann als seine Fähigkeit definiert werden "während eines Veränderungsprozesses, Störungen zu absorbieren und sich dergestalt zu reorganisieren, dass es dennoch die gleiche Funktion, Struktur, Identität und Feedbacks behält" (übersetzt von Walker, Holling, Carpenter, & Kinzig, 2004). Der gleichen Denkrichtung folgend beschreibt Folke (2006) die Resilienz als die Fähigkeit eines Systems und seiner Komponenten, sowohl Schocks zu widerstehen (Stabilität des Systems), als auch sich an veränderte Rahmenbedingungen anpassen zu können (Anpassungsfähigkeit des Systems). Systeme können dabei als Ensemble qualitativ verschiedener Systemkomponenten (Entitäten) und ihrer Verbindungen verstanden werden, z.B. Produktionsstätten, Verteilknoten und Konsumenten, die durch Energie- und / oder Informationsflüsse verbunden sind. Basierend auf diesem Systemverständnis kann Resilienz als eine Funktion der Diversität der Systemkomponenten und der Konnektionsmuster zwischen den Komponenten verstanden werden (Fath, Dean, & Katzmair, 2015; Lietaer, Ulanowicz, Goerner, & McLaren, 2010).

Die bisherige Forschung im Bereich der Ökologie weist zudem auf die sowohl statischen als auch dynamischen Elemente der Resilienz hin, die einem System erlauben, in einem dynamischen Gleichgewichtszustand zu bleiben (Folke et al., 2010; Foxon, Reed, & Stringer, 2009). Im weiteren Verlauf dieses Kapitels, berücksichtigen wir die ökologischen Aspekte des Energiesystems jedoch nur indirekt, durch das Ressourcenfundament, das den entsprechenden Technologien zu Grunde liegt und fokussieren uns auf ein sozio-technisches Systemverständnis (Geels, 2004).

Wir erachten eine Transition als resilient, wenn das untersuchte System entlang des gesamten Transitionspfades resilient ist (Gunderson, 2001). Daher wird ein Energiesystem während einer resilienten Transition verschiedene Phasen durchlaufen, stabilere und adaptivere, die durch unterschiedliche Konfigurationen der sozialen und technischen Subsysteme charakterisiert sind. Das System darf jedoch insgesamt seine Resilienz nie ganz verlieren.

Um unser Resilienzkonzept auf konkrete Fallbeispiele anwenden zu können, operationalisieren wir die sozialen Elemente eines sozio-technischen Energiesystems als *soziale Arenen* und die technologischen als *Technologiegruppen*. Fortan wird daher zwischen dem sozialen und dem technischen Teilsystem unterschieden. Ist das gesamte Energiesystem gemeint, wird vom sozio-technischen System gesprochen.

Soziale Arenen werden dabei als „gesellschaftliche 'Teilsysteme ', 'Sphären' [... definiert], die je nach ihrer Funktion durch unterschiedliche Rationalitäten bzw. ‚Codes' (nach Luhmannn) geprägt sind" (Späth et al., 2007). Gemeinhin werden diese Arenen durch ihre charakteristische Struktur sowie ihre funktionalen Eigenschaften gekennzeichnet. So kann beispielsweise zwischen der politischen, der unternehmerischen und der Bevölkerungsarena unterschieden werden. Dieser Arenenansatz erlaubt es, die große Anzahl und Vielfalt der Akteure eines Energiegouvernanzsystems sowie die Komplexität ihrer Interaktionsmuster besser zu bewältigen (Späth et al., 2007; Späth & Rohracher, 2010).

Bezüglich des technologischen Systems unterscheiden wir unterschiedliche Technologiegruppen zur Produktion (erneuerbarer) Energien, wie es von Kost et al. (2013) bereits angewandt wurde. Diese Unterscheidung erlaubt eine präzisere Analyse des Energieproduktionsystems als die Gruppierung nach Energieressourcen (Wind, Wasser, Sonne etc.), ist jedoch weniger detailliert als die Untersuchung jeder einzelnen Produktionstechnologie.

In den folgenden Unterkapiteln erläutern wir die von Binder et al. (2017) vorgeschlagenen Indikatoren, anhand derer Diversität und Konnektivität eines Energiesystems in Transition unter Berücksichtigung seiner sozialen und technologischen Elemente gemessen werden können.

2.1 Diversität

Nach Stirling (2007) wird der Diversitätsbegriff über verschiedene Disziplinen und Systemkontexte hinweg ähnlich definiert und gemessen. Diversität kann dabei auf Basis dreier grundlegender Eigenschaften konzeptualisiert werden: Varietät, Balance und Disparität (vgl. Tabelle 2.1). Obwohl eine fortwährende Debatte darüber besteht, ob diese drei Indikatoren ausreichend sind (Rafols & Meyer, 2008;

Sokal & Sneath, 1970; Stirling, 1998; Stirling, 2007, 2010), beschränken wir uns für die vorliegende Arbeit dennoch auf dieses drei. Aus Tabelle 2.1 können Vorschläge zur Messung und Anwendung der Diversitätsindikatoren für das Energiesystem entnommen werden.

Tabelle 2.1 : Operationalisierung von Diversität in sozio-technischen Systemen (basierend auf (Binder et al., 2017)

Indikator	**Definition**
Varietät	Varietät bezieht sich auf die Anzahl der Kategorien in welche die Systemelemente aufgeteilt werden können.
Balance	Balance bezieht sich auf die Verteilungsmuster von Elementen über die verschiedenen Kategorien hinweg.
Disparität	Disparität bezieht sich auf die Art und Weise sowie den Grad, zu dem Elemente qualitativ unterschieden werden können.

2.1.1 Varietät

Für das soziale Teilsystem beschreibt die Varietät die Anzahl an sozialen Arenen, welche im regionalen Energiegouvernanzsystem nachgewiesen werden können. Für das technische Teilsystem beschreibt die Varietät die Anzahl der Technologiegruppen, welche im regionalen Energieproduktionssystem an der Energieproduktion beteiligt sind.

Bedeutung für die Resilienz: Eine steigende Varietät der sozialen Arenen zieht eine höhere Anzahl an unterschiedlichen Sichtweisen und Perspektiven im regionalen Energiediskurs nach sich. Dies kann zu einer steigenden Anpassungsfähigkeit führen und den systemischen Wandel unterstützen. Gleichzeitig kann eine hohe Varietät im sozialen Teilsystem größere Anstrengungen zur Stabilisierung des Gouvernanzsystems nach sich ziehen. Eine hohe Varietät der Technologiegruppen im regionalen Energieproduktionssystem kann destabilisierend wirken und die Kosten des Energiesystems erhöhen. So müssen z.B. Grund- und Spitzenlasttechnologien integriert werden (Bruns, Futterlieb, Ohlhorst, & Wenzel, 2012; Grimm, 2007; Grünwald, Ragwitz, Sensfuß, & Winkler, 2012; Schill, 2013). Gleichzeitig ist ein Energiesystem, das sich durch eine hohe Varietät der Technologiegruppen auszeichnet, aber auch weniger anfällig auf externe Schocks, die bspw. eine spezifische Ressource oder Technologie betreffen. Je nach Art der Technologie können bei hoher Varietät Technologiegruppen (bis zu einem gewissen Maß) auch substituiert werden. Die Resilienz des Systems korreliert dabei jedoch nicht allein mit der Varietät, sondern ist gleichermaßen von den anderen Diversitäts- und Konnektivitätsfaktoren abhängig.

2.1.2 Balance

Für das soziale Teilsystem beschreibt die Balance die Anzahl der Akteure pro sozialer Arena im Vergleich zur Gesamtanzahl der Akteure im regionalen Energiegouvernanzsystem. Für das technische Teilsystem beschreibt die Balance den Anteil der einzelnen Technologiegruppe an der Gesamtenergieproduktion im regionalen Energieproduktionssystem.

Bedeutung für die Resilienz: Sind die Akteure über die beteiligten Arenen gleichmäßig verteilt, steigt die Wahrscheinlichkeit, dass die unterschiedlichen Standpunkte und Sichtweisen im regionalen Energiegouvernanzsystem gleichermaßen zur Sprache kommen und in den entsprechenden Entscheidungen ihren Niederschlag finden. Der Transitionsprozess ist dadurch auf eine breite Akzeptanz gestützt und gegenüber externen Schocks resistenter. Diese Stabilität kann jedoch die Effizienz der Entscheidungsfindungsprozesse insgesamt beeinträchtigen und den Prozess verlangsamen (Lietaer et al., 2010). Sind die Technologiegruppen in etwa gleichmäßig an der regionalen Energieproduktion beteiligt, bzw. besteht eine hohe Balance zwischen den Technologiegruppen, kann dies eine geringere Gesamtstabilität der netzbasierten Versorgung zur Folge haben (z.B. Integration unterschiedliche Lasttypen). Gleichzeitig wird jedoch die Anfälligkeit auf Schocks, welche spezifische Technologiegruppen betreffen, verringert und aufgrund der möglichen (kurzfristigen) Substituierung einer Technologiegruppe durch eine andere erhöht sich die Flexibilität und Anpassungsfähigkeit des technologischen Teilsystems.

2.1.3 Disparität

Für das soziale Teilsystem beschreibt die Disparität die qualitativen Unterschiede zwischen den sozialen Arenen des regionalen Energiesystems, die sich z.B. in unterschiedlicher Kommunikationsform, Koordinationsform, typischen Handlungsweisen, dem Zeithorizont oder der räumlichen Skalierung niederschlagen (Wyss, Mühlemeier, & Binder, Manuskript). Für das technische Teilsystem beschreibt die Disparität die qualitativen Unterschiede zwischen den Technologiegruppen des regionalen Energieproduktionssystems, die sich z.B. in unterschiedlicher Energieeffizienz, Ressourcenbasis, CO2-Emission, Oberflächenbedarf, Wetterabhängigkeit und Gestehungskosten äußern (Wyss, et al., Manuskript).

Bedeutung für die Resilienz: je unterschiedlicher sich die sozialen Arenen in Bezug auf ihre qualitativen Merkmale gestalten, desto unterschiedlichere Wissensformen und Sichtweisen können ihren Weg in den regionalen Diskurs finden. Höhe Disparität kann entsprechend dazu beitragen, Kurzsichtigkeit und Lock-ins im sozialen Subsystem zu verhindern. Gleichzeitig erschwert eine hohe Disparität die kollektiven Entscheidungsfindungen, und beeinträchtigt womöglich die langfristige Zieldefinition in der Region. Eine hohe Disparität der Technologiegruppen bietet ein breites Portfolio an Alternativen und verringert die Vulnerabilität des Systems gegenüber bestimmten, technologiespezifischen Schocks. Und auch wenn die Gefahr der schwierigen Integration verschiedener Technologien besteht, kann sich ein gewisser Grad der Disparität resilienzfördernd auswirken, da die Technologien ergänzend eingesetzt werden können (Biomasse für die Grundlast und PhotovoltaiK (PV) für die Spitzenlast). Eine hohe Disparität eröffnet zudem auch verschiedene Entwicklungsmöglichkeiten für das Energieproduktionssystem und trägt somit zur Resilienz der Transition entscheidend bei.

2.2 Konnektivität

Zur Operationalisierung des Konnektivitätsbegriffs, ziehen wir grundlegende Konzepte der Netzwerkanalyse für soziale und technische Systeme heran. Basierend auf der Netzwerkliteratur (Scott, 2012, S. 20; Wasserman & Faust, 1994) sowie deren Anwendung für die Energiesystemanalyse (Roege, Collier, Mancillas, McDonagh, & Linkov, 2014), haben wir folgende drei Hauptelemente zur Operationalisierung der Konnektivität identifiziert: Durchschnittliche Pfadlänge, Gradzentralität und Modularität (vgl. Tabelle 2.2). In der Resilienz-Literatur (Bergsten, Galafassi, & Bodin, 2014; Luthe & Wyss, 2016; Luthe, Wyss, & Schuckert, 2012) sind unterschiedliche Größen zur Messung der Konnektivität vorgeschlagen worden. Pfadlänge, Zentralität und Modularität sind dabei mit am weitesten verbreitet und haben sich in der empirischen Anwendung als belastbare Resilienz-Indikatoren bewährt.

Tabelle 2.2: Operationalisierung von Konnektivität in sozio-technischen Energiesystemen (Binder et al., 2017; Luthe & Wyss, 2016; Wasserman und Faust, 1994)

Indikator	Definition

Durchschnittliche Pfadlänge	Die durchschnittliche Pfadlänge beschreibt die Menge an Zwischenschritten, die vorgenommen werden muss, um zwei beliebige Knotenpunkten im Netzwerk zu erreichen.
Gradzentralität	Die Gradzentralität beschreibt die relative Position eines Knotenpunkts im Netzwerk in Bezug zu den anderen Knotenpunkten im System: ein Knotenpunkt ist zentraler wenn er mehr Verbindungen hat als andere Knotenpunkte (Freeman, 1978; Weimann, 1982).
Modularität	Netzwerkmodule beschreiben Teile eines Netzwerks, die bezogen auf das Gesamtsystem eine überdurchschnittliche Interaktionsintensität aufweisen (Clauset, Newman, & Moore, 2004; Newman, 2006).

2.2.1 Durchschnittliche Pfadlänge

Die durchschnittliche Pfadlänge beschreibt auf das soziale Teilsystem angewandt die Anzahl der Schritte, die man im Durchschnitt benötigt, um als Akteur einer Arena auf dem kürzesten Weg die Akteure einer beliebigen (anderen) Arena im System zu erreichen. Global betrachtet erlaubt eine kurze durchschnittliche Pfadlänge Informationen innerhalb einer Systems schneller zirkulieren zu lassen (Wasserman und Faust, 1994). Auf das technische Teilsystem angewandt beschreibt die durchschnittliche Pfadlänge die Anzahl an Knotenpunkten zwischen unterschiedlichen Produktionsstätten beziehungsweise zwischen Produktions- und Konsumtionsstätten innerhalb des Systems (z.B. Umspannwerke, Verteilstationen etc.).

Bedeutung für die Resilienz: direkte Kommunikationswege zwischen Akteuren unterschiedlicher Arenen führen in der Tendenz zu einer Erhöhung der Resilienz des Gesamtsystems. Dies einerseits in der kurzfristigen Perspektive, da angesichts eines drohenden Schocks eine effektive Zusammenarbeit zwischen Akteuren erleichtert wird, und andererseits längerfristig, da die Anpassungsfähigkeit des Gesamtsystems durch höhere Raten des Wissensaustauschs und der Kommunikation gestärkt wird (Scott, 2012; Wyss, Luthe, & Abegg, 2015). Im technischen System kann sich eine höhere Pfadlänge insofern resilienzfördernd auswirken, als dass die längere Übertragungszeit und die höhere Zahl an Knoten entlang eines Verteilungspfades Interventionen bei gefährlichen Versorgungsstörung im regionalen Energieverteilungsnetz erleichtert. Aus der Literatur ist bekannt, dass eine höhere durchschnittliche Pfadlänge generell die Stabilität technischer Systeme erhöht, welche anfällig auf Kaskadeneffekte sind (siehe z.B. Ash & Newth, 2007).

2.2.2 Gradzentralität

Die Gradzentralität stellt neben der Nähe- und der Zwischenzentralität den zentralen Indikator zur Messung von Zentralität in Netzwerken dar (Weimann, 1982). Für das soziale Teilsystem beschreibt die Gradzentralität die Anzahl der Verbindung zwischen Akteuren einer Arena und den Akteuren aller anderen Arenen im Vergleich zur Anzahl der insgesamt theoretisch möglichen Verbindungen zwischen den Arenen. Die Gradzentralität beschreibt entsprechend den Vernetzungsgrad eines Akteurs oder einer Arena im Gesamtsystem. Im technischen Teilsystem haben bestimmte Technologiegruppen (Flusslaufkraftwerke, Kohlekraftwerke, Atomkraftwerke) je nach Region historisch eine unterschiedlich hohe Zentralität entwickelt. Die Netzwerkstruktur des Energiesystems ist entsprechend auf die Dominanz bestimmter Technologiegruppen ausgelegt.

Bedeutung für die Resilienz: Akteure mit einer hohen Zentralität sind von besonderer Bedeutung hinsichtlich der Steuerung kollektiver Handlungen zwischen den Arenen. Sie können entsprechend Handlungen über die Grenzen sozialer Arenen hinweg koordinieren. Zentrale Akteure besitzen zwecks ihrer Stellung jedoch auch die Macht, die Veränderungen eines Systems zu verlangsamen oder gar zu verhindern, wenn dies in ihrem Interesse liegt (Wyss et al., 2015). Ein stark zentralisiertes System ist deutlich vulnerabler hinsichtlich eines Schocks, der den zentralen Versorger betrifft (wie z.B. Atomunfälle), mit der zunehmenden Dezentralität durch den erhöhten Anteil an erneuerbaren Energien, kann diese Gefahr abgemildert werden. Für die Resilienz der Transition ist es daher wichtig, neben den zentralen Verteilstrukturen auch dezentrale Kanäle der Energieversorgung auszubauen, um die dezentraleren Produktionsstrukturen in der Netzinfrastruktur widerzuspiegeln und eine anpassungsfähige Netzinfrastruktur bereitzustellen.

2.2.3 Modularität

Im sozialen Teilsystem beschreibt die Modularität die Tendenz der Akteure, über die Arenengrenzen hinweg Untergruppen zu bilden, die unter sich besonders gut vernetzt und vom restlichen Netzwerk teilweise losgelöst sind. Die Modularität im technischen Teilsystem kann unterschiedlich definiert werden. Für das Stromsystem können (teil-)abkoppelbare Verteilungsnetze von Produzenten zu Konsumenten identifiziert werden (Micro-Grids). Im Wärmenetz kann man die Modularität des Teilsystems als die (teil-)entkoppelte Versorgungsstruktur von Versorgungspunkten (Gas, Erdöl, Fernwärme) zu Konsumenten verstehen.

Bedeutung für die Resilienz: Eine hohe Modularität im sozialen System kann zu einem verstärkten Austausch innovativer Ideen in einer teilweise abgegrenzten Subgruppe des Systems führen und lokale Innovationen begünstigen (Luthe und Wyss, 2016), die letztendlich zu einer höheren Anpassungsfähigkeit des Gesamtsystems führen (Bodin, Crona, & Ernstson, 2006; Bodin & Crona, 2009). Gleichzeitig kann eine hohe Modularität jedoch auch den Informationsfluss zwischen Akteuren, die nicht Teil der gleichen Subgruppe gehören, erschweren und z.B: die Akzeptanz für neue Entwicklungen gefährden. Im technischen Bereich nimmt die Resilienz des Systems mit seiner Gesamtmodularität, bzw. der Clusterbildung zu (Rosenkrantz, Goel, Ravi, & Gangolly, 2005; Sharifi & Yamagata, 2016): in modularisierten Netzwerken verbreiten sich Schocks weniger schnell und können im Idealfall am Eingangsknotenpunkt eines Modules abgeblockt werden (Roege et al., 2014). Im Stromnetz wirkt sich eine zunehmende Modularisierung in regionalen Verteilnetzen, sie auch unabhängig vom Übertragungsnetzwerk funktionieren können (z.B. durch regionale Speichereinheiten) positiv auf die Resilienz der Transition aus. Die bisherigen Schwierigkeiten der zusätzlichen Netzbelastung durch die erneuerbaren Energien kann so abgefangen und der weitere Ausbau der Erneuerbaren fortgesetzt werden.

2.3 Idealtypische Fälle

Allgemein können vier idealtypische Fälle unterschieden werden, die sich bezüglich der jeweiligen Ausprägung der Diversität und Konnektivität unterscheiden (Binder et al., 2017): regionale Energiesysteme mit hoher Diversität und hoher Konnektivität, welche ideale Voraussetzungen für eine resiliente Transition mitbringen, regionale Energiesysteme mit tiefer Diversität und tiefer Konnektivität welche eine sehr eingeschränkte Resilienz der Transition aufweisen, und Mischformen mit unterschiedlicher Ausprägung der Diversität und Konnektivität in den sozialen und technischen Teilsystemen.

3 Methodik der Anwendung der Resilienz-Indikatoren auf die Transition des regionalen Energiesystems im bayerischen Allgäu

3.1 Untersuchungsregion „bayerisches Allgäu“

Im folgenden Abschnitt wenden wir das oben besprochene Indikatorenset zur Analyse der Resilienz eines regionalen Energiesystems in Transition auf die Region des bayerischen Allgäus an. Die Region umfasst die vier Landkreise Ost-, Ober- und Unterallgäu sowie Lindau und die kreisfreien Städte Memmingen, Kaufbeuren und Kempten und liegt am südwestlichen Alpenrand Bayerns (vgl. Abbildung 3.1). Das bayerische Allgäu kann als eine *der* Vorreiterregionen in Deutschland hinsichtlich des Fortschritts der Energiewende gesehen werden. Heute werden im bayerischen Allgäu ca. 39% des Gesamtstromverbrauchs aus erneuerbaren Energien produziert - der Landkreis Ostallgäu ist dabei mit 109 % Spitzenreiter in der Region (BStMWi, 2016).

Abbildung 3.1: Die Untersuchungsregion „bayerisches Allgäu“ (eigene Darstellung)

Aufgrund der naturräumlichen Bedingungen, wie großer Waldflächen (Landkreis Oberallgäu = 37% der Landkreisfläche (Bayerisches Landesamt für Statistik, 2015a) und Wasserläufen mit hoher Reliefenergie wurden die regionalen Ressourcen Holz und Wasser schon frühzeitig auch energetisch genutzt. Hohe Windgeschwindkeiten in Kammlagen erlauben darüber hinaus die Nutzung von Windenergie (StMWi, 2017).

Weiterhin begünstigt die landwirtschaftlich geprägte Landnutzung in der Region die Energiegewinnung aus Biomasse (50 % landwirtschaftlich genutzte Fläche, vgl. Bayerisches Landesamt für Statistik, 2015b). Viele Allgäuer arbeiten in traditionell ansässigen Industrie- und Handwerksbetrieben, die ein breites technische Knowhow in der Region zur Verfügung stellen (Bayerisches Landesamt für Statistik, 2015c, 2015d). Darüber hinaus spielen folgende Faktoren für den Fortschritt der Energiewende eine wichtige Rolle: i) die lokalen und kleinteiligen Besitzverhältnisse sowohl im Stromverteilnetz als auch bei der Energiegrundversorgung (LUTUM + TAPPE Geomarketing, 2017), die ein regionales Agieren unabhängig von großen Konzernen ermöglicht; ii) die frühe und lokal initiierte Institutionalisierung von Energiewende fördernden Richtlinien (z.B. Klimaschutzzielen) und Organisationen (wie z.B. der Vereine FEE, RENERGIE oder dem Energie- und Umweltzentrum Allgäu (eza!), die den Bestrebungen einen festen politischen und organisationalen Rahmen geben (vgl. Energie- und Umweltzentrum Allgäu (eza!), 2017a, 2017b; Renergie Allgäu e.V., 2017) sowie iii) die frühe Unterstützung der regionalen Energiewende durch konventionelle Akteure wie z.B. Stadtwerke, Abfallunternehmen, Waldbesitzerverband oder der Raiffeisenbank, die eine breite Akzeptanz des Transitionsprozess in der regionalen Bevölkerung begünstigte (Mühlemeier et al., eingereicht; (Mühlemeier & Knöpfle, 2016).

Auf Basis dieses besonders förderlichen regionalen Umfeldes hat schließlich eine gut vernetzte Gruppe an Pionieren aus den sozialen Arenen *Politik*, *Wirtschaft* (Energiewirtschaft, Land-, Forst- und Abfallwirtschaft) und Vereine (z.B. *Fördervereine* für die Energiewende, Branchenverbände) erheblich zur anfänglichen Entwicklung und fortwährenden Umsetzung der regionalen Energiewende beigetragen (Mühlemeier et al., eingereicht).

3.2 Untersuchungsmethoden der Fallstudienanalyse

Die Ergebnisse unserer explorativen Fallstudienanalyse wurden durch einen *Mixed-Methods* Ansatz erhoben (Flick, von Kardoff, & Steinke, 2004), der sowohl qualitative als auch quantitative Erhebungsschritte umfasst. Wie von Binder et al. (2017) vorgeschlagen, haben wir eine Untergliederung des sozialen Teilsystems in soziale Arenen sowie des technischen Teilsystems in Technologiegruppen vorgenommen (Binder et al. 2017), um eine vergleichbare Bezugseinheit im sozialen und technischen Teilsystem zu erhalten.

Der Analyse des sozialen Teilsystems liegen die 2014 und 2015 in der Region geführten Experteninterviews zu Grunde. Die Interviewpartner wurden nach dem sog. *Snowball Sampling* (Flick et al., 2004: 125; Flick, 2009: 168) ermittelt, bei dem „wichtige Pioniere der Energiewende in der Region" erfasst wurden. Die Interviewten wurden zu ihrer Wahrnehmung des Verlaufs der Energietransition in der Region, zu wichtigen Akteuren für den Fortschritt der Energiewende befragt, sowie nach ihrer Wahrnehmung fördernder und hemmender Faktoren und Organisationen. Die Auswertung der Interviews erfolgte durch eine *qualitative Textanalyse* (Kuckartz, 2014; Mayring, 2010, 2014) mit offener Kodierung in MAXQDA (http://www.maxqda.de). Für den vorliegenden Text wurden die von den Interviewten jeweils genannten wichtigen Akteure und Organisationen sowie ihre Vernetzung mit VISONE (Visualisierung sozialer Netzwerke, http://www.visone.info) dargestellt und in einem *one-mode network* analysiert (das heißt Akteure und Organisationen werden gleichwertig behandelt vgl. Wasserman und Faust, 1994: 36). Eine Verbindung besteht in diesem Netzwerk a) zwischen Akteuren, wenn sich diese kennen oder b) zwischen Akteur und Organisation bzw. unter verschiedenen Organisationen, wenn der Akteur oder die Organisation Teil einer (anderen) Organisation ist. Obwohl diese Methode keine vollständige Darstellung der Konnektivität des sozialen Teilsystems in der Region erlaubt, kann hiermit auch ohne Vollerhebung eine intersubjektive Aussagekraft erlangt werden.

Hinsichtlich des technischen Teilsystems konnte auf die Daten einer *Energieflussanalyse* (Baccini & Bader, 1996; Hendriks et al., 2000; Hug, Bader, Scheidegger, & Baccini, 2004) zurückgegriffen werden, die im Rahmen einer Masterarbeit des "Fit For Change" Forschungsprojekts „Transformationsprozesse zu einem nachhaltigeren Energiesystem" entstand (www.forchange.de). Hierzu wurden für die Region bayerisches Allgäu alle Energieflüsse (Produktion, Transport und Konsumption von Elektrizität und Wärme) ermittelt, die aus öffentlichen Daten für das Jahr 2011 berechnet werden konnten. Für die Elektrizitätsproduktion wurden das EEG-Register der Übertragungsnetzbetreiber (Amprion, 2017; TenneT, 2017; TransnetBW, 2017), EEG-Meldungen der Verteilnetzbetreiber (AllgäuNetz GmbH & Co. KG, 2017; Elektrizitätsgenossenschaft Rettenberg, 2017; Elektrizitätswerk Hindelang eG, 2017; LEW Verteilnetz, 2017; Stadtwerke Bad Wörishofen, 2017; VWEW-energie, 2017; Weißachtaler Kraftwerke, 2017), Daten des Energieatlas Bayern (StMWi, 2017) sowie Daten einzelner Anlagenbetreiber verwendet. Nicht EEG-geförderte Anlagen mussten geschätzt werden, PV und Windkraftanlagen konnten durch ihren geringen Anteil vernachlässigt werden (beides unter Zuhilfenahme des lokalen Expertenwissens der eza!). Für die Wärmeproduktion wurde ebenfalls dem Energieatlas Bayern, einem Bericht des eza! (Böhm, Sambale, Barth, & Botzenhart, o. J.)und Angaben einzelner Anlagenbetreiber entnommen. Visualisiert wurde die Analyse mit STAN 2.5 (http://stan2web.net). Es wurde davon ausgegangen, dass der Energieverbrauch im Bereich Mobilität auf fossilen Energieträgern basiert. Dieser Bereich wurde für den weiteren Verlauf der Analyse nicht berücksichtigt, da der Fokus auf den Wandel in Richtung eines höheren Anteils erneuerbarer Energien gelegt wurde und dieser im Mobilitätsbereich (noch) kaum spürbar ist.

4 Qualitative Ergebnisse zu den Resilienz-Indikatoren für die regionale Energiesystemtransition im bayerischen Allgäu

4.1 Diversität des sozialen Teilsystems

Zur Analyse der Diversität haben wir die drei erwähnten Indikatoren wie folgt angewandt: Varietät – wie viele soziale Arenen sind an der Transition des regionalen Energiesystems beteiligt? Balance – Wie viele Akteure sind pro Arena beteiligt? Disparität – Wie unterschiedlich sind die beteiligten Arenen?

4.1.1 Varietät

Folgende soziale Arenen konnten aus den Angaben der Befragten ermittelt werden:

- *Politik*: Kommunal- und Landkreispolitik und Verwaltung,
- *Vereine* (und Verbände): im Bereich Energiewende, Regionalentwicklung und Branchenvertretung,
- *Wirtschaft*: untergliedert in *Energiewirtschaft* und (sonstige) *Wirtschaft*,
- *Forschung*: privatwirtschaftliche und universitäre Institute
- *Medien*: lokales Printmedium.

Die Untergliederung der Arena *Wirtschaft* in *Energiewirtschaft* und (sonstige) *Wirtschaft* wurde vorgenommen, da es sich in der *Energiewirtschaft* häufig um Organisationen handelt, die durch ihre Funktion der Daseinsvorsorge eng an die lokale *Politik* gebunden sind (z.B. Kommunale Energieversorger) und daher anderen Logiken folgen als z.B. Elektro- oder Sanitärinstallationsfirmen (siehe auch Abschnitt Disparität). In der Region sind jedoch beide Teilarenen als sehr wichtig für das Energiegouvernanzsystem und den Fortschritt der Energiewende eingeschätzt worden. Die lokale Presse wurde auf Nachfrage hin in einigen Interviews ebenfalls genannt, jedoch eher als positiv unterstützender Begleiter, nicht als eigentlicher Akteur im Energiewendeprozess (vgl. Abbildung 4.1).

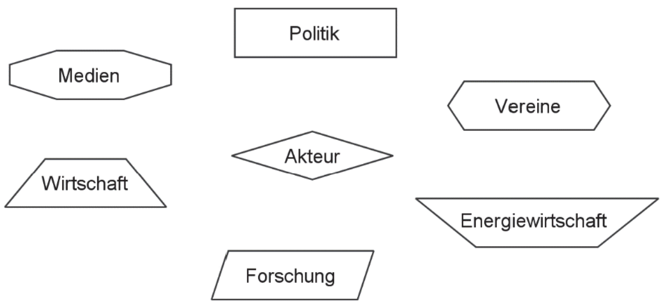

Abbildung 4.1: Schematische Darstellung der beteiligten Arenen (eigene Darstellung)

Die Varietät des sozialen Teilsystems ist im bayerischen Allgäu hoch und kann daher für die Resilienz der Transition des Energiesystems positiv bewertet werden, da verschiedene Gesellschaftsbereiche mit ihren Interessen an der Steuerung und Entwicklung des Energiesystems beteiligt sind.

4.1.2 Balance

Eine Berechnung der Balance – wie von Binder et al. (2017) vorgeschlagen – ist für diese Arbeit aufgrund der qualitativ erhobenen Wahrnehmungen der Befragten nicht sinnvoll. Es handelt sich um Einzelwahrnehmungen zu einem bestimmten Zeitpunkt, die keine Vollerhebung darstellen und die Balanceberechnung wäre darüber hinaus auch die Mehrfachbeteiligung der individuellen Akteure in verschiedenen Arenen (z.B. sowohl Inhaber einer Firma als auch Vereinsvorstand und Kommunalpolitiker) oder der gleichen Arena (z.B. in mehreren Vereinen) verzerrt.

Wir haben stattdessen aus den Experteninterviews deskriptiv abgeleitet, wie viele Organisationen von den Befragten in den jeweiligen Arenen genannt wurden (vgl. Abbildung 4.2), auch wenn dies ebenfalls nur ein Abbild einer einmalig erhobenen Wahrnehmung darstellt.

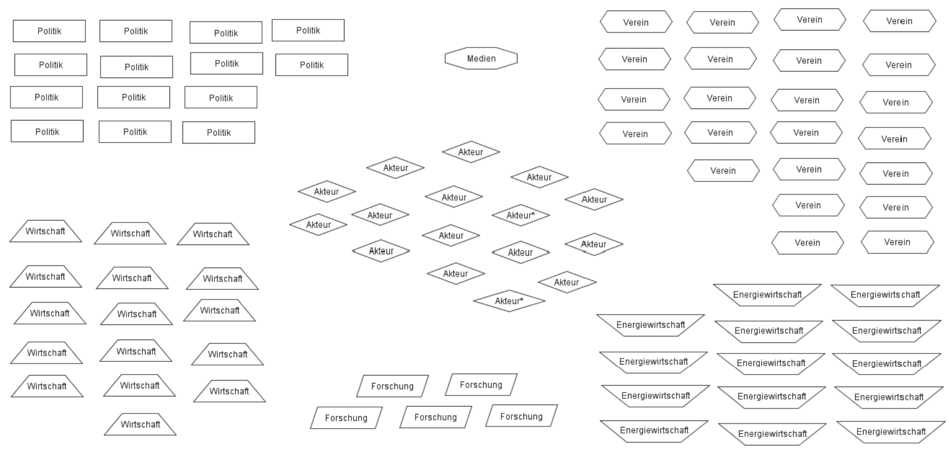

Abbildung 4.2: Akteure und Organisationen nach Arenen (eigene Darstellung)

Man kann aus dieser Erhebung ableiten, dass die meisten Organisationen im Bereich der Arena *Vereine* genannt wurden, darauf folgend etwa ähnlich viele in *Politik*, *Energiewirtschaft* und Wirtschaft; deutlich weniger dagegen in der Arena *Forschung* und am wenigsten in der Arena *Medien*. Die Balance des sozialen Systems ist daher insgesamt im mittleren Bereich, da in der Wahrnehmung der Befragten zwar nicht alle Arenen gleich stark vertreten sind, jedoch auch keine Arena das System allein dominiert. *Politik*, *Vereine*, *Wirtschaft* und *Energiewirtschaft* sind an der Transition des regionalen Energiesystems gleichermaßen beteiligt, was hinsichtlich der Resilienz des Prozesses positiv bewertet werden kann. Sollte ein externer Schock eine der Arenen besonders stark treffen und diese die Transition nicht weiter unterstützen, kann sie dennoch von den anderen Arenen weitergetragen werden.

4.1.3 Disparität

Wie bereits im Abschnitt zur Varietät angedeutet, definieren sich die sozialen Arenen durch ihre qualitativen Unterschiede, wobei der Unterschied zwischen der *Energiewirtschaft* und der sonstigen *Wirtschaft* besonders deutlich wird. Nach Wyss et al. (Manuskript) zeichnet sich die Arena *Wirtschaft* durch eine marktbasierte Koordination sowie produzierende, handelnde oder servicebasierte Handlungsweisen aus und ist dabei lokal bis hin zu global orientiert. Die Arena *Politik* zeichnet sich dagegen durch eine hierarchische Organisation, das Agieren durch Regulation oder Subventionen und ein Fokussieren auf die lokale oder regionale Ebene, aus. Die Teilarena *Energiewirtschaft* kann zwischen diesen beiden Archetypen angesiedelt werden, da z.B. Energieversorgungsunternehmen zwar marktwirtschaftlich funktionieren, jedoch gleichzeitig einer Kommune unterstellt oder rechenschaftspflichtig sein können. Die Arena der *Vereine* zeichnet sich schließlich durch eine netzwerkartige Organisation sowie eine Langfristorientierung und ebenfalls regionale Verankerung aus. Vernetzen, informieren und lobbyieren stellen ihre Hauptaktionsformen dar.

Für den sozialen Teil des Energiesystems bedeutet dies, dass die Disparität hoch ist und die Akteure in der Energiewende sowohl marktwirtschaftlichen als auch hierarchischen Logiken folgen. Sie produzieren und vermarkten einerseits Produkte in der Region, andererseits verwalten und vernetzen die Akteure des Energiesystems in der Region. Diese enorme Vielfalt der Handlungslogiken der Akteure kann natürlich zu Spannungen und Reibungsflächen führen und wird daher hinsichtlich der Resilienz der Transition sowohl positiv als auch negativ bewertet. Können die Differenzen zwischen den beteiligten Akteuren der verschiedenen Arenen nicht überwunden werden, wird die Transition ausgebremst. Findet sich aber ein Konsens zwischen den Arenen, kann auf unterschiedlichste Wissensformen, Handlungs- und Organisationsformen zurückgegriffen werden, die im Falle eines externen Schocks oder der Veränderung der Rahmenbedingungen die Anpassungsfähigkeit des Systems enorm erhöht - und die Resilienz der Transition steigt. Dies kann jedoch nur durch eine entsprechende Vernetzung der Akteure zwischen den Arenen gelingen, was im folgenden Abschnitt untersucht wird.

4.2 Die Konnektivität des sozialen Teilsystems

Für die Konnektivität des sozialen Systems haben wir die drei von Binder et al. (2017) vorgeschlagenen Indikatoren wie folgt angewandt: Durchschnittliche Pfadlänge – Wie direkt sind die Akteure bzw. über die Akteure auch die Organisationen miteinander vernetzt? Gradzentralität – gibt es einen Akteur, bzw. eine Organisation die besonders stark vernetzt ist? Modularität – gibt es Teile des Netzwerks, die vergleichsweise stärker untereinander vernetzt sind?

4.2.1 Durchschnittliche Pfadlänge

Auch für die von Binder et al. (2017) vorgeschlagene Berechnung der durchschnittlichen Pfadlänge muss einschränkend festgehalten werden, dass die qualitativ erhobene Datengrundlage, die keine Vollerhebung der sozialen Netzwerke in der Region darstellt, keine vergleichbare Pfadlängenberechnung erlaubt. Die hier angegebenen Zahlen sollen daher lediglich als Anwendungsbeispiel des vorgeschlagenen Ansatzes dienen.

Die wahrgenommene durchschnittliche Pfadlänge zwischen den befragten Akteuren beträgt für das untersuchte Netzwerk 2,9. Das heißt, dass im Durchschnitt jeder Akteur über zwei andere mit einem Dritten verbunden ist. Die Pfadlänge zwischen den Organisationen ist mit 1,7 deutlich kürzer, da nur einige wenige Organisationen direkt an anderen Organisationen beteiligt sind und die restlichen (die über Individuen vernetzt sind), automatisch mit dem Wert „0" verrechnet werden (siehe auch Abbildung 4.3). Die Pfadlänge des gesamten Netzwerks beträgt 2,7. Hinsichtlich der Resilienz kann man schließen, dass die Akteure untereinander zwar gut vernetzt sind, jedoch ohne die entsprechenden Verbindungen über die Organisationen Informationen häufig nicht direkt von Akteur zu Akteur, sondern über eine Drittperson fließt. Dies könnte die Anpassungsfähigkeit im Fall von kurzfristig auftauchenden Schock-Ereignissen beeinträchtigen. Längerfristig können höhere durchschnittliche Pfadlängen aber einem allzu starken Gruppendenken, also der ungefilterten Propagation von Ideen und Meinungen im Netzwerk vorbeugen und die langfristige Resilienz des Transitionsprozesses erhöhen.

4.2.2 Gradzentralität

Wendet man die von Binder et al. (2017) vorgeschlagene Formalisierung für die Messung der Gradzentralität an, so ergibt sich für die eza! ein Zentralitätswert von 9,7 %. Sie ist damit die zentralste

Organisation des Netzwerkes (vgl. auch Mühlemeier und Knöpfle, 2016). Daraufhin folgen die vier zentralsten Akteure: ein Landrat, ein Verbandsvorsitzender und zwei Akteure aus der *Wirtschaft* mit einer Gradzentralität von 4,7 % bis 3,4 %, sowie vier Organisationen aus der *Energiewirtschaft* und der Arena der *Vereine* (hier: zur Regionalentwicklung) mit einer Gradzentralität von 3,4 % bis 3,2 %. Auch für die Berechnung der Gradzentralität gilt die oben genannte Einschränkung und der Hinweis, dass es sich hier um individuelle Wahrnehmungen handelt, die nicht gewichtet werden konnten und lediglich der Veranschaulichung des theoretischen Ansatzes dienen. Trotzdem zeigt sich, dass Akteure und Organisationen aus den Arenen *Vereine*, *Politik*, *Wirtschaft* und *Energiewirtschaft* nicht nur am stärksten vertreten sind im Netzwerk (vgl. Balance), sondern auch die zentralsten Positionen im Netzwerk einnehmen. Es wird wiederum deutlich, dass abgesehen von der eza! keine Zentralität von Organisationen aus lediglich einer Arena festzustellen ist. Das soziale Teilsystem wird von den Akteuren insgesamt als ausgewogen wahrgenommen, mit einem klaren zentralsten Akteur, der eza! (vgl. Abbildung 4.3).

Für die Resilienz des Systems kann diese Struktur sowohl positiv wie auch negativ bewertet werden: solange die eza! als zentraler Akteur die Transition unterstützt und weiter vorantreibt und dabei von den Akteuren des Netzwerks unterstützt wird, wirkt sich dies enorm förderlich auf den Transitionsprozess aus, da direkte Impulse von der eza! in das gesamte Netzwerk ausgehen. Steht die eza! jedoch nicht mehr hinter der Transition oder wird als Treiber der Energiewende nicht mehr unterstützt, fehlt dem Netzwerk der zentrale Koordinationspunkt und die Transition gerät ins Stocken. Dies könnte eventuell durch die zentralen Akteure und Organisationen, die der eza! in der Abstufung der Zentralität folgen, abgefangen werden. Hier wirkt sich wiederum die Balance zwischen den Arenen positiv aus, die ein weiteres Gelingen der Energiewende ermöglicht.

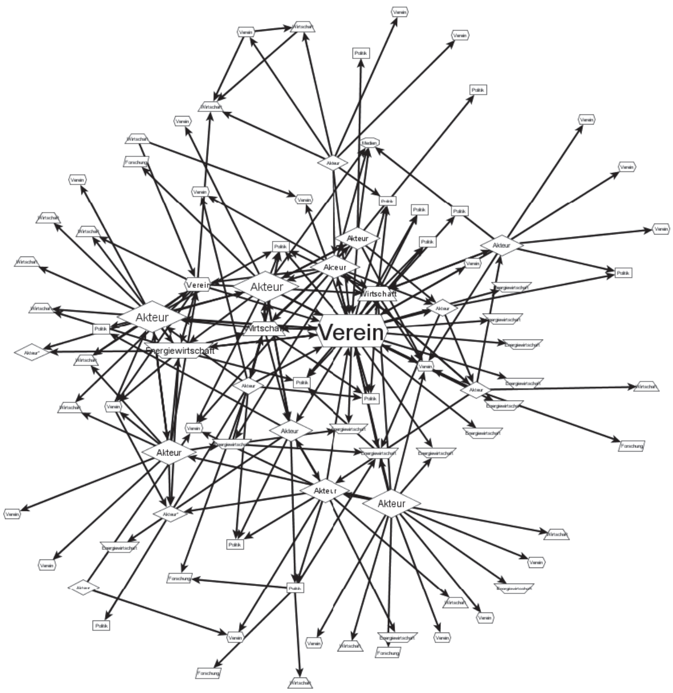

Abbildung 4.3: Gradzentralität: die Größe der Punkte stellt ihre Zentralität dar; Organisationen wurden nach ihrere Arenenzugehörigkeit anonymisiert) (eigene Darstellung)

4.2.3 Modularität

Die Berechnung der Modularität basiert auf dem Louvain-Algorithmus (Blondel, Guillaume, Lambiotte, & Lefebvre, 2008). Dieser Algorithmus fasst diejenigen Akteure und Organisationen zu einem gemeinsamen Modul zusammen, die eine stärkere Vernetzung untereinander als zu anderen Akteuren oder Organisationen im Netzwerk aufweisen. Dabei ergeben sich sieben Module innerhalb des Netzwerks (vgl. Abbildung 4.4), die jeweils wieder Organisationen aus den unterschiedlichen Arenen beinhalten. Vier Module beinhalten sowohl mehrere Akteure und mehrere Organisationen, zwei lediglich einen Akteur und mehrere Organisationen, und ein Modul besteht alleine aus Organisationen. Insgesamt zeigt es sich, dass in vier der sieben Module, die Akteure und Organisationen bedeutend stärker vernetzt sind als in den anderen drei. Bei diesen vier stärker vernetzten Modulen umfasst eines alle Arenen, die anderen umfassen keine Organisation aus den Medien und jeweils ein Modul hat keinen Politik- bzw. Energiewirtschaftsvertreter. Es zeigt sich, dass die Module sich nicht innerhalb der Arenen, sondern über Arenengrenzen hinweg bilden. Hinsichtlich der Resilienz der Transition kann dies positiv bewertet werden, da innerhalb der Module unterschiedliche Ansätze und Ideen zirkulieren können, diese aber dennoch von Vertretern aus unterschiedlichen Arenen geteilt oder diskutiert werden. Die Energietransition, die von dem hier untersuchten Akteursnetzwerk aus maßgeblich mit beeinflusst wird, ist aufgrund der Modularität des Netzwerks und der Repräsentation mehrerer Arenen in den Modulen für einen lock-in weniger gefährdet, was die Resilienz des Gesamtsystems steigert.

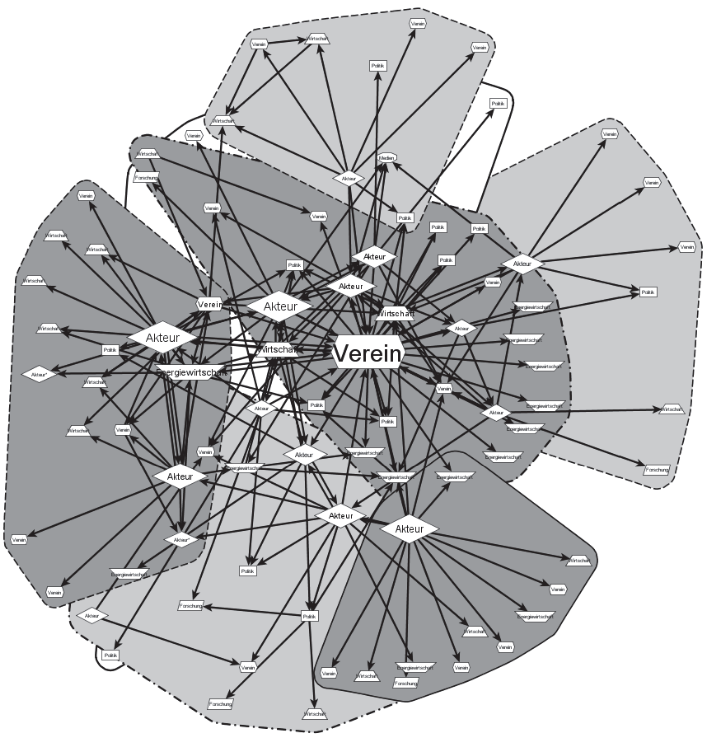

Abbildung 4.4: Modularität des sozialen Netzwerks (auf Basis der Zentralitätsanalyse) (eigene Darstellung)

4.3 Die Diversität des technischen Teilsystems

Für die Analyse der Diversität im technischen Teilsystem haben wir die vorgeschlagenen Indikatoren wie folgt angewandt: Varietät – Wie viele Technologiegruppen sind an der regionalen Strom- und Wärmeproduktion beteiligt? Balance – Welchen Anteil hat die jeweilige Technologiegruppe am insgesamt produzierten Strom und Wärme? Disparität – wie unterschiedlich sind die verschiedenen Technologiegruppen zur Strom- und Wärmeproduktion?

4.3.1 Varietät

Aus der Energieflussanalyse für das Jahr 2011 ergab sich, dass zur Stromproduktion im Allgäu

- Wasserkraftanlagen (Kleinkraftwerke, Flusskraftwerke),
- Windkraft- und Photovoltaikanlagen (PV) (Dach- und Freiflächen) sowie
- Biomassekraftwerke

eingesetzt werden. Zur Wärmeproduktion kommen

- Kraftwärmekopplungsanlagen (mit Biomasse betrieben)
- Biomasseheizwerke,
- Solarthermie und
- Wärmepumpen

zum Einsatz (vgl. Abbildung 4.6). Darüber hinaus werden für die Stromversorgung große Mengen des Stroms importiert, die aus dem durchschnittlichen nationalen Technologiemix entstehen. Für die Wärmeversorgung und Mobilitätsnutzung werden außerdem fossile Brennstoffe importiert (vgl. Abbildung 4.6). Insgesamt ist die Diversität der in der Region angesiedelten und über Importe genutzten Energieproduktionstechnologien daher sowohl für die Strom- als auch für die Wärmeerzeugung hoch und kann hinsichtlich der Resilienz der Energiewende positiv bewertet werden, da verschiedene Energieproduktionsquellen die Versorgungssicherheit auch bei großen externen Schocks ermöglichen und der Wandel des Energiesystems hin zu einem größeren Anteil an erneuerbaren Energien damit technisch nicht gefährdet ist.

4.3.2 Balance

Hinsichtlich des Anteils, den die Technologien am Gesamtenergieverbauch im Allgäu haben, zeigt sich erneut der jeweils große Anteil an Strom bzw. an den fossilen Brennstoffen, der in die Region importiert wird (64% des Gesamtstromverbrauchs und 84% der zur Wärmeproduktion verwendeten Ressourcen, vgl. Abbildung 4.5). Fokussiert man sich auf die Anteile der Technologien zur Energieproduktion aus erneuerbaren Energien, so zeigt sich, dass für die Stromproduktion, von den insgesamt 36 % an erneuerbaren Energien 14 % auf PV, 13 % auf Wasserkraft, 8 % auf Biomasse und 1 % auf Windkraftanlagen entfallen (vgl. Abbildung 4.6). Bei der Wärmeproduktion entfällt von den insgesamt 15 % erneuerbaren Energien mit 7 % der Großteil auf importiertes Holz. Lediglich 2 % kommen aus KWK Anlagen, 1 % aus Biomasseheizwerken und weniger als 1 % jeweils aus Solarthermie und durch Wärmepumpen (vgl. Abbildung 4.6).

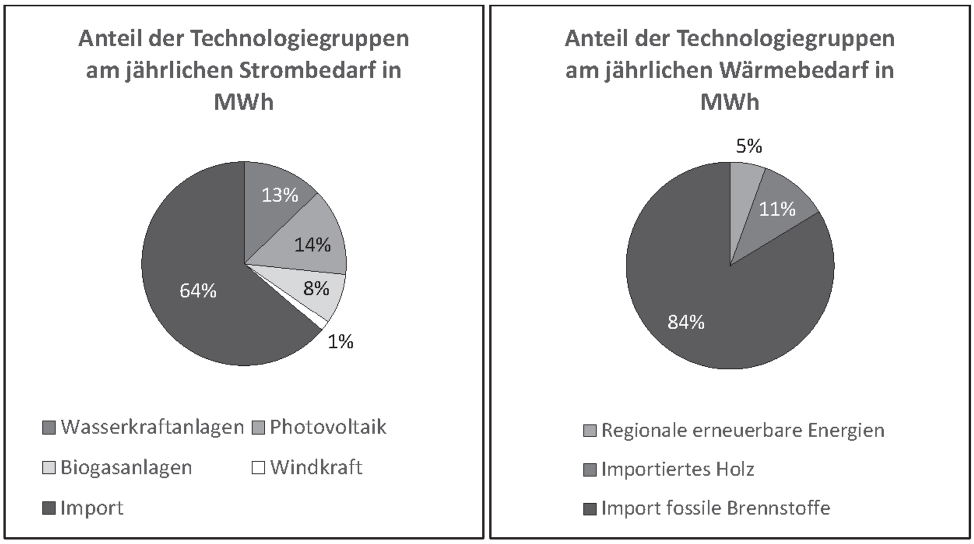

Abbildung 4.5: Balance: Anteil aller Technologiearten am jährlichen Strom- und Wärmebedarf 2011 in der Region

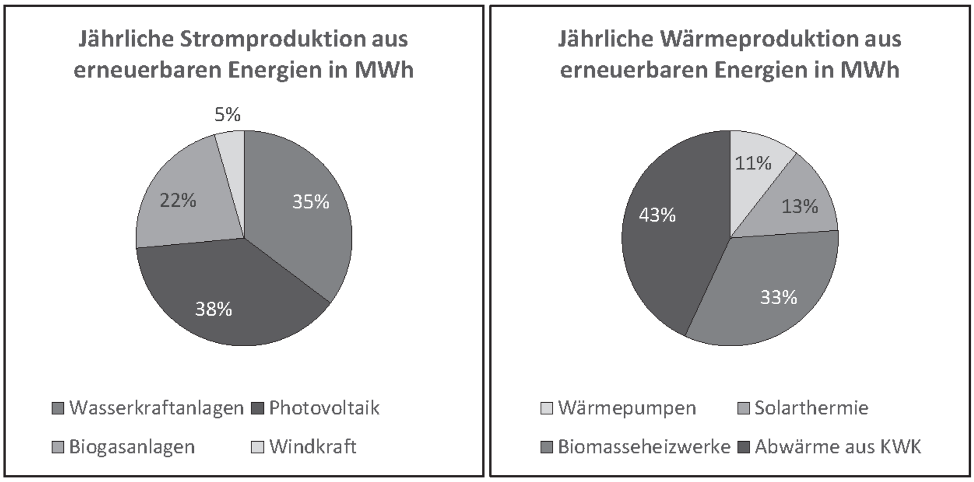

Abbildung 4.6: Balance – Anteil der erneuerbaren Energien an der jährlichen Strom- und Wärmeproduktion 2011

Betrachtet man die Balance innerhalb der regional produzierten erneuerbaren Energien, dominieren für die Stromproduktion PV und Wasserkraft (38% und 35%), gefolgt von Strom aus Biogasanlagen (22%) und Windkraft (4%). Bei der regionalen Wärmeproduktion dominiert die Abwärme aus KWK mit 43%, gefolgt von Wärme aus Biomasseheizwerken (33%), Solarthermie (13%) und Wärmepumpen (11%). Berücksichtigt man jedoch den Anteil der erneuerbaren Energien am Gesamtverbrauch, so fällt die Balance insgesamt für Strom mittel (36 % Anteil) und für Wärme sehr niedrig (15%) aus. Die Transition des Wärmesystems scheint daher - zumindest für die jüngere Vergangenheit - langsamer als die des Stromsystems zu sein (siehe auch Brockmann, 2017; Bundesregierung, 2014) und kann als weniger resilient angesehen werden.

4.3.3 Disparität

Für die Analyse der qualitativen Unterschiede beschreiben wir hier exemplarisch nur die regional vorhandenen Produktionstechnologien aus erneuerbaren Energien zur Stromproduktion, da die Importe aus dem nationalen Strom-Mix für die Charakterisierung des regionalen Produktionssystems wenig relevant sind. Es zeigt sich dabei eine hohe Disparität, da i) vier sehr unterschiedliche Ressourcengrundlagen verwendet werden, ii) Wind- und Wasserkraft deutlich effizienter sind als PV-Anlagen und Biomassekraftwerke zur Stromerzeugung und iii) die Wetterabhängigkeit von PV- und Windkraftanlagen deutlich höher ist, als die der Wasserkraft und Biomasseanlagen. Die Gestehungskosten variieren ebenfalls, jedoch weniger stark: nach Kost et al., (2013) liegen sie für Onshore-Windkraft bei 5 – 11 Cent per kWh, für PV im Mittel bei 8 – 17 Cent (Kost et al., 2013) und für Wasserkraft bei 5 - 10 Cent für Großanlagen und 10-20 Cent für Kleinanlagen (unter 10 MW) (Schünemann, 2011). Strom aus Biomasse (Biogas) mit 16 – 22 Cent per kWh ist dagegen teurer. In der Zusammenschau bedeutet dies, dass das regionale Stromproduktionssystem sehr dispers ist: Es vereint sowohl Grund- als auch Spitzenlasttechnologien, mehr oder weniger wetterabhängige Technologien oder auch teurere und weniger teure Technologien. Dies wirkt sich positiv auf die Stabilität des technischen Systems, bzw. auf die Versorgungssicherheit aus. Hinsichtlich der Resilienz der Transition ist die höhere Disparität ebenfalls positiv zu werten, da sich die Technologien aufgrund ihrer Unterschiedlichkeit gegenseitig ergänzen und die Versorgungssicherheit auch bei höheren Anteilen der erneuerbaren Energien gewährleistet wird. Zudem verringert die hohe Disparität die Vulnerabilität des technischen Systems für technologiespezifische externe Schocks und erleichtert ein ununterbrochenes Fortschreiten der Transition, selbst wenn solche Schocks eintreten sollte.

4.4 Die Konnektivität des technischen Teilsystems

Da zur Konnektivität des technischen Teilsystems in der Region keine direkt verwendbaren Daten zur Verfügung stehen, kann hier lediglich ein Vorschlag zur empirischen Anwendung der Indikatoren gemacht werden. Dieser wird dann exemplarisch mit Erkenntnissen aus dem Allgäu gespiegelt. Für die Analyse der Konnektivität im technischen Teilsystem ist es ebenfalls sinnvoll Strom und Wärmenetze zu unterscheiden, da sie sehr unterschiedliche Charakteristika aufweisen: für die Verteilung von Elektrizität steht nur ein Netz zur Verfügung, das über seine verschiedenen Spannungsebenen (Höchst-, Hoch-, Mittel- und Niederspannung) stark integriert ist. Es integriert alle Technologiearten zur Stromproduktion in einer Netzstruktur. Im Bereich der Wärmeversorgung gibt es - je nach Produktionstechnologie - mehrere Netzwerke, die sich durch ihre unterschiedliche Vernetzungsstruktur unterscheiden: Nah- und Fernwärme, Erdgas- und Biogasnetze, Erdöl- und Holztransportnetze; wobei letztere keine physischen Netzwerke darstellen, sondern sozioökonomische Händlernetzwerke, über die die Materialien von Produzenten zu Konsumenten fließen.

Für die Analyse der Konnektivität des technischen Bereichs des Energiesystems haben wir die vorgeschlagenen Indikatoren wie folgt interpretiert: Durchschnittliche Pfadlänge – Wie viele Knoten sind im Netzwerk zwischen Produzent und Verbraucher geschaltet und wie können analog zu den sozialen Arenen Pfade zwischen den Technologiegruppen gedacht werden? Zentralität – Wie viele Verbraucher sind bei den unterschiedlichen Energietechnologien an einen Versorgungsknoten angeschlossen und welche Zentralität haben die Technologiegruppen untereinander? Modularität – Lassen sich Modulstrukturen in den Verteilnetzen der unterschiedlichen Produktionstechnologien erkennen und bilden gewisse Technologiegruppen untereinander Module?

4.4.1 Durchschnittliche Pfadlänge

Das Stromnetz verfügt auf der Höchstspannungsebene über eine geringe Pfadlänge zwischen den Produktions- und Abnahmepunkten; dies um eine hohe Transportgeschwindigkeit und geringe Verluste zu erreichen. Die tieferen Netzebenen haben eine höhere Pfadlänge, da sie über mehrere Umspannungsprozesse den Strom in der Region verteilen und andersherum auch fehlerhafte Knoten aus dem Netz isolieren können müssen, um eine schnelle Fehlerverbreitung zu verhindern (Islanding) (vgl. Abbildung 4.7).

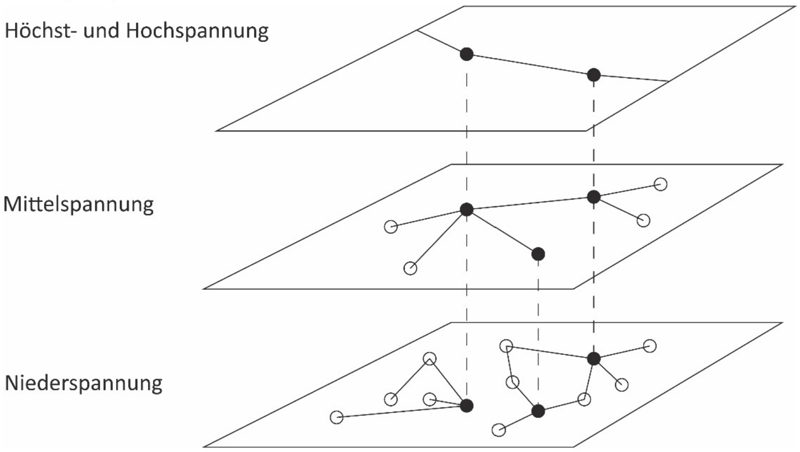

Abbildung 4.7: Schematische Darstellung der verschiedenen Spannungsebenen des Stromnetzes – Umspannpunkte sind in schwarz verzeichnet (eigene Darstellung)

Das Stromnetz integriert somit alle Produktionstechnologien zur Stromerzeugung in einem Netz und verbindet sie über möglichst kurze Pfadlängen direkt mit den Abnehmern. Dennoch verfügen regional angesiedelte Produktionstechnologien über kürzere Pfadlängen zueinander und zu den Abnehmern, da sie nicht so häufig umgespannt werden müssen. Für den Fall des Allgäus hieße das, dass z.B. PV, Wasserkraft und Windkraft über eine kürzere Pfadlänge miteinander verbunden sind als z.B. mit der Stromproduktion aus Kohle oder Atomkraft. Die Mehrebenenstruktur des Stromnetzes mit den entsprechend unterschiedlichen Pfadlängen wirkt sich dabei sowohl positiv als auch negativ auf die Resilienz des Energietransitionsprozesses aus: einerseits können die dezentral auf Verteilnetzebene zunehmenden Erneuerbaren über die langen Pfadlängen in den unteren Spannungsebenen geregelt werden, sodass sich eventuelle Störungen nicht auf Hochspannungsebene verbreiten. Die Versorgungssicherheit kann somit trotz Wandel garantiert werden und die Transition kann fortschreiten. Auf der anderen Seite steht diese fixe Zusammensetzung aus unterschiedlichen Pfadlängen über die Spannungsebenen auch einer regionalen Transition im Weg, da aufgrund fehlender Leitungen, Überkapazitäten nicht auf niederen Spannungsebenen zwischen Regionen verteilt werden können, somit der weitere Ausbau der Erneuerbaren immer die Gesamtnetzstabilität betrifft und die Transition entsprechend beeinträchtigt ist.

Im Gegensatz zum Stromnetz in dem alle Produktionstechnologien in einem Netz integriert sind, kann man im Wärmebereich nicht von *einem* Wärmenetz sprechen. Analysiert man die einzelnen Netze der Produktionstechnologien im Allgäu getrennt, zeigt sich, dass sich Nah- und Fernwärmenetze durch die geringste Pfadlänge auszeichnen, da die Wärme direkt vom Produzenten zum Konsumenten transportiert wird und diese, um Transportverluste zu minimieren, weder transformiert noch über lange Strecken und über mehrere Abnehmer hinweg verteilt wird (vgl. z.B. Fernwärme Marktoberdorf GmbH, 2014; ZAK Kempten, 2017). Erd- bzw. Biogasnetze können deutlich höhere Pfadlängen aufweisen, da die Wärme nicht direkt, sondern in Form von Gas transportiert wird und somit auch über Dritte an den

Konsumenten fließen kann. Da Gas aufgrund seiner Lagerfähigkeit auch nicht-netzgebunden von Produzent zu Kunde gelangen kann, sind zudem Inselstrukturen möglich (bestehend aus Tank und Abnehmer) (EKO Gas, 2017; Erdgas Schwaben, 2015). Weitere nicht-netzgebundene Ressourcen, wie z.B. Erdöl, Kohle oder Holz, werden über soziale Händlernetze vom Produzenten zum Kunden gebracht und können damit potentiell die längsten Pfadlängen aufweisen (vgl. Abbildung 4.8) Im Allgäu ist das Holznetz jedoch von sehr kurzen Pfadlängen geprägt, da es nicht nur lokal produziert, sondern auch regional über eine gemeinschaftliche Vermarktungsplattform direkt zum Kunden gebracht wird – im Gegensatz zur Erdölversorgung, die international über mehrere Zwischenhändler erfolgt.

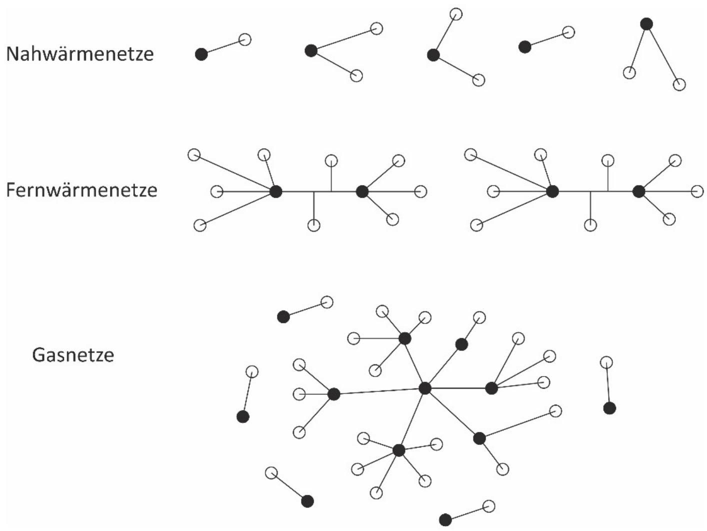

Abbildung 4.8: Schematische Darstellung der verschiedenen Wärmenetze (eigene Darstellung)

Bezüglich der Verbindung zwischen den Produktionstechnologien kann man festhalten, dass Technologien, welche z.B. die gleiche Ressource teilen (KWK, Biomasseheizwerk) oder deren Produkt in der gleichen Netzinfrastruktur verteilt werden kann (Biogas und Erdgas) entsprechend über einen direkten Pfad verbunden sind, während z.B. zwischen einer Solarthermie- oder Ölheizung keine solche Verbindung besteht. Im Falle des Allgäus können so z.B. bestehende Erdgasleitungen in Zukunft mit Biogas genutzt werden, was bedeutend zur Resilienz der Transition beiträgt.

4.4.2 Gradzentralität

Die bisherige Stromversorgungsinfrastruktur im Allgäu basiert auf Technologien mit stark zentralisierten Kraftwerksstrukturen (Wasserkraft, Importe aus Atom- und Kohlekraft), die viele, auch weit entfernte Abnehmer mit Strom versorgen. Mit dem Ausbau der Technologien zur Stromproduktion aus erneuerbaren Energien (Windenergie und PV) nimmt der Grad an Dezentralisierung stark zu und bringt die bestehende Stromnetzstruktur unter Druck, da sie für die Dezentralität der neuen Technologien nicht angelegt war. Dies gilt gerade auch für die regionalen Verteilnetze, die beispielsweise im Allgäu an sonnigen oder windigen Tagen den in der Region anfallenden Strom sowohl regional wie auch überregional weiterverteilen müssen. Hinsichtlich der Resilienz der Transition ist der hohe Grad an Zentralität zunächst negativ zu bewerten, da er keine alternative Struktur der Stromverteilung zulässt. Andererseits ermöglicht es die hohe Zentralisierung des Netzwerkes auf höheren Netzebenen, dass trotz fundamentaler Veränderung der Produktionstechnologien und dem Zubau der Erneuerbaren die Versorgungssicherheit weiterhin gewährleistet bleibt. In diesem Zusammenhang würden sich regionale Speicher positiv auf die Resilienz der Transition auswirken, da sie die zentralisierte Verteilstruktur und die dezentralisierte Produktionsstruktur ausgleichen und zudem die regionale Abhängigkeit von Stromimporten minimieren könnten.

Für die Wärmenetze müssen die verschiedenen Technologien erneut getrennt betrachtet werden: Nah- und Fernwärmenetze zeichnen sich durch eine hohe Zentralität aus, da eine Produktionseinheit mehrere Abnehmer versorgt. Im Gasnetz, wie auch in den Erdöl- oder Holzversorgungsnetzen fällt die Zentralität oft geringer aus, da potentiell mehrere Produzenten oder Händler die Konsumenten versorgen können (vgl. Abbildung 4.8). Es ist jedoch auch möglich, dass lediglich eine Produktionsstätte oder ein Händler im Netzwerk alle Konsumenten versorgt (z.B. staatliche Betriebe, Kartelle). Wie auch bei der Pfadlänge zeigt sich, dass die Vernetzungsstruktur hier kaum bis gar nicht von der Produktionstechnik selbst, sondern vielmehr von der Form der entsprechenden sozioökonomischen Produktions- und Händlerstrukturen abhängig ist. Die momentane Dominanz zentralisierter Technologien zur Wärmeproduktion, insbesondere von Öl und Gas, ist hinsichtlich der Resilienz des Systems und seiner Transition kritisch zu bewerten: Die Abhängigkeit von häufig importierten Energieträgern kann sowohl die Vulnerabilität des Systems gegenüber externen Schocks erhöhen (bspw. Preisexplosionen) als auch z.B. durch den aktuell niedrigen Ölpreis die Resilienz der Transition des regionalen Energiesystems negativ beeinflussen. Mit der stärkeren Nutzung der erneuerbaren Energien zur Wärmeproduktion könnte die Abhängigkeit von zentral angelegten Energieimporten abgeschwächt werden und Öl oder Gas durch Biogasanlagen, Biomasseheizwerke oder moderne Holzverbrennungsanlagen ersetzt werden, welche dezentral versorgt werden können.

4.4.3 Modularität

Das bisherige Stromnetz im Allgäu und in Deutschland ist kaum modular: Der Strom wird von einer zentralen Verteilung auf Hochspannungsebene in die Regionen transferiert und es gibt keine untergeordnete, abkoppelbare Verteilstruktur in der Region, die autonom, ohne die Einbettung in die höheren Spannungsebenen, funktionieren könnte. Möglich ist es lediglich, Teile des Netzes auf einer bestimmten Netzebene abzukoppeln, um so z.B. die Störungsverbreitung im Netz zu verhindern (Islanding). „Das Wärmenetz“ ist dagegen deutlich modularer strukturiert: nicht netzgebundene Technologien (Ölheizung, Holzheizung) können dabei als Inseln betrachtet werden, Nah- und Fernwärme bilden bereits kleine, lokale Module und Gasnetze sind oftmals regional integrierte Netze, so z.B. auch im Allgäu. Hinsichtlich der Resilienz der Transition kann sich auch hier eine zunehmende Modularität durch den Ausbau regionaler Fernwärme- oder Gasnetze, wie auch die Etablierung lokaler Speicher oder aber die Vernetzung von Strom und Wärme über Power-to-Gas, positiv auf die Resilienz auswirken, da neben den zentralisierten Strukturen regionale Versorgungsmodule etabliert werden können. Diese Module können im Fall externer Schocks autonom funktionieren und im Fall größerer Störungen als Back-Up zum überregional integrierten System dienen.

5 Diskussion und weiterer Forschungsbedarf

In dieser ersten empirischen Anwendung des von Binder et al. (2017) vorgeschlagenen indikatorengestützten Ansatzes zur Analyse der Resilienz von Energiesystemen in Transition zeigt sich, dass das regionale Energiesystem im Allgäu durch eine hohe Diversität im sozialen Teilsystem charakterisiert ist: Es werden Akteure und Organisationen aus mehreren, qualitativ sehr unterschiedlichen sozialen Arenen als zentral für die regionale Energiewende wahrgenommen, wobei die unterschiedlichen Arenen dabei ähnlich stark vertreten sind (bis auf die Arena *Medien*). Die regionale Energiewende ist daher breit über viele Gesellschaftsbereiche gleichmäßig gestützt, was hinsichtlich des Fortschritts der Energiewende sehr positiv bewertet werden kann.

Im technischen Teilsystem ist die Diversität geringer ausgeprägt: Ein großer Teil des regionalen Energiebedarfs wird über Importe abgedeckt. Mit Bezug auf die lokal produzierte Energie zeichnet sich im Strombereich eine höhere Diversität mit eher ausgeglichenen Anteilen an der Gesamtproduktion und sehr unterschiedlichen Technologiegruppen ab, während Wärme in erster Linie aus Abwärme von Kraft-Wärme-Koppelungsanlagen und aus Biomasseheizwerken gewonnen wird. Die regionale Energieproduktion ist daher zwar von höherer Varietät und Disparität geprägt, hat jedoch einen geringen Anteil an der in der Region verbrauchten Energie. Hinsichtlich der Resilienz der Transition sind die Vielfalt und Unterschiedlichkeit der regional eingesetzten Technologien positiv, die hohe Abhängigkeit von Importen jedoch negativ zu bewerten, da auf die Transition der Quellen der importierten Energie kein direkter Einfluss genommen werden kann.

Die Konnektivität des sozialen Teilsystems zeigt sich in folgenden Charakteristika: die Pfadlängen zwischen den Akteuren und Organisationen sind verhältnismäßig lang, das Netzwerk wird von einer prägenden Organisation mit hohem Zentralitätswert dominiert und es zeichnet sich eine Reihe von Modulen innerhalb des Netzwerkes ab. Spannend ist, dass die sozialen Arenen im gesamten Netzwerk untereinander jedoch alle etwa ähnlich gut vernetzt sind (ausgenommen *Forschung* und *Medien*). Das regionale Energiegouvernanzsystem ist daher nicht nur von vielen Gesellschaftsbereichen getragen, sondern auch gut aber nicht zu dicht zwischen diesen vernetzt. Hinsichtlich der Transition des Systems ist dies unterschiedlich zu bewerten: einerseits positiv da eine zentrale Organisation vorhanden ist, die die Transition steuern kann, sowie die höhere Modularität und Pfadlänge einem lock-in der Entwicklung vorbeugen können. Negativ wendet sich diese Vernetzungsstruktur jedoch, wenn z.B. der zentrale Steuerungsknoten entfällt und über die längeren Pfadlängen, die Informationen nicht besonders schnell fließen.

Bei der Konnektivität im technischen Bereich wird deutlich, dass bei dieser Betrachtung zwischen Strom und Wärme unterschieden werden muss. Das Stromnetz ist über die verschiedenen Spannungsebenen stark vernetzt, wobei alle drei Indikatoren - Pfadlänge, Gradzentralität und Modularität - in Richtung Niederspannung zunehmen. Wärmenetze sind dagegen je nach Technologie sehr unterschiedlich vernetzt und je nach Technologiegruppe in ihrer Vernetzung auch stärker von der sozioökonomischen Struktur abhängig. Die Vernetzungsstruktur gestaltet sich daher sehr unterschiedlich zwischen Wärme und Strom, bezüglich der Resilienz der Transition sind beide jedoch eher kritisch zu sehen, da die Vernetzungsstruktur für eine Einbindung höherer Anteile erneuerbarer Energien grundlegend umgebaut werden muss und hohe Investitionskosten anfallen. Regionale Speicher für den Strom sowie eine Nutzung der bestehenden Gasnetze für Biogas könnten hier gute Alternativen darstellen.

Insgesamt zeichnet sich das Energiesystem im Allgäu in jüngster Vergangenheit somit durch eine hohe Diversität im sozialen und eine mittlere Diversität im technischen Teilsystem aus. Die Konnektivität des sozialen und des technischen Teilsystems ist mittelmäßig ausgeprägt – nimmt man Strom- und Wärmeproduktion zusammen. Zieht man die von Binder et al. (2017) entwickelten vier Fälle zu möglichen Kombinationen aus hohen und niedrigen Ausprägungen der Konnektivität und Diversität heran, so fällt das Allgäu zwischen Fall A (beide hoch ausgeprägt) und Fall C (Konnektivität niedrig ausgeprägt). Binder et al. (2017) schätzen die Resilienz der Transition im Fall A besonders hoch ein, für Fall C kann es sich um ein Zwischenstadium auf dem Transitionspfad handeln, der ein bestimmtes Systemstadium auf dem Pfad einer resilienten Transition darstellt. Aus dem Interviewergebnissen der Fallstudie ist jedoch Fall C naheliegender, da mehrere Akteure betonten, sie sähen die Energiewende im Allgäu momentan zwar im Stocken, dies stelle jedoch nur einen Zwischenschritt darstelle und sie schätzten den weiteren Verlauf positiv ein.

Die hier gezeigte, empirische Anwendung des indikatorengestützten Ansatzes zur Analyse der Resilienz von Energiesystemen in Transition hat es ermöglicht, eine strukturierte Analyse der technischen und sozialen Teilsysteme des regionalen Energiesystems vorzunehmen. Mehrfach hat sich gezeigt, dass die gleichzeitige Anwendung der Indikatoren auf die technischen und sozialen Teilsysteme besonders bereichernd ist. So zeigt sich empirisch, wie soziale und technische Netzwerke zusammenhängen, beispielsweise wie die Modularität der Wärmenetze von sozialen Strukturen abgeleitet werden kann. Insgesamt erlaubt es dieser Ansatz auch, die Resilienz der verschiedenen sozialen und technischen Netzwerkebenen zu analysieren, die übereinander gelagert ein regionales Energiesystem ausmachen.

Darüber hinaus lassen sich anhand der präsentierten Resultate auch einige Politikempfehlungen ableiten, die die Resilienz der weiteren Transition erhöhen können. Wie bereits erwähnt, ist das soziale Subsystem hinsichtlich der Diversität resilient einzuschätzen, im Bereich der Konnektivität besteht jedoch die Gefahr eines lock-ins. Dementsprechend wäre bei der weiteren regionalen Entwicklung darauf zu achten, dass nicht nur die Diversität der Akteure (weiterhin) gewährleistet ist, sondern auch die Zentralisierung reduziert und das Einbinden weiterer Akteure in der Region angestrebt wird. Im technischen Subsystem kann die Diversität der Technologiegruppen z.B. durch eine diversifizierte Förderstruktur noch weiter forciert werden. Vor allem in der Speichertechnik und Wärmeproduktion besteht hier noch ein enormes Potenzial, z.b. durch den Zubau von Wärmenetzen, regionalen Speichern oder kombinierten Lösungen wie Power-to-Heat/Gas. Dies würde zur allgemeinen Erhöhung der Konnektivität im technischen Subsystem beitragen und damit den Fortschritt der Energiewende erleichtern: Die steigende Volatilität und Dezentralität der erneuerbaren Energien kann durch erhöhte Vernetzung und damit einhergehender Flexibilität kompensiert werden.

Insgesamt muss jedoch einschränkend festgehalten werden, dass der vorgeschlagene Ansatz eine sehr hohe Datenqualität voraussetzt. Im technischen Teilsystem sind entsprechende Daten oft nicht vorhanden, da die Daten regional nicht erhoben werden oder nicht öffentlich zur Verfügung stehen. Im sozialen Teilsystem könnten entsprechende Daten zwar generiert werden, würden aber eine umfangreiche Datenerhebung mit den damit einhergehenden Ressourcen verlangen, bspw. durch eine Vollerhebung des sozialen Netzwerks. Da dies im vorliegenden Fall nicht möglich war, wurde das soziale Netzwerk durch ein *snowball sampling* ermittelt. Dieser Ansatz erlaubt es, Aussagen über die Struktur des regionalen Netzwerks zu ziehen, die quantifizierten Ergebnisse können aber nicht direkt auf das Energiegouvernanzsystem der gesamten Region übertragen werden. Für das technische Teilsystem konnten aufgrund der fehlenden Datengrundlage keine quantifizierten Analysen zur Konnektivität durchgeführt werden, dies sollte in zukünftigen Verwendungen des Ansatzes weiterverfolgt werden.

Die von Binder et al. (2017) vorgeschlagenen Metakonzepte der sozialen Arenen und Technologiegruppen haben sich für die Resilienzanalyse des regionalen Energiesystems zwar grundsätzlich bewährt, sie müssen jedoch für die empirische Arbeit weiter konkretisiert werden. So sind es im sozialen Teilsystem die einzelnen Akteure und Organisationen welche als Referenzobjekte agieren und untereinander vernetzt sind, während es im technischen System spezifisch hergestellte Energieeinheiten sind, welche zwischen Produzenten und Konsumenten ausgetauscht werden. Die Metakonzepte *soziale Arena* und *Technologiegruppe* eignen sich daher eher als interpretative Konzepte, um die Ergebnisse, gerade auch in Bezug zum gesamten Energiesystem, besser bewerten zu können.

Angesichts dieser Einschränkungen könnte es in Zukunft hilfreich sein, für die empirische Analyse entweder eine kleinere räumliche Ebene zu wählen, z.B. eine Kommune oder eine Stadt, oder auf Ebene des Regierungsbezirks, bzw. Bundeslandes zu arbeiten, da hier die Daten zum technischen System gebündelt werden, aufbereitet vorliegen und leichter zugänglich sind. Energieregionen, wie das Allgäu, liegen oftmals zwischen den traditionellen administrativen Ebenen (z.B. Landkreis und Regierungsbezirk) und haben daher meist nicht die Kapazitäten, umfassende Daten über die Region zu erheben. Für eine Vollerhebung des sozialen Netzwerks wäre in diesem Kontext sowohl eine detaillierte, vergleichende Analyse mit Primärdaten auf kommunaler Ebene , als auch eine grösser angelegte, Sekundärdaten basierte Netzwerkanalyse auf Regierungsbezirks- bzw. Bundeslandebene (z.B. auf Basis formeller Beziehungen wie Vereinsstrukturen) sehr interessant. Weiterhin sollte versucht werden, die verschiedenen Phasen des Transitionspfades im Verlauf der Zeit zu analysieren, um ein vollständigeres Bild der Resilienz des gesamten Prozesses zu erlangen.

Für weitere Überlegungen zur Konzeptualisierung von Resilienz in regionalen Energiesystemen siehe auch Kapitel xx „Resilienz regionaler Energietransitionen – Versuch einer Konzeptualisierung aus praxistheoretischer Perspektive“ in diesem Band.

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B.2 Analyzing the resilience of a transition: an indicator-based approach for socio-technical systems

11 Analyzing the resilience of a transition: an indicator-based approach for socio-technical systems*

Claudia R. Binder, Susan Mühlemeier and Romano Wyss

1. INTRODUCTION

The transitions occurring in our society, for example, our current energy transition from a fossil-based system to a system based on renewables, are complex and long-term societal transitions, involving not only the technical but also the social and ecological sub-systems (Grin et al. 2010). According to Grin et al. (2010, p. 196) '[transition processes] are interwoven with economic sectors (mobility, housing, agriculture) and in fact deeply rooted in our societal structures, routines and culture'. From an analytical perspective, the current transition processes (for example, specifically sustainability transitions) can be understood as a succession of both intended disruptive changes and incremental adaptation processes along a particular change path (Rotmans et al. 2001). Throughout this change process, humans have to anticipate, to adapt to, and to learn from and within fundamentally new situations (Martens and Rotmans 2005; Fischer-Kowalski and Rotmans 2009). This fundamental system transformation raises the question of how to measure the continuing progress (in our terms, the resilience of this process) over time.

At first sight, the term of resilience as defined by Walker et al. (2004) seems to be the contrary of a transition (Olsson et al., 2014). Walker et al. (2004, p. 5) define resilience as 'the capacity of a system to absorb disturbance and reorganize while undergoing change, to still retain essentially the same function, structure, identity, and feedbacks'. Furthermore, they state that resilience is a necessity to 'avoid shifting to an alternative regime'. Along these lines, the term of resilience has found wide acceptance in psychology (Werner et al. 1971; Bonanno 2004; Almedom 2005) and disaster management (Brown and Westaway 2011). In these cases, resilience is linked with a positive normative view, that is, it is good that a person is resilient to stress, or preserving and restoring 'essential basic structures and functions' in disaster management (United Nations International Strategy for Disaster Reduction 2009). This view, however, falls short when we are dealing with complex system processes involving social systems such as those taking place in socio-technical systems, and their changes over time. In these cases, we are concerned instead about socio-technical change and the resilience of the change process, than about the stability of the current stage (Olsson et al. 2014; Böschen et al. 2017).

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Several scholars have reflected on how the two terms of resilience and transition can be reconciled and made fruitful in combination (Binder et al. 2017; Schilling et al. 2017; Mühlemeier et al. 2017, 2018; Wyss et al. 2018). Schilling et al. (2017) propose seven theses explaining how different resilience characteristics can be embedded in transition thinking. These theses provide the first comprehensive conceptualization of a resilient system in transition. Boeschen et al. (2017) explore quantitatively theoretical models of resilience which were applied in an interdisciplinary collaborative research network of 13 research projects. They showed that the theoretical models used differ (1) concerning the concepts of their basic system understanding (structure versus process-orientated) and (2) with respect to their context-relation (open versus closed). Using the empirical evidence provided by the projects, they identified four types of resilience concepts; that is, stability, interference, expansion and transformation models (Böschen et al. 2017). The transformation model provides a perspective on resilience looking at the entity and its stability within a given context. It relies on a procedural view – studying the process of change, thus, linked to transformation – and it analyzes the entity in relation to its context (they talk about second order resilience). This is closely linked to what Olsson et al. call 'the resilience of a new direction' (Olsson et al. 2014, p. 1). Along this line, Binder et al. (2017) and Mühlemeier et al. (2017) developed indicators which allow the measuring of the resilience of a system during the transformation process itself (Mühlemeier et al. 2017, 2018).

In this chapter, we build on the indicator set developed by Binder et al. (2017) and present a methodological approach for analyzing the resilience of a transition. We tackle the following questions: (1) how can the resilience of a transition be analyzed and what are adequate indicators? (2) How can these indicators be measured in a mixed methods approach for the social and the technical subsystems? (3) What are results that can be obtained with these measures? (4) What are the advantages and disadvantages of the approach?

The chapter is structured as follows. We first present the conceptualization of the indicators to measure the resilience of the transition. We continue by presenting a mixed method approach to measure these indicators for the social and technical subsystems, with examples from our research on the transition of energy regions in Austria and Germany. Then, we discuss the methods analyzing the energy transition and we present exemplary results. Finally, we conclude with a reflection on the added value and limitations of our approach as well as on the further research needed.

2. THEORETICAL BACKGROUND

Walker et al. (2004) define resilience as 'the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks'. Accordingly, Folke (2006) describes resilience of a system as the capacity of the system and its components to withstand shocks (stability) and to adjust to changing external conditions (adaptive capacity), based on the flexibility of the system's configuration. Thereby, a system is conceptualized as an ensemble of qualitatively diverse system components and their interlinkages, for example, by means of the flow of energy or information. Based on this system understanding, resilience can be defined as a function of the diversity of system components and the connectivity patterns between the components (Lietaer et al. 2010; Fath et al. 2015).

Social-ecological resilience has its roots in systems thinking. Holling's original concept of resilience in the field of ecology (Holling 1973, 1986) builds on both static and dynamic elements. A resilient system stays in a dynamic equilibrium, where system elements are in a sustainable relation to one another, not endangering the long-term stability (Foxon et al. 2009; Folke et al. 2010). A key concept in this context is the adaptive cycle (Foxon et al. 2009; Folke et al. 2010). The core idea behind the adaptive cycle is that ecological and social systems are forced to cope with internal and external change factors and shocks. Adaptation to change and shocks can take place on different scales and over different lapses of time, with diverging effects on the systems composition. In socially imprinted systems, owing to human agency, foresight and deliberate adaptation, the total reconfiguration in the aftermath of a shock can potentially be circumnavigated, if the necessary adaptation measures are put in place at the right time (see Luthe and Wyss 2015).

In comparison to the social-ecological system (SES) literature, resilience thinking has only sporadically been used as an explanatory concept in socio-technical systems (STS) studies. Aside from studies with a strong technical orientation (Linkov et al. 2013; Roege et al. 2014; Rochas et al. 2015), the only scholars who have tried to link a comprehensive resilience concept to socio-technical issues, to our knowledge, are Smith and Stirling (2008, 2010). The authors stress the commonalities between SES and STS. They call for an application of resilience as a guiding research concept for combined socio-technical and ecological systems (STES). In doing so, research can provide informed policy recommendations in how to support progress towards the goal of more sustainable societies, and therefore also give answers to '[who] governs who, whose system framings count, and whose sustainability gets prioritized' (Smith and Stirling 2010).

For the remainder of the chapter, we build on the understanding of resilience in STES (Ostrom 2007; Foxon et al. 2009; Smith and Stirling 2010), assuming that socio-technical transformation processes go hand in hand with a co-development of the social and technical subsystems (Little 2004; Vespignani 2012; Binder et al. 2017). Within this understanding, ecological aspects are indirectly accounted for via the resource base that underlies the respective technology. We consider a transition to be resilient if the resulting system is resilient along the whole transition process, in analogy to the phases of the adaptive cycle (Gunderson and Holling 2001). Thus, during a resilient energy transition the system will pass through both, stable and rather adaptive stages, characterized by differing configurations of both the social and the technical components, but will never lose its overall resilience.

2.1 Operationalizing Resilience of Energy Systems in Transition

We operationalize the resilience of energy systems in transition building on two core attributes of resilience, namely, diversity and connectivity (Binder et al. 2017). Diversity depicts the structural attributes of the system and connectivity relates to the interaction between the system's components (Gunderson 1999; Folke et al. 2002; Ernstson et al. 2010). According to Gunderson and Holling (2001) these two system characteristics co-determine the structural stability and adaptive capacity of the system with regard to continuously changing external conditions or disruptive shocks. Holling (1973) furthermore states that 'Stability . . . is the ability of a system to return to an equilibrium state after a temporary disturbance. The more rapidly it returns to an equilibrium state and with the least fluctuation, the more stable it is'. When we study the resilience of a system in transition, this suggests that on the one hand we need a minimal level of both component-based diversity and interaction-based connectivity for the system to be resilient. However, we postulate that the levels of diversity and connectivity can vary along the transition pathway so that the system can maintain its adaptive capacity (Luthe and Wyss 2015).

2.1.1 Conceptualization of diversity

We conceptualize diversity using three fundamental indicators: variety, balance and disparity (Table 11.1). It has been found that each of these indicators is necessary to measure diversity. However, each by itself is not sufficient for doing so (Sokal and Sneath 1970; Stirling 1998; Stirling 2007; Binder et al. 2017). These indicators are independent of research area and are applicable to the social and technical subsystems (Stirling 2007).

Table 11.1 Suggested measures for operationalizing diversity and interpretation for resilience

Indicator	Definition	Measure	Role for resilience
Variety	Number of categories in which the system elements can be divided	Category count N	The higher the number of categories, the higher the stability, adaptability and flexibility
Balance	Distribution patterns of the system elements across the different categories	Shannon evenness $S = -\sum_i pi{*}ln(pi)lnN$ (11.1) Shannon Weaver (includes variety) $S = -\sum_i pi{*}ln(pi)$ (11.2) whereas: ln the natural logarithm and pi the proportion of system category i; N: number of types	Social: the more even the entities are distributed among categories the higher the stability of the system and higher degree of flexibility Technical: potentially efficiency can decrease with even distribution, depending on the types of categories
Disparity	The way and the degree in which the categories of the elements can be distinguished from each other	$Di = f(\text{dij})$ $f(\text{dij})$ (11.3) is the function of distance in disparity space between categories i and j	Social: the higher the disparity, the higher the potential for complementary competences and multidimensional solutions. However, it's a problem if the system is too segmented with little communication between them Technical: the broader the portfolio, the higher the preparedness to unforeseen shocks and balancing capacity

Source: Based on Binder et al. (2017)

Variety is 'the number of categories (we use the term type) into which system elements are apportioned' (Stirling 2007, p. 709). It is quantified by the 'category count' (N in Table 11.1). According to Stirling (2007), 'all else being equal, the higher the variety, the greater the diversity'.

Balance relates to the patterns of allocation of the elements across the different categories. Stirling (2007) proposes several indicators for measuring balance. The most popular and easiest to use is the Shannon index. The Shannon evenness index (Smith and Stirling 2010) is explicitly used to measure balance (Table 11.1, equation 11.1). Kharrazi et al. (2015) suggest applying the Shannon-Weaver index which combines variety and balance (Table 11.1, equation 11.2). In both cases: the higher the value of the Shannon index is, the more even the balance. According to Stirling (2007, p. 709) 'all else being equal, the more even is the balance, the greater the diversity'.

Disparity relates to 'the manner and the degree in which the categories (types) may be distinguished' (Stirling 2007, p. 709). We suggest estimating a multi-attributive disparity (Stirling 2007; Stirling 1998; Awerbuch et al. 2006) (Table 11.1, equation 11.3). Thereby, disparity (D_i) is a function of the different attributes characterizing the different categories. With the analysis of the multi-attributive disparity, we can account for different attributes of these categories in social, technical or ecological systems. According to Little (2004) 'all else being equal, the more disparate are the presented elements, the greater the diversity' (Little 2004, p. 109).

2.1.2 Conceptualization of connectivity

To operationalize connectivity, we build upon basic concepts from network analysis. Based on the social network analysis literature (Wasserman and Faust 1994; Scott 2012), as well as the application of network metrics to energy systems (Roege et al. 2014), we identify three main aspects of connectivity, namely path length, centrality and modularity (Table 11.2). These three indicators can be applied to social, technical and ecological systems.

The average path length describes the amount of intermediate steps between any system entities of interest (Table 11.2). A short average path length allows a system to be more easily steered, and for information to circulate faster (Wasserman and Faust 1994).

Degree centrality describes the relative position of a system's entity with respect to the other entities of the system (Freeman 1978; Weimann 1982). It is calculated as the number of direct links that exist between a network component and its network environment (Marsden 2002; Scott 2012). When looking at the system as a whole, the average degree centrality describes the concentration of network ties linked to individual entities, as the sum of the individual degree centrality measures in relation to the overall number of possible ties. Entities with an over-average centrality in a system can be described as hubs, which are central to the functioning of a networked system owing to their role as connecting entities. Hubs which specifically build bridges between otherwise unconnected parts of the system are often described as brokers (Ash and Newth 2007).

Network modules describe parts of the network that share above-average interaction intensity (when compared with the system as a whole) and that are partially detached from other parts of the network (Clauset et al. 2004; Newman 2006). Modularity measures can either be applied to predetermined entities (such as social arenas) and utilized to distinguish between in-group versus out-group connection, or can be applied to investigate overall network structures (Baggio 2011).

Table 11.2 Suggested measures for operationalizing connectivity in socio-technical energy systems

Indicator	Definition	Measure	Role for resilience
Average path length	Number of steps needed to connect two nodes to each other on shortest path	Average path length $l_G = I > jl(i,j)n(n)\ (n-1)^2$ (Baggio et al. 2010) with average path length in the network being the arithmetical mean of all the distances $l_G = 1/n(n-1)\sum_{i\neq j} d_{ij}$ (Baggio et al. 2010)	The longer path length is more difficult for the sharing of knowledge and experience Increased reaction time However, a longer path length decreases the velocity of propagation of harmful supply perturbations
Degree centrality	Relative position of each node in the network with regard to the other nodes	Degree Centrality $C_D(n_i) = d(n_i) = \sum x_{ij} = \sum x_{ji}$ (Wasserman and Faust 1994) The degree centrality of a node is calculated by summing up the connections that a node has to other components in the network. Can distinguish between in- and out-degree centrality The average degree, which is an indicator of the overall density of the network, can be defined as: $\bar{d} = \sum^{g}_{i=1} d(n_i)/g$ (Wasserman and Faust 1994)	The higher the centrality, the better the node is usable for an intervention and the higher the coordination power. Too much degree centrality causes dependency and decreasing flexibility.
Modularity	Parts of a network with an over-proportional interaction intensity compared with the system	Modularity index $Q = \sum_i (e_{ii} - a_i)^2$ (Baggio and Sainaghi 2016) where *eii* is the fraction of edges in the network between any two nodes in the module *i*, and *ai* is the total fraction of links originating from it and connecting nodes belonging to different modules	The higher modularity, the better autonomous functioning of parts of the system and the more likely the creation of new ideas within partially secluded subgroups

Sources: Based on Binder et al. (2017); Mühlemeier et al. (2017).

The resistance and adaptive capacity of complex systems depends to a major part on the configuration of the system. Connectivity is an essential aspect in how system components (social or technical) are interrelated and depend on one another. If, for example, a shock affects a system, the way the system can withstand and respond to this shock does not only depend on the characteristics of the system components, but also on the way the system components are linked. This affects, among others, the propagation speed at which information, power failures or infections spread, and the amount of resistance the system should counter these interferences.

2.2 Operationalization of the Energy System as Socio-Technical and Ecological System

2.2.1 Operationalization of social subsystem: social arenas

To analyse the diversity and connectivity of the social subsystem we propose to use the concept of 'social arenas' (Späth et al. 2007, p. 41; Späth and Rohracher 2010; Binder et al. 2017). Social arenas are defined as 'societal subsystems or spheres, characterized by their rationality and codes depending on their function' (translated from Späth et al. 2007). We differentiate the arenas through their specific structure and their functional characteristics. Arenas, which can be encountered in a system in transition are, for example, political, entrepreneurial or private households. For the transition to be resilient and to ensure the functionality of the system, actors of different arenas have to be included in the process and a governance structure or collaboration platform has to be designed (Schilling et al. 2017). We define diversity as the functional qualitative difference between arenas and social connectivity as the exchange patterns between actors from different social arenas.

2.2.2 Operationalization of the technical subsystem: technology groups

To analyze the diversity and connectivity of the technical subsystem, we distinguish between different groups of technologies (for example, different groups of renewable energy production (Kost et al. 2013; Binder et al. 2017). We could think of differentiating the technology groups according to their locality, their efficiency or their dependency on specific inputs. For measuring diversity in the energy sector, Binder et al. (2017) considered different types of technologies, such as hydropower (small and big plants), photovoltaic (rooftop and open field), solar thermal energy, biomass heating and combined heat power production (CHP). Regarding connectivity, Binder et al. (2017) based the operationalization of the energy sector on the transmission infrastructure that links the various production entities among each other, and to consumers.

3. OPERATIONALIZATION OF THE INDICATORS FOR THE SOCIAL AND TECHNICAL SUBSYSTEMS (AFTER BINDER ET AL. 2017)

3.1 Diversity

3.1.1 Social subsystem

Variety In the social subsystem, variety relates to the different types of social arenas which are prevalent in the governance structure of the system to be analyzed (for example, politics, industry, research, society or media).

Role for resilience: from a resilience perspective, the higher the variety of social arenas, the more views and perspectives are present in the transition discourse of the system (for example, regional energy system, regional tourism system and community). On the one hand, this can lead to an increasing adaptive capacity; on the other hand, this might lead to less stability. Both developments are supportive for systemic change. A too low variety on a long run, however, might also lead to the destabilization of the systems, as relevant actor groups (arenas) might be excluded.

Balance In the social subsystem, balance relates to how many actors are active in each type of social arena compared with the overall number of actors in the governance system.

Role for resilience: from a resilience perspective, the higher the balance, the more even the distribution of the viewpoints within the governance system. This increases the stability to the system. This might, however, lead to decreasing efficiency as suggested by Lietaer et al. (2010). An uneven distribution of viewpoints could imply a domination by one party – which can potentially accelerate a transition – but also cause neglect of significant aspects for the stabilization of each transition step.

Disparity In the social subsystem, disparity relates to how different from each other the arenas are. Possible attributes for the analysis of disparity are (1) time horizon of different actors (short-term for entrepreneurs versus medium-term for politicians) (Binder et al. 2004, 2017), (2) their modes of action (communication, coordination), (3) their structure, and functionality (legislation for politicians, investments for entrepreneurs) (Späth et al. 2007), and (4) their spatial reference (regional for politicians, cross-regional for entrepreneurs and local for private households).

Role for resilience: from a resilience perspective, the higher the disparity among the arenas, the higher the adaptive capacity of the social subsystem because different and diverse types of knowledge and viewpoints can be integrated into the discourse within the governance system. A high disparity, thus, contributes to avoiding 'short-sightedness' within the social subsystem and creates new options and strategy spaces. Low disparity implies that the knowledge base and viewpoints of the arenas involved are similar. This lowers the transaction costs, makes the system more efficient and potentially stabilizes it, however, potentially reducing its adaptive capacity.

3.1.2 Connectivity

Average path length Applied to the social subsystem, the average path length can be interpreted as the relative social distance between actors from different social arenas. It can be measured by looking at whether actors are in direct contact with one another, and if not, how many mediating steps lay between them (Luthe et al. 2012; Wyss et al. 2015).

Role for resilience: direct communication channels between actors from different arenas, related to low average path length, strengthen resilience by allowing for effective short-term collaborative action in the face of imminent shocks. Furthermore, efficient sharing of knowledge and experience across different arenas owing to direct links between actors also allows for a higher adaptive capacity of the system in the longer run (Scott 2012; Wyss et al. 2015).

Degree centrality Degree centrality measures can be applied to measure the importance of actors within the social arenas regarding their capacity to be in direct contact with other actors, both within and across arena boundaries. The higher the degree centrality, the higher the coordination power of actors within the system, for example, with respect to planning and implementing changes in the production and distribution capacities of the regional energy system. High degree centrality supports actors in making their concerns heard. Owing to their central position in the network, central actors can actively steer governance processes, and influence others. On the downside, if central actors are exposed to too many obligations, they may also be constrained in taking specific, especially unpopular, actions (Bodin et al. 2006; Bodin and Crona 2009).

Role for resilience: in the face of system-wide shocks, the initiation and coordination of collaborative action by central actors, who can directly communicate with many other actors across the various arenas allows for swift implementation of specific adaptation measures. Central actors can be important to steer collective action in social subsystems, by coordinating activities across arena boundaries. Central actors can also have the power to slow down or even prevent a system to adapt to changing circumstances if they follow certain vested interests (Wyss et al. 2015). Central actors can also act as knowledge brokers across arena boundaries, giving them high power in what information they distribute, for example, concerning financial or technical issues (Luthe and Wyss 2016).

Social modularity Modularity measures can be applied to measure the interaction intensity within social arenas versus the interaction intensity between the arenas (see Luthe et al. 2012 for an application in the tourism sector). If the modularity index is high, this means that many subgroups exist, which may be detrimental to overall cooperation in the system. Low modularity measures indicate a homogenous distribution of connections within the network, with actors from various arenas sharing similar numbers of connections and a high potential for exchange of information across arena boundaries.

Role for resilience: high modularity can lead to an intense sharing of new ideas within partially secluded subgroups, resulting in higher (local) innovation, and therefore higher overall adaptive capacity of the system (Bodin et al. 2006; Bodin and Crona 2009). At the same time, high modularity can impede the flow of information between actors that are not part of the same subgroup. If subgroups form across arena boundaries, the variety of information shared is higher when compared with subgroups that are formed of actors from the same arena. This is important when it comes to supporting regional (social) innovation processes (Luthe and Wyss 2016), which can lead to higher long-term resilience of the system by supporting both resistance and adaptive capacity.

3.2 Technical Subsystem

3.2.1 Diversity indicators for the technical subsystem

Variety In the technical subsystem, variety refers to the amount of different types of technologies present in the region (for example, for renewable energies: photovoltaic, solar heat, hydropower, combined heat and power).

Role for resilience: a high technical variety, that is, a high amount of different technology types, might destabilize the system and lower its stability. However, this can also increase the adaptive capacity; a high variety of technology groups also represents a window of opportunity where new technologies emerge and potentially lead to a system change if they can be integrated into the existing structure. At the stabilization point of the transition, the best-suited technologies establish themselves. A low variety within the technical subsystem contributes to stability but lowers the potential adaptive capacity of the energy system, which might be needed to react to external shocks.

Balance In the technical subsystem balance refers to the share of each technology group in the overall production system.

Role for resilience: from a resilience perspective, the higher the balance the more even is the distribution of technologies in the system studied. This might provide a lower stability (for example, in the energy system different load types must be handled), but also, potentially, a higher degree of flexibility and adaptability, depending on the types of technology. A low balance means that the production system is composed of a few specific technology groups. This potentially leads to a higher stability of the system but at the same time to a lower degree of flexibility and potential for adaptability.

Disparity For the technical subsystem, attributes for analyzing the disparity of the different production technologies can be (1) production costs, (2) environmental impacts (for example, CO_2 emissions and global warming potential), (3) dependency on location (height, weather), (4) surface needed, and (5) efficiency of each technology group (Binder et al. 2017).

Role for resilience: from a resilience perspective, disparity is the system's structural basis to 'choose' between qualitatively diverse alternatives. High disparity provides a broad portfolio of options for a system to develop and is a crucial factor in terms of preparedness to especially unforeseen shocks. Low disparity means that the technology 'portfolio' to choose from is limited, having for example, similar efficiencies, dependencies on raw materials or environmental impacts. Low disparity also implies a low flexibility and low adaptive capacity. However, depending on the technologies, it can also lead to high redundancy, thus system stability.

3.2.2 Connectivity indicators for the technical subsystem

BOX 11.1 THE ENERGY TRANSITION IN THE ALLGÄU REGION

The Allgäu Region is a rural, partly Alpine area, located in the south-west of Bavaria, Germany. It encompasses four districts (Lindau, Ost-, Ober- and Unterallgäu) and three cities (Memmingen, Kaufbeuren und Kempten). The Allgäu region has been one of the pioneering regions in the energy transition in Germany. About 39 percent of the total electricity demand is covered through renewable resources. The district Ostallgäu, the front-runner, produces 109 percent of the electricity demand from renewables (StMWi 2017a). Historically, the region has a long tradition for decentralized energy production. In earlier times the large forest areas and the Alpine rivers were used for energy production (Bayerisches Landesamt für Statistik 2015b) and today, the high wind speeds on the top of the hills and the large quantity of biomass produced in agriculture are additionally used for electricity and heat production from renewables (Bayerisches Landesamt für Statistik, 2015a; StMWi, 2017b). Similarly, as in EWG, the focal energy agency of the region was founded in 1996. It coordinates the regional energy transition, supports the communes in establishing energy transition and climate change policies, advises citizens for energy efficiency measures, and manages a large network of local firms working in the domain of energetic renovation and energy services. We found that the early support of traditionally powerful actors such as municipal utilities, waste management firms and forest owners but also politicians from all parties and regional banks, helped decisively to institutionalize the regional energy transition. They form a highly connected network of regionally well embedded actors (see also Mühlemeier and Knöpfle 2016; Mühlemeier et al. 2017).

Average path length In the technical subsystem, average path-length can be understood as the average length of the transmission lines between different nodes (production and consumer). While longer path lengths imply a higher loss of energy given a stable loss per kilometer of wire, the propagation 'speed' of supply perturbation will most likely be lower in systems with higher path lengths, that is, with more potential intervention points (nodes) for a given grid size.

Role for resilience: higher path length (more nodes between different parts of the system) results in a slower propagation of harmful supply perturbations. Ash and Newth (2007) suggest that longer path lengths can be a stabilizing factor increasing resilience in technical subsystems that are prone to cascading effects, such as energy distribution networks.

Degree centrality Within the technical subsystem, degree centrality measures can be applied to estimate the role technology groups (for example, solar and wind) have with respect to both the overall output they generate, as well as to the number of pro-/consumers they are linked to. If centrality is high, the production or distribution sites of the individual technology groups can be seen as local hubs of the system, which are critical for the system's stability and should be protected, especially in scale-free networks (Ash and Newth 2007). As centrality partially correlates with modularity, high-centrality nodes bridging between (production-) modules have an above average importance for the stability of the system as a whole (Wasserman and Faust 1994; Baggio et al. 2010; Nastos and Gao 2013; Sharifi and Yamagata 2016).

Role for resilience: central nodes represent intervention points to allow for a swift (re-) stabilization of the system's functioning in the presence of external or internal shocks. High overall degree centrality can also have a destabilizing effect on (energy) network if

BOX 11.2 THE TRANSITION OF THE ENERGY REGION WEIZ-GLEISDORF

The energy region Weiz-Gleisdorf (EWG) is located around 20 kilometers east of the city of Graz. It has 41 800 inhabitants and a population density of 158 people per square kilometer (BEV 2012). It has an area of 264 square kilometers, whereby 44 percent of this area serves agricultural purposes and 42 percent is used as forest area. The EWG was founded in 1996 as a federation of 18 municipalities. In 2005, it became EU LEADER region for the period 2007–13. This led to funding of a management position for the region. In 2010, all mayors of the communities involved in the EWG signed the Energy Charta which declared as a common vision to become CO_2 neutral by 2050. The EWG was stated as a 'climate and energy model region' of Austria. The focus of the EWG has been to develop flagship projects in the area of housing and mobility, to create incentives through municipal subsidies and regulations, and to coordinate educational programs. One key aspect of the EWG's approach to the energy transition has been to include social and cultural organizations in the communication process, and to develop and implement diverse promotion and sensitization activities (Energieregion Weiz-Gleisdorf 2007). For more information on the past transition process, see Hecher et al. (2016). During the transition period studied, the EWG increased its degree of energy self-sufficiency (defined as the yearly amount of energy produced from regional energy sources divided by the respective regional production of energy for heat, electricity and transport) from 18 percent to 26 percent (Binder et al. 2014).

these hubs are removed or destabilized. Ash and Newth (2007) proposed that interconnection of hubs (nodes with high centrality measures) enables quick distribution and hence absorption of disturbances (Ash and Newth 2007, p. 681), thus propagating inter-hub connectivity. Other authors have come up with contrary views, stressing the danger of (involuntary) hub removals (Albert et al. 2000).

Modularity In the technical subsystem, modularity measures describe the presence of autonomous production or distribution modules within the overall network, which can sustain energy distribution independently over a certain period of time. An autonomous functioning of certain parts of the system allows a blocking-off of harmful effects by islanding parts of the network (Trodden et al. 2013).

Role for resilience: Rosenkrantz et al. (2005) suggest that the resilience of a system increases, if the overall modularity or/and the clustering of a system increases (Rosenkrantz et al. 2005). They relate this to concepts of edge resilience and node resilience (see Sharifi and Yamagata 2016, p. 116). Shocks spread less quickly in modularized networks, and can be 'blocked' at the entrance node to the module. Linked to this, Roege et al. (2014) postulate that – given a certain modular structure – system components (modules) can function autonomously, if the essential functional aspects are covered within the module itself. This is important to be able to detach parts of the network in the case of (localized) perturbations, enabling an overall stabilization of the functioning of unaffected parts of the network, and thereby increasing the resilience of the network as a whole.

4. METHODS FOR MEASURING THE INDICATORS

For measuring the indicators, we suggest taking a mixed method approach (see Table 11.3). We describe below the methods and show how they were applied to analyze the resilience of the energy transition. The use of the methods did not only allow us to elicit the indicators but to also obtain knowledge on the context. The methods were applied to the two energy regions described in Box 11.1 and Box 11.2.

Table 11.3 Mixed method approach for measuring the selected indicator set

Method	Used for indicator	References
Document analysis – qualitative content analysis	All indicators	Flick et al. (2004); Mayring (2014)
Expert interviews	All indicators for eliciting and validation	Flick et al. (2004); Flick (2009)
Mental models and cognitive modelling	Connectivity indicators of social and technical subsystem	Binder et al. (2014); Otto-Banaszek et al. (2011); Vanwindekens et al. (2013)
Social network analysis	Connectivity indicators of social and technical subsystem	Wassermann and Faust (1994); Kelman et al. (2016)
Energy flow analysis	Diversity indicators for the technical subsystem	Baccini and Bader (1996); Brunner and Rechberger (2004)
Statistical analysis	Technical diversity indicators	

4.1 Document Analysis: Qualitative Content Analysis

Documents analysis aims to reveal important information from 'written texts that serve as a record or piece of evidence of an event or fact' (Flick et al. 2004, p. 284). The types of texts can vary, including scientific or political reports, newspaper and journal articles, legal texts and transcribed conversations. There are various approaches to document analysis, however, the qualitative content analysis (Mayring 2014) is widely accepted as one structured approach to analyse different types of documents. Mayring (1991) differentiates three types of content analysis: structuring, summarizing and exemplifying content analysis (Mayring 1991). In structuring analysis, parts of the texts are selected according to predefined criteria. The results are paraphrased and reduced to the most important findings. In the summarizing technique, the researcher writes a summary of the documents he or she read – again guided by the research question. Finally, in the exemplifying text analysis, the researcher exemplifies unclear sections of the documents in his or her own words. All three approaches share the basic 'content analysis techniques of paraphrase and reduction, which target only the intended information content' (Flick et al., 2004, p. 288). That is, the content analysis of documents intends to reveal information from texts which are considered to be of relevance for a certain research question.

In the case of the energy transitions studied, the documents analyzed were documents describing the goals and development of the regions, for example, Böhm et al. (n.d.) and Energieregion Weiz-Gleisdorf (2014), as well as legal documentation of the region showing the institutional development. These documents provided the basis for defining the arenas (Späth et al. 2007) which were active in different time periods of the transition process. Furthermore, we obtained an insight into technology development, the role of pioneers and the visions put forward by the key actors.

4.2 Qualitative (Expert) Interviews

Qualitative interviews are used for obtaining a more in-depth qualitative understanding of the research object. According to their form, qualitative interviews can range from individual stories about certain events which are not pre-structured by the interviewer – often used in psychology – to completely pre-structured interviews in a more journalistic style. Moreover, they can be differentiated according to the type of interviewee, ranging from laymen to experts, people affected by a certain issue or non-affected people.

In the context of our analysis, we applied semi-structured expert interviews, first for validating and further deepening the insights gained through document analysis. Secondly, we asked questions about the experts' perceptions on the connectivity measures – in the technical and the social subsystem (Table 11.4). To select the interviewees, we pursued the snowball principle (Flick 2009, p. 168). This allowed us to obtain a broad as possible overview of the actors in the region as well as their networks (Mühlemeier et al. 2017; Wyss et al. 2018). The recorded interviews were transcribed and analyzed according to the structured content analysis (Mayring 1991) using the software MAXQDA.[1] From the

[1] See http://www.maxqda.de (accessed 22 August 2018).

Table 11.4 Examples for questions posed for analyzing the indicators sets in an interview

Question	Purpose/analysis perspective
Who were in your perspective the most important actors in the regional energy transition?	Variability, balance
Who is collaborating with whom?	Path length, centrality, modularity
Who are the most central actors in the regional governance system?	Centrality
Are there any subgroups prevalent in the governance system?	Modularity
What are the most important energy production technologies in the region?	Centrality, variety
How did the energy supply system change from 1996 to 2016 regarding the centrality of the energy production technologies?	Centrality
Is it possible to decouple particular parts of the energy supply system?	Modularity, centrality

transcripts, we identified actors and organizations, which the interviewees mentioned as important for the regional energy transition, as well as the interrelations among them.

4.3 Mental Modeling and Cognitive Mapping

'Mental models can be defined as preexisting mental constructs through which people decipher information and understand the environment, and which they use to solve the problems they face (Denzau and North 1994, p. 4). They provide a heuristic function by allowing information about situations, objects, and environments to be classified and retrieved in terms of their most important features (Cannon-Bowers et al. 1993, p. 226; Otto-Banaszak et al. 2011). Mental model approaches can be used to analyse stakeholders or experts' perceptions of the research object (Özesmi and Özesmi 2004; Vanwindekens et al. 2013; Binder et al. 2015). For this research purpose, cognitive mapping is a widely accepted tool to visualize the individual mental models.

Among various other approaches (for a good overview, see Johnson et al. 2006; Vanwindekens et al. 2013), we chose the Cognitive Mapping Approach for Analysing Actors' Systems of Practices (CMASOP) by Vanwindekens et al. (2013) for our analyses. The CMASOP contains four steps: conducting qualitative interviews, coding the interviews, deriving individual cognitive maps, and merging the individual maps to a common 'social cognitive map' (Vanwindekens et al. 2013, pp. 353–4). In addition, we conducted a second interview series, where we directly asked the interviewees to draw their conceptual maps of the regional energy governance system, focusing on the social arenas, their proximity and their most important actors for the years 1996, 2011 and 2016. This approach allows the former dataset to complement a graphical representation of the perceived configuration of the social subsystem in the past and its changes over time.

For average path length, we analyzed the mentioned relations between particular actors of different social arenas – whether they were direct or indirect (the latter leading to a higher path length). In addition, we derived the perceived distance between the actors based on how close or distant the actors had been drawn by the interviewees.

For centrality, we revealed notions of central actors – as representatives of their social arena – and analyzed the drawn concept maps regarding the central position of actors as well as their relatively higher share of relations to other actors. Finally, for modularity, we analyzed notions on subgroups with stronger links within the group than to the rest of the governance system.

4.4 Social Network Analysis

'Social Network Analysis (SNA) is a technique allowing the systematic quantitative and qualitative analysis of the links amongst actors in various contexts (Scott et al. 2009), helping to understand how the system in which those actors operate functions (Wasserman and Faust 1994)' (Kelman et al. 2016). A social network consists of nodes and links (also ties or edges). Nodes can represent actors – individuals or groups – or other physical or non-physical entities, while links can represent any type of connections among nodes (for example, by means of information exchange or capital flow). 'SNA provides useful formal tools . . . for characterising networks of individuals or collectives and the strength and distribution of links within those networks' (Kelman et al. 2016).

Wasserman and Faust (1994) differentiate between two different sorts of social networks following central characteristics of how they are built up. First, a differentiation along the kind of nodes that form the network: one-mode networks consist of characteristically similar nodes, whereas two mode networks account for two conceptually differentiated types of nodes (for example, individuals and organizations). Second, social networks can be differentiated according to the data collection approach chosen: ego-centered networks represent 'only' the links that originate from individual nodes, whereas a full sample network aspires to integrate all possible nodes and links of a given system (Wasserman and Faust 1994).

In our context, we identified actors and organizations from the interview transcripts, which the interviewees mentioned as important for the regional energy transition, as well as the interrelations among them. The representations and analyses of the revealed network were performed using the software package VISONE.[2] We analyzed the actor network as a one-mode network where actors and organizations were treated equally (Wasserman and Faust 1994). Although this qualitative network analysis does not fully represent the local actor network – since it is based on the actors' perceptions at one point, it nevertheless allows for intersubjective validity without having employed a full sample method (Mühlemeier et al. 2017).

4.5 Energy Flow Analysis

For measuring the technical subsystem in the energy transition we used an energy flow analysis (EFA) (Müller et al. 2004; Hecher et al. 2016). The goal of the EFA is to identify the key processes of the energy system, together with the corresponding flows, and to detect relevant system changes over time. We suggest defining the spatial boundaries as being the border of the energy region studied. Depending on the indicator studied,

2 See http://www.visone.info (accessed 22 August 2018).

however, data might not be readily available and the system boundaries will have to be adapted to the data availability (see below).

In an EFA all inputs, stocks and outputs of energy processes are balanced according to the law of thermodynamics (Baccini and Bader 1996; Brunner and Rechberger 2004). The basic algorithm for the calculation is the balance equation: Σ inputs = Σ outputs + change in stock. For visualization and analysis, we suggest using the software STAN 2.5.[3] The data available for all energy flows, together with the appropriate range of uncertainty and corresponding physical units is inputted into the software program. Where sufficient information is lacking, STAN 2.5 estimates missing data by minimizing the total error of the final model (Cencic and Rechberger 2008). The output is presented in the form of a Sankey diagram (energy data is always expressed in joule per year). Energy self-sufficiency is defined to be achieved if the yearly amount of energy for heat, electricity and transport regionally consumed is covered by the energy produced from regional energy sources (in an accounting sense).

An energy system can be conceptualized by categorizing the key processes into four groups, that is, primary energy sources, energy transformation (for example, heat pump, photovoltaic and solar thermal, biomass plants, hydropower), energy distribution (for example, electricity grid and distributed heating system) and energy consumption (for example, private households, industry and transport, public sector and industry) (Hecher et al. 2016). The overall system process is as follows: primary energy sources (sun power, water, etc.) are inputs to the system. They are transformed into useful energy by means of various technologies. The energy output is either distributed through the energy grid or consumed directly, as are fossil fuels and electricity imports. Losses through energy transformation and distribution exit the system. The energy is finally consumed by different sectors providing energy services. The energy consumed in the final services exits the system in the form of used energy to balance the system.

The typical data needed for developing the EFA are statistical data and company data. For examples see Hecher et al. (2016) and Mühlemeier (2017).

5. DERIVING THE INDICATORS FROM THE METHODS APPLIED

5.1 Deriving the Diversity Indicators for the Social Subsystem Based on Document Analysis and Expert Interviews

The three indicators for the diversity of the social subsystem should be derived together, since the disparity attributes define which social arenas are present in the region (variety) as well as how many actors can be assigned to an arena (balance). This is exemplified in Figure 11.1 (after Stirling (2010). The number of different arenas is derived by the disparity attributes of the arenas and is needed to calculate the balance of the system.

In our case, we derived a set of attributes of disparity as presented above and shown in Table 11.5. The four key social arenas which we could differentiate in the EWG were industry, associations, research and politics, leading to a variety of four.

[3] See http://stan2web.net (accessed 22 August 2018).

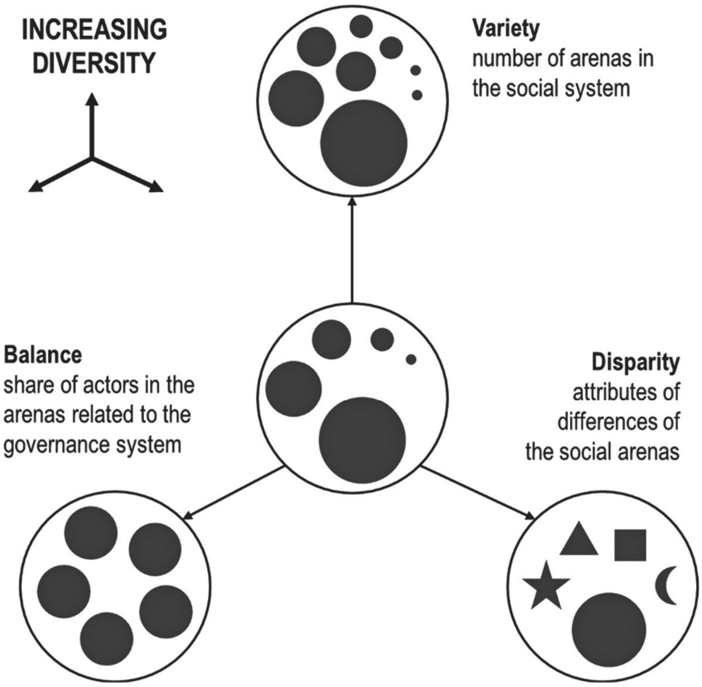

Figure 11.1 A schematic view of the three elements constituting diversity in the social system (after Stirling 2010)

Table 11.5 Attributes used to analyze the disparity of the arenas in EWG

Arena / Disparity attribute	Industry	Associations	Research	Politics
Structure and core actors	Energy producers, cooperatives, construction and production firms	Local energy associations LEADER groups Industry associations	Local innovation center Universities, research institutions Research departments in firms	Municipalities, provinces, EU,
Coordination	Market	Network	Network	Hierarchy
Functionality and communication	Investing in renewables, providing energy and energy-related products	Coordinating and representing regional actors, providing funding, integrating external actors	Developing and testing new technologies, introducing new knowledge in the region	Regulating, subsidizing, investing in energy plants and research projects
Time horizon	Medium term	Long term	Medium term	Short term
Spatial reference	Local – international	Local – regional	Regional – national	Local – international

In the EWG the variety of the arenas remained constant in the course of the transition (Mühlemeier et al. 2017; Wyss et al. 2018). However, as far as can be derived from interview data, the balance of the arenas seemed to have evolved from balanced to less balanced. At the beginning of the transition process, every arena was represented by a few but equal number of actors. Over the years, the industry arena became more important, reflecting also the stabilization of the transition through increasing involvement of the production sector.

5.2 Deriving the Connectivity Indicators for the Social Subsystem Using Mental Models, Cognitive Maps and SNA

As for the diversity indicators, the individual connectivity indicators need to be derived closely together as an indicator set, rather than as singular indicators (for example, the centrality is to a certain degree opposite to the modularity and a higher path length also indicates a lower centrality). In the case of the Allgäu region, we represented the mental models of the regional energy governance system through a SNA (see Figure 11.2). For the Allgäu region, we found that the social subsystem of the regional energy system is perceived by the interviewees as having a medium average path length, a high centrality of the regional energy agency and a medium modularity. Interestingly, the modules were

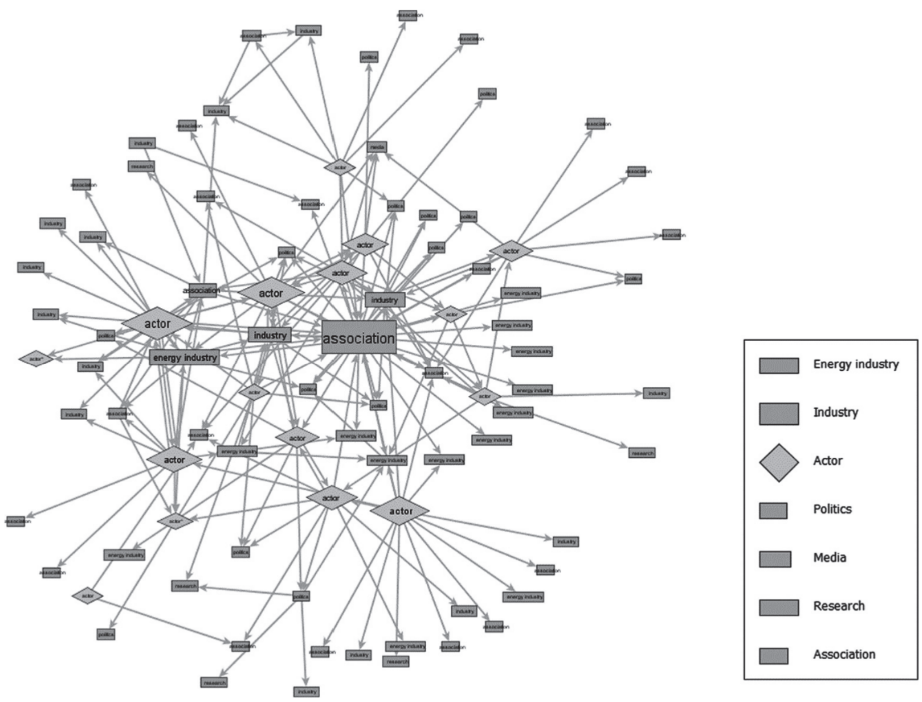

Figure 11.2 Degree centrality of the social subsystem in the Allgäu region

formed across all social arenas, having connecting actors with diverging backgrounds and thereby causing both stability and flexibility in the context of the energy transition.

For the EWG case study, we also relied on mental models for the analysis of the connectivity in the social subsystem. In addition, we asked the interviewees to draw their cognitive maps of the social subsystem and its changes over time, which we afterwards analyzed according to the connectivity measures. At the beginning of the transition in the EWG, the interviewees perceived the social subsystem as a network of a few actors with a short path length, high centrality of politics and almost no modularity. In the course of the transition, the short path length remained but the centrality of politics decreased and actors from industry and research became more important. The modularity also slightly increased since there were more project specific collaborations within the social subsystem.

5.3 Deriving the Diversity Indicators for the Technical Subsystem Using EFA

As for the social subsystem, the calculation of the three diversity indicators for the technical system should be connected to each other. For example, the variety of the technologies used in the EWG is closely linked to the disparity of these technologies. Table 11.6 presents the analysis of the disparity of the main technologies used in the region. As mentioned above we considered attributes related to economic and ecological characteristics to analyze the disparity of the technologies. When looking at the disparity of the technologies we find three technology groups, which differ in respect to most of the indicators selected thus leading to a variety of technology groups of three. According to Table 11.7 the variety has not changed over time.

To calculate the balance of the technical subsystem, we analyze the share (in respect of energy production) of each technology group (as derived by the disparity analysis) in the

Table 11.6 Disparity attributes of energy production technologies employed in EWG

Technology / Disparity attribute	Hydropower	Biogas	Biomass power plant (CHP)	Photovoltaic	Solar heat
Energy conversion efficiency (η) (Hecher et al. 2016)	0.85	–	0.85	0.08–0.16	0.5–0.7
Resource base	Water	Biomass	Biomass	Sunlight	Sunlight
Direct CO_2 emissions	No	Yes	Yes	No	No
Land consumption (Reitberger 2015)	Low	High	High	Medium	Medium
Dependency on weather events	Medium	Medium	Medium	High	High
Costs (cent/kWh) (König 2009; Deutsches Zentrum für Luft- und Raumfahrt et al. 2010; Kost et al. 2013; Peter et al. 2013; Nestle and Kunz 2014)	15.6–17.8	13.5–21.5	12.2	7.8–14.2	22

Table 11.7 *Example for the energy flows in the EWG and its changes between 2000 and 2010 (MWh/a, rounded values)*

	Energy production in 1000 MWh		Share on renewables (%)		Shannon Weaver Index	
	2000	2010	2000	2010	2000	2010
Biomass plants (small and large scale)	222.0	422	87.0	91.0		
Hydropower	26.0	26.0	10.0	5.6		
Solar thermal and PV	4.2	9.3	1.7	2.0		
Heating pumps	3.1	6.7	1.2	1.4		
Total	255.0	464.0	100.0	100.0	0.48	0.39

Source: Extracted from Binder et al. (2014).

overall production system. Table 11.7 shows as an example the results for the balance of the technological system based on the EFA for the EWG and its development from 2000 to 2010. The overall amount of energy produced by renewables almost doubled from 2000 to 2010. The high share of biomass and the decreasing Shannon index indicate a decreasing balance of the energy technologies, that is, an increasing dependency of one technology group and one primary resource, in this case biomass. Thus, the overall diversity of the technical subsystem of renewable energies has decreased (see also 6.2).

5.4 Deriving the Connectivity Indicators for the Technical Subsystem Using Document Analysis and Expert Interviews

In both case study regions, we could only rely on aggregate information about the connectivity in the technical subsystem (for example, maps on the electricity and gas grid) and complemented the data by statements and evaluations from experts (regional grid operators and utility companies). In both regions, the connectivity measures for the electricity grid did not change significantly, since the evolving shares of renewables could be included in the grid owing to its existing buffering capacity. However, all experts agreed on the fact, that in the near future, the grid needs to become less centralized and allow for regional modules in order to incorporate higher shares of renewables. Regional modules would facilitate the regional electricity supply on a lower tension level, which would contribute to an overall grid stability. In this context, regional storage capacities but also the technical possibilities related to digitalization (for example, smart metering, peer to peer trade or demand response management) will play a crucial role (Mühlemeier et al. 2017, 2018).

In the heat sector, it was even difficult to apply the connectivity measures, since there is no network connecting all heat production technologies. Instead, we differentiate grid-bounded energies (for example, gas or district heating or cooling) from off-grid energies (burning wood, oil or biomass for heat, and solar thermal heat or ambiance heat). In the course of the energy transition, the connectivity in the regional heat supply in the EWG evolved towards higher shares of district heating (which increased modularity and path lengths in a theoretically assumed overall heat supply network), whereas in the Allgäu region biomass power plants for direct heat use increased and only a slight increase of district heating (based on combined heat and power, and waste incineration) could be observed (Mühlemeier et al. 2017; Wyss et al. 2017).

6. DISCUSSION AND FURTHER RESEARCH

This chapter presented an indicator set to study the resilience within a transition process. It provides a set of indicators for diversity and connectivity which can be applied to a socio-technical system by using a mixed methods approach ranging from experts' interviews, energy flow analysis to social network analysis.

We show how the indicator set developed in the previous sections can be applied to another thematic context, namely, tourism (for a more extensive discussion of the application of resilience measures to tourism, see Wyss et al. 2014; Kelman et al. 2016). It is important to note that, even with the system of interest and its associated social and technological composition changing, in our view the basic measures of diversity and connectivity can be universally applied and interpreted in terms of the system's resilience.

When applying these indicators and measurements the following issues have to be considered and taken care of: (1) selecting the system boundaries for the social and technical subsystems; (2) conceptualizing the indicators for diversity and connectivity as an indicator sets rather than as separate indicators; (3) using a mixed methods approach for quantifying the indicators; and 4) interpreting the results by looking at both indicator sets together as well as at the coupled socio-technical system as a whole.

6.1 System Boundaries

When studying coupled socio-technical systems and energy systems in particular, we are confronted with the fact that the system boundaries relevant for the (regional) governance system (for example, social system in the energy transition) differs from the one of the technical system (for example, regional energy structure embedded in a national grid structure). Our first studies applying the indicator set (Mühlemeier et al. 2017; Wyss et al. 2018) have shown that for the social subsystem, the characteristics of the system components and the connections between these components have to be analyzed on a regional scale, or even on the level of the individual community to gain valid results. However, the technical subsystem, for example, the energy distribution systems, goes often beyond the typical political borders and thus, the resilience indicators should be studied at the state level or in a nested systems perspective. Furthermore, data availability at local or regional level might be limited.

6.2 Conceptualizing the Indicators for Diversity and Connectivity as Indicator Sets

Even though the three indicators for diversity are different from one another and measure specific aspects of the system itself, they are interdependent and they should be measured using the same definition of what a group and a category is. As shown in Figure 11.1, diversity increases if the three measures variety, balance and disparity increase. However, each of the measures provides a distinct view on diversity and is needed for its estimation,

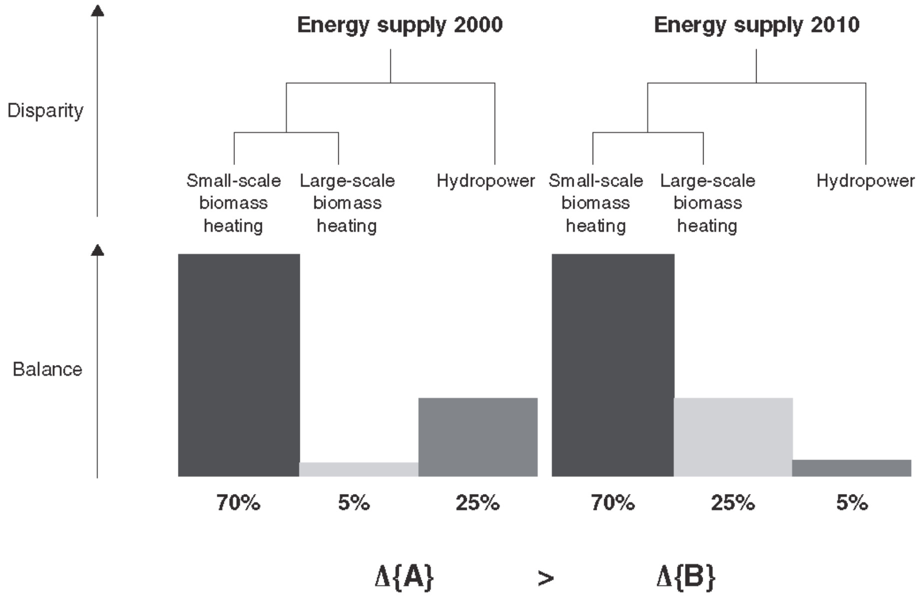

Figure 11.3 *Effect of disparity and balance on diversity (after Stirling, 2010)*

as illustrated by Figure 11.3 and in more detail in Figure 11A.1 in the appendix to this chapter (after Stirling 2010).

If we only would consider the technologies or the primary energy sources (disparity and variety), we would say that energy supply 2000 and energy supply 2010 are equal as both consist of three technologies or two primary energy sources, which differ from each other. Only if we include the additional criterion balance in the analysis, do we find that energy supply 2000 has a lower diversity than energy supply 2010.

For the connectivity indicators, the situation is slightly different: here the individual measures are partially interrelated, and do not logically build on one another (though they might be highly correlated in reality). Average path length, degree centrality and modularity are therefore not directly interdependent. A network with a high centrality can have a high or low modularity, depending on the overall distribution of nodes and ties. For example, a highly compartmentalized network can have a high or low overall centrality, depending on the connections within the compartments, and whether these are well connected by means of brokers present between the compartments. In a similar vein, the average path length does not necessarily have to be low in a highly centralized network, since, apart from the connection to the centralized actors, the actors might also have greater or lesser connections to other actors in the network, though average path length and centrality tend to be correlated in practice. Hence, each connectivity measure needs to be interpreted as complementary characteristic of connectivity which cannot simply be added up to one overall connectivity indicator. However, low average path length, high centrality and (most likely) low modularity would characterize a high connectivity.

6.3 Using a Mixed Method Approach

Our experience showed that analyzing and measuring the resilience of energy transitions with a mixed method approach is a necessity. The approach chosen overcomes problems in data availability while still obtaining a picture of the diversity and connectivity of the system in transition. Furthermore, linking qualitative with quantitative measures enables deepening the understanding of the system, supporting a better interpretation of the results. Nevertheless, there are some caveats to this approach. By means of interviews with stakeholders, we can obtain additional information on how routines, world views and perceptions affect the functioning of the system. This is of special importance when analyzing the social aspects of the system in transition. Ideally, snowball sampling and qualitative SNA based on perceptions of local change agents, which provide information on connectivity in the social subsystem, are complemented with quantitative measures, such as the number of exchanges per time lapse, or joint membership in professional associations and committees.

6.4 Co-evolution of the Social and Technical Subsystems

When studying the resilience of a transition, we have found that even though the technical and social subsystems are deeply interlinked, their connectivity and diversity measures develop in a diachronic way. Our results suggest that the trigger for change often comes from one of the two, for example, the formulation of a political goal, or the development of a new technology, and initializes change in the other subsystem (see also Hecher 2016). Whereas technical solutions might be available, the key issue for change often lies in the social subsystem, for example, new arenas are included in the regional governance system and new institutions are developed. When these social barriers are overcome, then new connectivity patterns in the technical subsystem will manifest themselves, for example, in the propagation of decentralized energy solutions. This implies that the resilience of the transition (in this case towards a renewable energy system) should be analyzed by looking at the technical and the social subsystems in an integrative way, and by looking at different development steps over time.

6.5 Application to Tourism

Coupled systems, which are built up of different subsystems, cannot only be found in the energy sector but in many realms of modern life. In tourism, for example, technical infrastructure, social practices, economic offers and the ecological resources, on which the former are based, constitute an exemplary social-ecological-technical system. To understand the dynamics of the system as a whole, and the way change processes over time affect resilience, dynamics in all subsystems have to be considered (see Luthe and Wyss 2015). If, for example, in the course of climate change, snow becomes scarcer and permafrost begins to thaw, winter sport practices are called into question and economic offers have to be adjusted. With some temporal delay, this often results in the implementation of technical adaptation measures (see, for example, Wyss et al. 2014; Luthe and Wyss 2016). Thus, to understand the resilience of a transition process in the tourism sector, on the one hand, the major characteristics of the components that constitute the technical, social, economic and ecological subsystems should be considered. This can be done by applying diversity indicators along the lines of variety, balance and disparity presented earlier in the chapter. On the other hand, the interdependency of components within and between subsystems should be accounted for, which can be achieved by applying connectivity indicators, such as average path length, centrality and modularity. For example, if climate change affects the ecological resource base upon which winter tourism offers are built, for instance, by changing the dynamics of the water cycle, this will not only alter the diversity of resources present, but also entail changes in the other subsystems. In the case of the Surselva Gotthard region (see Kelman et al. 2016; Luthe and Wyss 2016), the manifested and expected effects of climate change have led to a reorganization of the local tourism sector with regard to how actors cooperate and what offers are promoted. This change can be traced over time and interpreted in terms of resilience by applying diversity and connectivity measures.

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APPENDIX

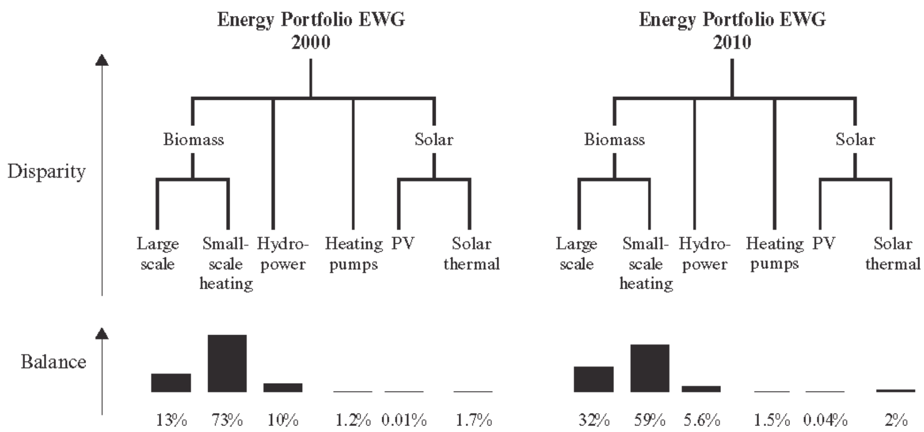

Figure 11A.1 Disparity and balance within the energy portfolio at the EWG

B.3 ”A particular species” urban utility companies in Germany and Switzerland

Title:

“A particular species” Urban utility companies in Germany and Switzerland – characteristics, challenges and strategic actions[1]

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Abstract: This article presents the characteristics of urban utility companies in Germany and Switzerland and examines their challenges and strategic actions in context of the energy transition. In so doing, it explores a particular actor type in communal infrastructure service organisation.

1 Introduction

Urban utility companies (municipal utility companies, owned by large cities, like Cologne or Geneva) represent a particular actor type in the German and Swiss energy sector. Due to the federal organisation of these two countries, the cities traditionally have the legal and financial autonomy to organise their infrastructure services – electricity, gas, water, public transport, telecommunication, waste – on the communal level[2]. For this purpose, the cities run their own utility companies which provide a varying breadth of these infrastructures to the city. As such, they are communal firms and at the same time large companies – in their energy division they belong to the biggest energy suppliers in both countries (StromMagazin) [“They function like large corporations. If you look at their turnover, they are large corporations. However, through their communal structure they are still also very bureaucratic and political” DE2][3]. Thus, the urban utility companies (UUC) are key players in the national energy sectors in Germany and Switzerland and play an important role for its transition. At the same time, they present an interesting example of how large cities (self-)organise their infrastructure services on a communal level in the context of the energy transition, which is yet rarely considered in scholarly and public debates.

To approach this particular actor type, the article provides an overview on characteristics of UUC in Germany and Switzerland and their current situation, by examining their challenges and strategic actions in an exemplary manner.

Methodically, this article is based on an explorative expert interview series, focussing on the energy division of some of the biggest UUC in Germany and Switzerland: Munich, Cologne, Hannover and Zürich, Geneva, Basel and Bern. In 2017, 40 experts were interviewed, coming from research,

[1] Author’s accepted manuscript. This paper was published 2018 in Network Industries Quarterly Vol. 20 No 1.
[2] This also holds true for the Austrian energy sector, however, this study only focusses on the Swiss and German case.
[3] Original Language of the interview quotes is German and French. They have been translated and anonymised by the author. DE stands for interviewees from Germany. CH stands for interviewees from Switzerland.

consulting, service providers and associations as well as the CEOs and members of the strategy units in large and middle sized UUC themselves (see table 1).

Table 1: Overview on interviewees per country and group

	Large UUC	Middle-sized UUC	Research	Consultancies, service provider	Sectoral association	Environmental association	Politics
GER	4	1	5	7	2	1	
CH	4	3	4	4	3		1

In a one-hour semi-structured interview, the experts were asked about their personal perspective on structural and cultural characteristics of UUC; political, economic, technological and organisational challenges as well as the strategic actions of UUC to face these challenges. The interviews were transcribed and analysed through a semi-structured coding process in MAXQDA: Under the predefined codes “characteristics”, “challenges” and “strategic actions”, the statements were grouped according to categories, emerging from the interviews.

2 Characteristics: public enterprises in federalist states operating network infrastructures

The key task of UUC in Germany and Switzerland is the provision of **infrastructure services** to “their” city - like electricity, gas, sometimes district heating, water and waste management, public transport, telecommunication and sometimes even public housing. Depending on the individual city, the organisational form of these infrastructure services varies: most of the UUC cover energy and water services and sometimes the fibre-optic grid within one firm, transport, waste and sometimes public housing are organised in “sister”-firms which are owned by the city (**varying horizontal integration**). As in any company, the horizontal integration plays an important role for risk allocation and diversification opportunities.

Regarding the **legal form** of the UUC, there is a major difference between Germany and Switzerland. While in Germany, the UUC are independent firms under private law, in Switzerland most of the UUC are independent firms under public law (Basel, Bern, Geneva) – only Zurich is an exception, where the gas supply is organised in a corporation under private law but the electricity and telecommunication services are still part of the city administration. Among the interviewees, there was disagreement, whether the legal form of the UUC influences their entrepreneurial opportunities. [“The legal form is not so decisive; it is more about the personalities. As long as the administrative board influences the firm’s strategy, there is control.” DE8; “every legal form has its means and one can design a utility company as if it would be a city department or as if it was an AG.”DE6; “the legal form makes the difference. It influences the flexibility, the financial resources, the mind-set, the profit orientation” CH16]

Despite the enormous variety among the UUC, all interviewees agreed on two aspects, which make UUC unique: being **multi-utility companies** (several types of infrastructure services) and **multi-energy companies** (supplying several types of energy) (see figure 1). This differentiates them from large energy providers like RWE or EON, but also from “regional providers like Romande Energie or Groupe E in Switzerland, who are mainly active in electricity” (CH 8).

Another characteristic, which they all have in common, is their **vertical integration** ["From the plant to the socket, they can cover all” CH16]. UUC are typically fully integrated firms, producing and trading electricity, gas and water but also **owning and running the distribution grids** for electricity, gas, water and sometimes district heating, respectively public transport and telecommunication. They also directly supply a broad range of customers and offer a broad range of energy related services. As such, they are at the same time **monopoly and market actors** (see figure 1). The grid operation is a natural monopoly - production, trade and retail, however, are organised through markets. There are again two important differences between Germany and Switzerland. While German UUC are fully embedded in the European market and operate their grid "unbundled" from production and retail, Switzerland is politically not a member of the EU and so the unbundling regulation does not apply for the Swiss UUC. They cover the distribution grid operation, production, trade and retail all together in one firm. Additionally, Swiss UUC still have a monopoly in gas and electricity supply for households in their local territory, since the **Swiss electricity market is only partly liberalised** (for large consumers – more than 100.000 kwh/a).[4]

Another distinct characteristic of UUC in both countries is the fact that they are in **public ownership** of the city and at the same time, they are **corporatized firms.** Consequently, they are expected to act according to the public interest and fulfil service public tasks for the urban system. At the same time, they should make profit for the city administration, in order for the city to finance non-profit services. The particular situation of the UUCs makes it, that the city does not only encounter them as their owner (shareholder), but also in different roles as political representative of the cities´ citizens (stakeholder). Again, there is a major difference among the two countries in the sphere of public interest: In Germany, the **service public task** for the UUC is focussed on the monopoly, which mean the provision of equitable access, quality and prices for the network infrastructure services to the citizens, which are financed through taxes and fees. For the supply of energy, however, the guarantee of the service public is within the national responsibility of the regulator, the Bundesnetzagentur Germany. In Switzerland, the service public is (still) the city´s responsibility and due to the monopoly for household supply also holds true for part of the retail, such that the cities define the "equitable price" for electricity and gas for their citizens. Moreover, being non-unbundled, the Swiss UUC **cross-finance** their different infrastructure services ["The non-separation in grid and production facilitates that the retail losses due to efficiency can be compensated by the grid revenues" DE14]. They ensure the service public of all infrastructures for the city on the city level.

This very different situation of the UUC in Germany and Switzerland consequently causes different challenges in the context of ongoing technical and regulatory transitions in the energy sector and leads to interesting communalities and difference in the strategic actions of Swiss and German UUC.

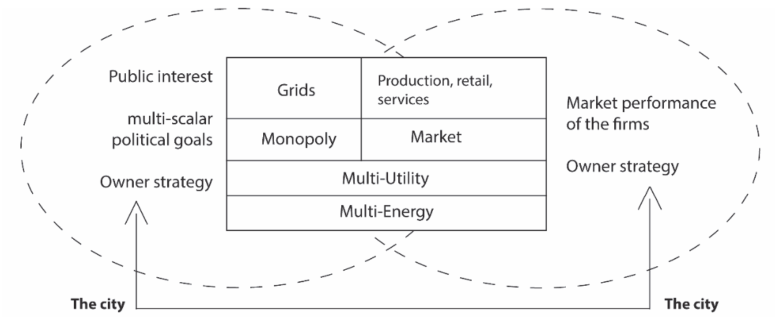

Figure 1: Overview on characteristics of UUC (own figure)

[4] This particular Swiss situation is part of the current discussion between the EU and Switzerland and might change in a near future.

3 Challenges

Global challenges

For a long time, the energy sector in Germany and Switzerland used to be very stable and static regarding both, production and distribution technologies as well as the overall regulatory frame. However, for the last 20 years, successively, three large change processes were ongoing in the two countries - and beyond. First, the political integration in Europe which caused the **liberalisation** and subsequent **re-regulation** of the energy, and respectively the electricity sector. Today, the created markets still need to be designed and re-regulated ["Five years ago energy market design was not even a term in the discourse, so this shows how things change" DE8]. UUC encounter more and more diverse competition ["Start-ups, energy retail platforms (e.g. verivox) but also Google, Telecom, actors who are able to deal with data" DE9] as well as more individualised customer demands. Second, the **political goal change on energy production technologies**: **decarbonising energy supply and phasing out nuclear power plants**. Subsequently, Germany, as many other European countries, launched subsidiary schemes for renewable technologies, which caused a decisive increase in decentral production capacity, volatility of supply and bi-directionality in the electricity grids, decreasing electricity prices as well as an enormous increase in actors involved in the sector. Third the general trend of **digitalisation** and "smartness" in the energy sector. The decisive acceleration in information exchange changes not only energy trading and retail but also provides new grid monitoring and management opportunities, with which the UUC need to catch-up. These three global changes cause at the same time a regulatory openness and speed of regulatory change, which the sector did not encounter before as well as a fundamental technology change in decentral production, storage and grid management.

All traditional energy companies face these fundamental challenges, however, the UUC are also confronted with some particular challenges, which are related to their characteristics presented above.

Particular challenges

The two major trends of liberalisation and the political goal change for a more sustainable energy supply system cause **contradicting expectations** for the UUC, which are of particular relevance due to their public ownership. As mentioned above, the city expects them to act according to the public interest and make profit at the same time. With the current political goal change, public interest does not mean only, ensure energy supply security and system reliability and be locally engaged by taking part in every city council meeting and sponsor local events, but also increase the share of renewables, invest in new infrastructures, implement energy efficiency measures and help customers to reduce their energy consumption ["Cities are more than just owners, they are stakeholders – they have political expectations and they are in a double-role: owner and political actor, so the claim political goals as owner" DE10; "earning money is the main expectation from the politics. Of course they always say please think also about the Energiewende but still the main claim is, it needs to be profitable" DE18]. Consequently, the **owner strategy of UUC often includes contradicting goals** from both "sides" (see figure 1). In comparison to private energy companies, where the political goals and the societal interest are external to the company, in German and Swiss UUC, the political goals are often directly formulated in the **owner strategy and goals** and can contradict the economic interests. Furthermore, in the federalist states, UUC are located in the communal political level and so they encounter not only the communal political interest, but also the cantonal/Länder interest, the national and the European at the same time. And the **political goals can vary** a lot among the communal and the national level as well as among the different cities, which additionally complicates the situation of UUC.

In both countries, the **clash of public and private (economic) interest** is also reflected in controversial opinions on which profiles and competences should be included in the **administrative board of UUC**. The public interest argues for a democratic representation of the citizens, the private interest argues for entrepreneurial, and sometimes for technological expertise. Consequently, the composition of the administrative board varies among the cities in both countries and causes additional challenges in the management of an urban utility company ["Who is sitting in the administrative board of a UUC? Local politicians. And the minority has a profound understanding and knowledge of the energy sector – the rest has communal political interests and basically wants money for the service public" DE3; "In the administrative board, who are the politicians? Are they experts in the energy field or in politics or are they more like knowledgeable citizen?" DE12]

The global challenges mentioned above, also require a decisive **change in the firm culture**, as well as in the individual profiles and competences of the employees in all areas. Entrepreneurship, risk affinity and innovation capacity, acceleration of decision making processes, competences in marketing, customer relations, new ways of management and working modes as well as new competences in smart technologies are required. Swiss and German UUC used to be characterised by an **administrative and engineering mind-set and culture** which allowed them to provide the public services and manage the cities infrastructure systems ["UUC are characterised by a particular type of employee. An engineer who is focussed on technology while thinking in social dimensions. He is not primarily interested in profit for the UUC but in facilitating the life of the city" DE16]. This mind-set only slowly adapts to the liberalised conditions in the sector ["It is not about the structures; it is the way of thinking in people's minds. And you won't change them in a few months" DE3]. Additionally, they are still expected to fulfil these public services and manage the urban infrastructure in a constant and reliable manner, however they should also perform as successful companies in uncertain and volatile market conditions. Thus, one of their major challenges is the incorporation of all necessary competences and the implementation of an **organisational change with a constant public and private performance**.

A second major field of challenges is related to the **mismatch among the regulations caused by the liberalisation** (e.g. unbundling) and the **technological requirements of productions technologies form renewable energies** - especially for the UUC in Germany. In order for the utility companies to include and manage decentral, dispersed and volatile renewable production, storage technology and flexibility mechanisms are central tools to ensure the supply security. However, questions of whether a distribution operator is allowed to install or use an existing production plant or storage capacity to balance the grid and whether this plant is financed under the monopoly or market scheme still need to be regulated. ["Integrated resource planning is really complicated with unbundling - even when there are contracts of data exchange, so the classical full integrated firm would work, they could decide: do we want to install LED or do we want to build a new plant" CH10]. On a more general level, the **regulatory frame for liberalisation and the regulatory frame for the "Energiewende" are partly contradictory** and thus cause challenges for the strategic orientation and investment decisions of the UUC – especially in Switzerland with regard to the uncertainty in political discussions with the EU. ["The whole unbundling regulation was made before the energy transition and the digitalisation and it hinders it right now. The utility companies get no feedback on the needs and the reaction of the customers – this is still designed for the uni-directional system and need to be revised in the future" DE3; "if somebody has the responsibility, he should also have the possibility to interfere" DE12]

4 Strategic actions: adapt to the market logics and valorise particular characteristics

In the context of the vast array of challenges, the UUC strategic actions in both countries can be grouped in two areas: On the one hand the **adaptation to market logics** by taking over strategic behaviour from private industry. On the other hand, the **strategic utilisation of their particular characteristics** in order to meet the diverging requirements and face the global challenges mentioned above.

Adapt to market logics

Although the liberalisation in Germany is already further advanced, interviewees in both countries mentioned a recent strategy refinement and subsequent **organisational and cultural changes** as main strategic actions in the context of liberalisation. Interviewees mentioned the implementation of innovation process management as well as the establishment of an innovation culture, including new profiles and competences in the firm as well as establishing new management cultures and working modes ["Recently an employee of an UUC told me, that she does not have business cards anymore, because she does not want to order new ones every year. She prefers to wait until she knows, in which department of the firm she will finally be located" DE16; "You design quicker products, innovation circles and beta versions, which are improved on the go" CH3]. Topics like customer orientation, increasing cost efficiency the exploration of new business models - close or more distant to their core business area, the design of new products in retail and services as well as the investment in renewable production capacities beyond their city territory were mentioned in almost every interview in both countries ["Reduce the costs and look for new business opportunities are the main two topics, we have" DE2; "They invest heavily in renewables, e.g. in wind parks in the Nordic Sea" DE12; "They all try to develop more retail and new products, but there is not yet an UUC which has a completely new business model" DE17].

For this purpose, UUC in both countries buy IT and engineering firms, which allow them to incorporate the necessary competences. Moreover, they also **cooperate with established and new players from other industries** (IT, telecommunication, car manufacturers), especially for new business model development ["If you can't beat them, join them" DE14; "strategic alliances in production, grids, IT, energy services... and not only horizontal but also with private actors" DE15; "This cooperation allows for all parties learning processes and reduces investment costs" CH8]. UUC in Germany additionally emphasised the increasing importance of the cooperation with other UUC (**inter-city cooperation**) but also with the "sister" firms in the same city (**intra-city cooperation**). ["We want to create 'experience worlds' for our customers – add-ons to the traditional commodity, plus-offers based on digitalisation, e.g. bundling e-mobility and smart home, therefore cooperation with our communal sister" DE10]

Utilise particular characteristics

While the UUC in both countries adapt to the market logics and take over strategies from private industry, they also strategically use their characteristics of being network infrastructure providers and multi-utility and multi-energy companies. On the one hand they **strengthen their monopoly position** and invest in grid concessions, respectively invest in new grid infrastructure like fibre optic grids and district heating grids ["They all do fibre optic, which is infrastructure and close to the core business" DE12; "The new business areas are heat and telecommunication – therefore they invest in district heating and fibre optic grid, since they think in electricity and gas they lose their profits" CH17]. On the other hand, they **invest in grid convergence** through Combined Heat Power plants in district heating networks or power-to-X solutions by using their gas grid infrastructure. Based on these investments, especially the German UUC offer new supply package products and technology management packages for prosumers, city districts, large buildings and companies. ["There should be a modular design of products – packages where the customer can add and delete parts ... – for example for industry buildings we would buy the security services into the package, but as much as possible we want to offer ourselves – to get the most out of it. And before amazon starts to sell electricity, we want to sell services" DE10].

Finally, they also **explore options for sector coupling** by cooperating with their "sister"-firms or subsidiaries in telecommunication and public transport. Based on their diverse infrastructure assets, they thus try to diversify their products to ensure the revenue stream and economic performance, but at the same time they also use the diversification to improve their system management functions and ensure their public service performance. ["Sector coupling is an opportunity, we have all the grids and can jointly optimise it." DE10].

Furthermore, in both countries UUC also build on their particular characteristic of being a locally embedded public enterprise and **push for their interest through their political representatives –** besides being part of sector associations, most utility companies individually lobby on the national and European level. Interestingly, only in Switzerland, the interviewees explicitly mentioned the cooperation with local politicians and citizens ["Local parliament and local society are the daily and first partners, which they aim at first" CH4; "we have different political layers - on the local level we have a strong interaction with the city" CH11]. In both countries, the **stakeholder involvement** and close collaboration with "their citizens" was emphasised to strengthen the customer relation and improve the innovation management to cope with the increasing competitive pressure ["We collaborate with our customers and do design thinking workshops to develop pilot products, try things out, experiment and become quicker" CH3].

Overall, UUC in both countries face similar challenges and thus some of the strategic actions are similar. However, the **large strategic lines** differ, at least from what was mentioned in the interviews. UUC in Germany focus actively on economic growth strategies and push for the further implementation of the "Energiewende" ["So that we can grow. We need to look beyond the region for making our business" DE9]. At the same time, they emphasised the re-orientation towards the commune and the local level, aiming for a network builder role in their "traditional territory" ["To cooperate still in a good way with the city and the communal structure to position themselves as infrastructure service provider in the communal environment and remain visible" DE11). UUC in Switzerland, however, strategically aimed at becoming quicker and more flexible and at engaging more in "do-it-yourself" strategies. ["Try to establish agility, to enable change while respecting the tradition, reliability and long term orientation, which can be an asset in the digital age" CH11; "To gain as much as possible of market responsibility, which leads to more agility" CH18]. Additionally, some of the Swiss interviewees stressed that the UUC engage in "double-side" strategies pro and contra the "Energiestrategie" ["From the civil society, they are seen as a strong actor for the energy transition, but at the same time, they need to get their business done and ensure their profits in the future - so there are two heads in the companies" CH19].

5 Discussion: typical challenges of public enterprises in network industries

The results presented above, mirror the particular situation of the UUC in Germany and Switzerland, however, they also reflect some of the major issues discussed in scholarly literature on public enterprises and network industries.

A key challenge for UUC as public companies - which are corporatized but still have a public owner - is the political control. Contradictory 'public' and 'private goals' in the owner strategies or the disagreement on the competences needed in the administrative board, reflect the problem of how to ensure and design the public control on the company. In scholarly literature on public corporate governance (Schedler, Finger 2008; Schedler et al. 2011), the so called **principal-agent theory** is often cited to explain this problem. The theory describes the problematic, that the (public) owner, called “principal”, is not the operator of the firm (agent) and thus lacks information on its performance. Consequently, the principal tries to establish different control mechanisms (e.g. political representatives in the administrative board) to overcome this gap which causes problems for the entrepreneurial performance of the agent. [SM1]

Furthermore, the particular UUC challenge of operating infrastructure networks, produce and supply energy in a liberalised scheme, plus the political decision to push for a “decarbonising” technology change, represent two typical problems of network industries: first, discussions on **liberalisation and the subsequent re-regulation of network industries**, second, the problem of **lacking coherence among the current regulatory framework and the technological development(s)**. In scholarly literature these two topics are widely discussed (Finger et al. 2005; Finger 2011; Florio 2017; Finger, Jaag 2015) and also relevant to other network industries, like the railway sector. However, the problem, that the regulatory frame caused by liberalisation hampers the actions needed to foster technology change towards a more sustainable energy supply system, is a particular debate in the energy sector and here latest, Germany and Switzerland could profit a lot from the others experiences.

To sum up, UUC are indeed particular actors in the German and Swiss energy sector, their characteristics, challenges and strategic actions, however, are explainable by common scholarly theories on public enterprises and network industries. Moreover, they represent an interesting case of urban self-organisation of infrastructure services in federalist states and question the common liberalisation paradigm, which should be subject to further research.[5] [SM2]

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[5] The results presented above are based on a rich basis of experiences and knowledge of different experts in the German and Swiss energy sector. Since they mirror the experts’ individual perceptions they only can present an intersubjective truth, no objective truth. Additionally, the interviewees’ statements as well as the authors’ analysis are bound to their temporal context and since the energy sector is changing very quickly, the interviewees would perhaps see challenges and strategic actions differently, today.

B.4 Zielkonflikte bei den Stadtwerken

Zielkonflikte bei den Stadtwerken[1]

Matthias Finger & Susan Mühlemeier

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Stadtwerke sind traditionell Unternehmen der Städte, um deren Grundversorgung in den Bereichen Elektrizität, Gas, Wasser, Abwasser, Telekommunikation u.a.m. sicherzustellen. Als sogenannte «Kommunalversorger» bedienen sie die BürgerInnen einer territorialen Einheit mit Public Services. Als «Verbundunternehmen» bauen sie auf den Synergien der verschiedenen Dienstleistungen auf. Typischerweise sind sie deshalb in öffentlicher Hand und in Haupteigentümerschaft der Städte. Mit der Liberalisierung des Elektrizitätsmarktes - und wohl bald auch des Gasmarktes - sind die Stadtwerke vor grosse Herausforderungen gestellt: sie verlieren ihre grössten Kunden, ihre Netzaktivitäten werden reguliert und sie können kaum mehr quersubventionnieren. Wie können sie diese und andere Zielkonflikte überwinden? Ist die Schweiz ein Spezialfall?

Ausgangslage

Stadtwerke sind Teil der Netzwerkindustrien, gehen aber über diese hinaus. Als Netzwerkindustrien werden Industrien bezeichnet, die ihre Dienstleistungen auf der Basis von Infrastrukturnetzen erbringen. Bei diesen Netzen handelt es sich um sogenannte «natürliche Monopole», da eine parallele Netzinfrastruktur, die von einem zweiten Anbieter betrieben wird und den gleichen Service ermöglicht, volkswirtschaftlich nicht sinnvoll ist. Daneben umfassen Netzwerkindustrien meist kritische Infrastrukturen (wie z.B. das Stromnetz), die eine „kritische“ Bedeutung für das Funktionieren der Wirtschaft und der Gesellschaft haben. Sie sind daher traditionell oft in öffentlichem Besitz und stark reglementiert, um einen gerechten und sicheren Zugang für alle Teile der Gesellschaft zu diesen kritischen Infrastrukturen zu ermöglichen (Service Public).

Auf dem Gebiet einer Stadt (oder einer Gemeinde) kommen viele dieser Netzwerkindustrien zusammen: das Elektrizitäts- und Gasverteilnetz, Trinkwasser und Abwasser, aber auch die verschiedenen Elemente des lokalen öffentlichen Verkehrs (Bahn, Metro, Bus, Tram). In den meisten Ländern sind die meisten dieser lokalen Netzwerke in öffentlicher Hand, d.h. sie sind im Eigentum der Stadt, aber manchmal auch des Nationalstaates. In gewissen Ländern werden einige dieser lokalen Netzwerke von privaten Unternehmen betrieben. Das ist traditionellerweise (seit

[1] Akzeptierte Autorenfassung des Manuskripts, Publiziert als: Matthias Finger & Susan Mühlemeier. “Good Governance in Netzwerkindustrien – Zielkonflikte bei den Stadtwerken“ In: Ronny Kaufmann & Stefan Rechsteiner „Hin zu einem Energiesystem der Zukunft“ (in press)

[2] Es handelt sich hier um persönliche Meinungen des Autors und nicht die der ElCom.

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Anfang 20. Jahrhundert) der Fall in Frankreich im Wasser- und Abwassersektor sowie im öffentlichen Verkehr. In England wurde der Betrieb dieser lokalen Netzwerke erst in den 1980er Jahren an private (oft französische) Unternehmen ausgelagert. Eine Spezifizität der deutschsprachigen (Deutschland, Österreich, Schweiz) under skandinavischen Länder sind die sogenannten «Stadtwerke». Es handelt sich hier um eine Organisationsform, in welcher die verschiedenen Netzwerke in einem lokalen öffentlichen Unternehmen zusammengefasst werden, was seinerseits Quersubventionnierungen zwischen den verschiedenen Sektoren erlaubt. Das ermöglicht einen finanziellen Ausgleich zwischen mehr und weniger profitablen Dienstleistungen auf lokaler Ebene, ohne dabei zwingend auf nationale Unterstützung zurückgreifen zu müssen.

Liberalisierung

Das Stadtwerkmodell bekommt nun aber wegen der europaweiten Liberalisierung des Strom-und Gassektors Probleme. Liberalisierung in Europa hat das Ziel einen europäischen Binnenmarkt zu schaffen. Dazu werden die Netze in verschiedenen Liberalisierungsschritten von Produktion und Verkauf getrennt. Das ist das sogenannte «Unbundling» im Stromsektor. Und dieses Unbundling betrifft in der EU nicht nur das Übertragungsnetz, sondern auch die grösseren Stadtnetze. Stadtwerke müssen also ihre Verteilnetze vom Verkauf der Elektrizität institutionell trennen, d.h. die Stadtwerke aufspalten. Die Preise, die von den Stadtwerken für die Benutzung der Verteilnetze verrechnet werden dürfen, werden reguliert. Quersubventionnierungen aus dem Netz heraus werden verboten. Bisher sind die Stadtwerke in der Schweiz nicht dazu verpflichtet, Produktion und Verkauf vom Betrieb des Verteilnetzes zu trennen. Es wird sich zeigen, wie die Schweiz mit diesen Entwicklungen in der EU in Zukunft umgehen wird. Absehbar ist jedoch, dass der Status quo in der Schweiz auf Dauer nicht aufrecht erhalten werden kann.

Zudem ist der Elektrizitätsmarkt in Europa geöffnet. Ebenso der Gasmarkt. Das heisst einerseits, dass die Kunden in einer Stadt vom städtischen Elektrizitätsanbieter (Stadtwerk) zu einem Konkurrenten wechseln können. Andererseits ermöglicht dieselbe Liberalisierung (zumindest theoretisch) einem Stadtwerk ebenfalls Elektrizität in anderen Städten und an andere Kunden zu verkaufen: eine Chance, die aber nur einige wenige grosse Stadtwerke bisher wahrgenommen haben.

Um in diesem liberalsierten Markt bestehen zu können, werden Stadtwerke zunehmend «korporatisiert». Das bedeutet, dass sie in eigenständige Unternehmen, oftmals Aktiengesellschaften umgewandelt werden, die aber weiterhin im mehrheitlichen Besitz einer Stadt sind. In der Tat bleiben in den meisten europäischen Ländern, wie auch in der Schweiz, städtische Netzinfrastruktur und Vertrieb in öffentlicher Hand, da u.a. weiterhin das Verständnis herrscht, dass der service public dieser kritischen Infrastrukturen besser durch die öffentliche Hand organisiert sein sollte. Die ehemaligen Staatsbetriebe oder Verwaltungsdepartemente wurden „lediglich“ korporatisiert, um im Wettbewerb effizient agieren zu können. Beides, Korporatisierung und Wettbewerb, schaffen Zielkonflikte, denen sich die Stadtwerke zu stellen haben.

Das Stadtwerk im Zentrum von Zielkonflikten

Aus einem Kommunalversorger, Verbundunternehmen und Service Public Anbieter werden nun korporatisierte Stadtwerke. Diese sind mit vier verschiedenen Zielkonflikten konfrontiert.

Wettbewerb zwischen öffentlichen und privaten Unternehmen: In der Produktion und im Vertrieb von Elektrizität und Gas konkurrieren öffentliche Stadtwerke gegen private Firmen. Private Firmen suchen sich dabei die lukrativsten Kunden und Märkte aus (sogenanntes «Cherrypicking» oder «Creamskimming»), was wiederum dazu führt, dass bei den Stadtwerken die weniger lukrativen Kunden hängen bleiben, was seinereseits die Wettbewerbsfähigkeit eines Stadtwerkes beeinträchtigt. Dies führt früher oder später dazu, dass ein Stadtwerk (wenn nicht schon regulatorisch dazu gezwungen) sein Verteilnetz von Verkauf der Energie trennen wird und das Energiebusiness allenfalls sogar verkaufen muss.

Service Public vs. Profit-Orientierung: Als Kommunlaversorger ist ein Stadtwerk ein (integriertes) Service Public Unternehmen. Das gilt weiterhin für diejenigen (aber immer reduzierteren) Bereiche, in welchen noch kein Wettbewerb stattfindet, wie zum Beispiel im Wasser oder Abwassersektor. In den Bereichen, in welchen nun Wettbewerb herrscht (Elektrizität, Gas, Abfallbewirtschaftung, etc.) ist einerseits Profitorientierung (bei den Dienstleistungen) oder Regulierung (bei den monopolistischen Netzen) angesagt. Dieser Zielkonflikt ist institutionell nur so aufzulösen, dass die von der Stadt (Gemeinde) aufgetragenen Service Public Aufgaben präzis definiert und entsprechend abgegolten werden. Idealerweise näme dies die Form eines Leistungsvertrages an.

Demokratische Kontrolle vs. Wettbewerbsperformance: Die durch die Liberalisierung erfolgte Korporatisierung der öffentlichen Unternehmen - die zwar ein effizienteres Agieren im Wettbewerb ermöglicht - verändert gleichzeitig aber die Möglichkeiten demokratischer Kontrolle über das Unternehmen. Dieses Phänomen wird in der Literatur als Prinzipal-Agenten Problem bezeichnet, da der Eigentümer (Prinzipal) nicht mehr die operative Führung (Agent) des Unternehmens innehat und somit ein Informationsgefälle entsteht. Dem wird durch Berichterstattungsauflagen und Eigentümerstrategien sowie –ziele versucht entgegenzuwirken, um die nötige Transparenz zu wieder zu schaffen. Oftmals bergen die Eigentümerstrategien öffentlicher Unternehmen in Netzwerkindustrien aber enorme Zielkonflikte zwischen öffentlichem und privaten Interesse des gleichen Eigentümers (z.B. einer Stadt). Diese Konflikte erschweren das operative Geschäft der Unternehmen teilweise massiv. und sind auch hinsichtlich der demokratischen Kontrolle und Transparenz nicht förderlich. Dieser Zielkonflikt ist schwierig, wenn nicht unmöglich, auf institutioneller Ebene aufzulösen und bleiben am Schluss oftmals bei Personen hängen (CEOs, Verwaltungsratspräsident).

Föderalismus (Kleinräumigkeit) vs. Effizienz (Skaleneffekte): Stadtwerke sind typischerweise Teil und Ausdruck einer subsidiären und föderalen Staatsstruktur. Wettbewerb und Markt sucht umgekehrt ökonomische Effizienz durch Skaleneffekte. Lokales und kleinteiliges Management, das aus Redundanzen besteht (z.B. Verteilnetzbetreiber in jeder Kommune) und auch an den Wert der direkten demokratischen Kontrolle gebunden ist, kann jedoch kaum grossflächig ökonomisch effizient sein, und wird schlussendlich zu einer gewissen Konzentration (Konsolidierung durch Fusionen) der Stadtwerke und politischer Zentralisierung (Gemeindefusionen) führen. Dieser Zielkonflikt lässt sich institutionell nicht auflösen, sondern muss politisch entschieden werden. Er ist letztendlich auch eine Frage des Wohlstandes eines Landes, ob es sich dezentrale und ökonomisch weniger effiziente Strukturen leisten kann und will. Ist Zentralismus politisch nicht wünschbar, bleibt die Frage wie ein föderales System schlussendlich ökonomisch effizient gestaltet werden kann.

Wir sind somit wiederum bei der Frage der Governance der Infrastrukturen. Und diese Frage kann nicht nach einem einfachen Assessment-Prozess vor dem Hintergrund internationaler Standards abgehandelt werden. Sie ist auch nicht singulär zu beantworten hinsichtlich dessen, was technologisch am besten, ökonomisch am effizientesten oder politisch am gerechtesten wäre. Vielmehr handelt es sich – in demokratischen Gesellschaften – um einen gesellschaftlichen Aushandlungsprozess, in dem technologische Grundlagen, ökonomische ebenso wie politische Maximen ausbalanciert werden. Und gerade in Zeiten politisch und technologisch vorangetriebenen Wandels des Energiesektors (Dekarbonisierung, erneuerbare Energien, Digitalisierung) muss die Frage nach der Good Governance des Energiesektors und die Rolle der Stadtwerke darin neu und länderspezifisch beurteilt werden.

Quid de la Suisse?

Diese Zielkonflikte gibt es natürlich auch in der Schweiz. Dazu kommen aber noch ein paar weitere Spezifizitäten, die es zu berücksichtigen gilt. Festzuhalten ist, dass kommunale Energieversorger, Stadt- und Gemeindewerke in föderalen Energiesystemen wie der Schweiz eine lange Tradition und zentrale Rolle haben. Sie garantieren den Kommunen die direkte, lokale Kontrolle ihrer kritischen Netzinfrastrukturen (Strom, Gas und Wasser) sowie die lokale Energie- und Wasserversorgung. Kleine Gemeindewerke haben vor allem die Funktion des Verteilnetzbetreibers und Energieversorgers, grosse Stadtwerke sind traditionell auch an der Energieproduktion für die Stadt beteiligt. Sie halten deshalb entweder Anteile in Partnerwerken oder besitzen und betreiben auch eigene Kraftwerke, innerhalb der Stadt sowie in deren Umland. Die gesamte Verteilnetzebene föderaler Energiesysteme ist somit in kommunaler Hand.

Teilmarktöffnung: Die bis jetzt wichtigste Spezifizität der Schweiz ist, dass bis heute der Elektrizitätsmarkt nur teilweise und der Gasmarkt überhaupt nicht liberalisiert worden ist. Das führt dazu, dass die Stadtwerke bis jetzt kaum dem Wettbewerb und der Konkurrenz ausgesetzt worden sind und bis heute meist von kostenbasierten, regulierten Energietarifen profitieren können. Als Resultat davon stehen die Kommunalversorger finanziell immer noch gut da., und dies im Gegensatz zu denjenigen Unternehmen, die keine gebundenen Endkunden mehr haben (vor allem Alpiq und Axpo). Dies kann sich in Zukunft aber ändern (siehe dritter Punkt unten).

Selbstproduktion: Ein Teil der schweizerischen EVUs produzieren selber Elektrizität, heute noch vorwiegend aus (günstiger) Wasserkraft. In der Vergangenheit durften sie diese günstige Energie an ihre freien Kunden weiterverkaufen, was einige auch getan haben. Zwischenzeitlich hatte die ElCom diese Praxis unterbunden, so dass die EVUs ihre Eigenproduktion anteilsproportional an alle ihre Kunden weitergeben müssen und somit nicht nur freie, sondern auch (tarif)gebundene Kunden in den Genuss günstiger Strompreise kommen. Das Bundesparlament hat im Kontext der Revision des Stromversorgungsgesetzesdiese diese Durchschnittspreismethode jedoch wieder aufgeweicht. Zwar sind die Grundversorger weiterhin dazu verpflichtet „Preisvorteile aus günstig zugekauftem Strom weiterzugeben", die inländische Produktion erneuerbarer Energien wurde jedoch von der Durchschnittspreismethode ausgenommen und Preisvorteile müssen bis 2022 nicht weitergegeben werden.

Europa: Die Schweiz hat immer noch kein Stromabkommen mit der EU, und solange das der Fall ist, wird auch die Teilmarktöffnung bestehen bleiben und die finanziell komfortable Situation der

EVUs so bleiben. Das wird sich aber mit dem Stromabkommen ändern, und die Schweizer Stadtwerke werden, wie alle Europäischen auch, mit den obigen vier Zielkonflikten konfrontiert. Dazu kommen, im Stromabkommen noch das Unbundling, jedoch nur für die grössten Stadtwerke, sowie eine stringentere Regulierung der Staatsbeihilfen. Letztere wird Quersubventierungen aus monopolistischen Aktivitäten wie zum Beispiel Wasser und Abwasser in Zukunft unterbinden.

Energiewende: Die Schweiz hat 2017 per Referendum die Energiestrategie 2050 beschlossen. Das entsprechende Gesetz ist seit 2018 in Kraft. Das öffnet für die Stadtwerke neue Geschäftsopportunitäten in einem bis anhin relativ unregulierten Bereich und schafft neue Möglichkeiten, die oben genannten Zielkonflikte neu anzugehen.

Welche Opportunitäten für die Stadtwerke, in der Schweiz und anderswo?

Im Hinblick auf die oben identifizierten Zielkonflikte ergeben sich für die Schweizer Stadtwerke, inbesondere gerade im Kontext der Energiewende neue Opportunitäten.

Wettbewerb, Wirtschaftlichkeit: Kommunalversorger sind auf Unternehmensebene nicht per se besonders effizient und sorgen im Energiesystem für Redundanzen, die kostenintensiver sind als eine zentrale Steuerung. Andererseits ist z.B. das Lohnniveau egalitärer und transparenter, und Wertschöpfung wird auch in ländlichen Regionen gebunden. Ob eine föderale Governance Struktur volkswirtschaftlich per se teurer ist als eine zentralisierte, bleibt gerade vor dem Hintergrund der Energiewende - die Innovation braucht – offen und sollte in entsprechenden politischen und wissenschaftlichen Diskursen zur stärkere Berücksichtigung finden.

Service Public: Service Public ist für die Stadtwerke oft Kernaufgabe. Dieser Auftrag ist damit nicht nur ein politisches Ziel, das extern des Unternehmens festgelegt wurde, sondern bildet integraler Bestandteil der Unternehmensstrategie. Die Stadtwerke bauen hier auch auf langjähriger Erfahrung des Systemmanagements und im Umgang mit lokal spezifischen Kundenbedarfen auf. Sie geniessen daher das Vertrauen der lokalen Bevölkerung und Politik, das sie auch in einem Wettbewerbsumfeld nutzen können.

Demokratische Kontrolle: Die meisten Kommunalversorger sind in öffentlicher Hand und der Verwaltungsrat setzt sich aus politischen Vertretern zusammen; eine demokratische Kontrolle ist daher auf lokaler Ebene möglich. Da die Kommunalversorger meist in 100%er Eigentümerschaft der Kommunen und Städte sind, sind (politische) Entscheide meist leichter durchführbar. Dies kann ebenfalls als Vorteil verstanden und genutzt werden: Zielkonflikte können z.B. gegenüber der Politik und Bevölkerung transparent gemacht sowie die Ziele für Unternehmen und Service Public lokal neu ausgehandelt und definiert werden.

Föderalismus: Kommunalversorger sind integraler Bestandteil und die zentralen Akteure des föderalen Systems, sie managen das Energiesystem vor Ort und spiegeln in ihrer Organisationsform und Funktionsweise und die Werte der lokalen Gesellschaft wider. Sie tragen deshalb zur Diversität, Dezentralität und schlussendlich Resilienz der Energieversorgung bei.

Die zentrale Funktion der Stadtwerke lässt sich an den drei Dimensionen Versorgungssicherheit, Dekarbonisierung und Resilienz klar aufzeigen. In der Tat leisten kleine Kommunalversorger auf Verteilnetzebene einen entscheidenden Beitrag zur *Versorgungssicherheit*. Sie übernehmen die

Netzsteuerung und Instandhaltung der physischen Infrastruktur. Grosse Stadtwerke tun das auch im Bereich der Produktion, indem sie sich an der der Energieproduktion beteiligen und z.B. in erneuerbare Energien investieren.

Zudem haben Kommunalversorger das Potential aktiv zur *Dekarbonisierung* des Energiesystems beizutragen, was aber stark von Einzelpersonen und dem politischen Willen der Gemeinde abhängig ist. Hier gibt es daher ebenso viele Positiv- wie Negativbeispiele. Der Beitrag grosser Stadtwerke zur Transition ist jedoch eindeutig positiv, da die Städte in der Regel politisch progressiver ausgerichtet sind, über entsprechende finanzielle Mittel verfügen und somit ihre Stadtwerke zum Vorantreiben der Transition anhalten.

Welche Rolle spielen nun die Kommunalversorger für die *Resilienz* des Energiesystems? Kommunalversorger haben traditionell in kleinere und vielfältigere, oft erneuerbare Stromproduktionsanalagen und jüngst auch Speicheranlagen investiert und managen zugleich die Prosumer in ihrem Verteilnetz. Die diversen, modularen Strukturen, die dennoch aus einer Hand von Ihnen gemanagt werden, erlauben eine hohe Netzresilienz und können auch entscheidend zur Resilienz des Übertragunsnetzes beitragen. Andererseits haben sie auf Basis ihrer Gasnetzstruktur auch in Projekte der Sektorenkopplung (Wärme, Verkehr) investiert und nutzen ihre Telekommuniaktionsnetze mehr und mehr zur digitalen Steuerung der Infrastrukturen. Im technischen Bereich spielen sie daher eine entscheidende Rolle für Diversität und Vernetzung des Energiesystems.

Zukünftige Rollen für Stadtwerke, EVUs bzw. Kommunalversorger

In Abhängigkeit der Ihnen übertragenen Verantwortung, und dem Grad der demokratischen Kontrolle lassen sich für Stadtwerke, EVUs oder Kommunalversorger folgende drei «idealtypische» zukünftige Rollen herauskristallisieren. Alle drei Modelle bauen auf den Möglichkeiten der Digitalisierung auf.

- *«Smarter Netzwerkbetreiber»*: Die Kommunalversorger wird sich auf das regulierte Geschäft zurückziehen, dafür jedoch weiterhin alle lokalen Netzwerke managen (Gas, Wasser, Elektrizität, Fernwärme) und die Service Public Aufgabe auch im digitalen Bereich Daten übernehmen. Dieses Modell erlaubt demokratische Kontrolle über die kritischen Infrastrukturen, (incl. der Dateninfrastruktur), lässt gleichzeitig jedoch Raum für Wettbewerb in Produktion und Vertrieb.

- *«Smarter regionaler Aggregator»:* Die Kommunalversorger ziehen sich auf das Netzgeschäft zurück, übernehmen zeitgleich jedoch auch die Rolle des Aggregators und damit die zentrale Rolle in der Steuerung der Verteilnetze und der dezentralen Produktion. Sie werden einerseits dem Übertragungsnetzwerkbetreiber Flexibilitäten zur Verfügung stellen, andererseits auch das Demand-Side-Management der Verbraucher (incl. smart home) übernehmen. Sie würden damit nicht nur den Service Public der Datenzurverfügungstellung übernehmen, sondern zeitgleich auch Dienstleistungen anbieten. Es bleibt zu diskutieren, inwiefern sie lediglich regulierte Systemdienstleistungen oder auch Services im Wettbewerb anbieten dürften oder sollten. Dieses Modell würde (wenn nicht anders reguliert) zu einer gewissen Konsolidierung der Kommunalversorger führen, da diese Dienstleistungen erst ab einer gewissen Grösse ökonomisch sinnvoll sind, ihnen zeitgleich jedoch eine machtvolle Position eines dezentralisierten Energiesystems verleihen. Parallel wäre eine ähnliche Rolle für gewisse Regionalversorger auch denkbar, um eine föderale Struktur auch im digitalisierten System darstellen zu können.

- *«Smarter vollintegrierter Energieversorger»:* Das ist der voll integrierte Kommunalversorger, der auch in einem voll liberalisierten Markt die ganze Wertschöpfungskette abdecken wird und regulierte und wettbewerbliche Bereiche in unterschiedlichen Tochterfirmen separiert. Diese Kommunalversorger werden ebenfalls in einem gewissen Masse konsolidiert, um sich im europäischen Wettbewerb behaupten zu können und werden die kommunalen Gelder auch international investieren, um die ihnen nach wie vor öffentlich vorgegebenen strategischen Ziele zu erreichen. In diesem Modell werden die Kommunalversorger smart Services anbieten und das auch in Konkurrenz zu privaten Aggregatoren. Dieses Modell ist in der Tendenz z.B. bei den grossen Kommunalversorgern in Deutschland aber auch der Schweiz bereits zu beobachten. Dieses Modell erweitert die demokratische Kontrolle auch auf Produktion und Services und forciert damit einen demokratisch gesteuerten Ausbau der Erneuerbaren Energien bzw. auch des Ausstiegs aus nicht erneuerbaren Energien. Es verschafft den grossen Städten, in denen die grossen Kommunalversorger meist angesiedelt sind, Möglichkeiten für zusätzliches Einkommen, es bleibt jedoch zu diskutieren, ob dieses Modell volkswirtschaftlich am effizientesten ist und wie ein Wettbewerb zwischen öffentlichen und privaten Firmen geregelt werden kann.

Es besteht natürlich auch die Möglichkeit sowohl Netze als auch Produktion und Vertrieb zu privatisieren. Dadurch würde die direkte demokratische Kontrolle verloren gehen, auch wenn über strenge Konzessionsrechte weiterhin Einfluss genommen werden könnte. Eine Privatisierung forciert jedoch die Profitorientierung und damit die Tendenz zu Skaleneffekten, sodass die Betreiber selten kleinteilig strukturierte und lokale Unternehmen sein werden, die dem föderalen Verständnis entsprächen und die Wertschöpfung regional binden würden. Der Service Public und die Versorgungssicherheit müssten über strenge Regulierungen garantiert werden, die nicht mehr integraler Bestandteil der Unternehmensstrategien wären, sondern von diesen als externe Anforderungen betrachtet werden. Insgesamt müsste eine volle Privatisierung stark regulirt werden um den oben erwähnten grundlegenden Werten zu entsprechen. Ob eine Privatisierung sich positiver auf die Energiewende auswirken würde, kann nicht gesagt werden.

Stadtwerke und Kommunalversorger stehen im Zentrum des föderalistisch organisierten Schweizer Energiesystems. Verteilnetze und lokale Energieversorgung sind in kommunaler Hand. Im Kontext der europäischen Integration und der damit einhergehenden Liberalisierung der Strom- und Gasmärkte stehen die Stadtwerke in der Schweiz, wie in anderen föderalen Staaten Europas, jedoch zwischen vier Zielkonflikten: i) *Wettbewerb zwischen öffentlichen und privaten Unternehmen, ii) Service Public vs. Profit-Orientierung, iii) Demokratische Kontrolle vs. Wettbewerbsperformance iv) Föderalismus (Kleinräumigkeit) vs. Effizienz (Skaleneffekte).* Zusätzlich ergeben sich für Schweizer Stadtwerke weitere Herausforderungen wie die z.B. Teilmarktöffnung oder die Beziehungen zu Europa und die damit verbundenen Regulierungen des Energiesektors. Die Stadtwerke stehen in der aktuellen Energiewende jedoch gut da: sie tragen auf lokaler Ebene massgeblich zur Versorgungssicherheit, Dekarbonisierung und Resilienz des Energiesystems bei. Stadtwerke sollten diese guten Ausgangsbedingungen nutzen, um an Lösungen für die bestehenden Zielkonflikte zu arbeiten. Im direkten Austausch mit der Eigentümerin, der lokalen Stadtbevölkerung, anderen Stadtwerken sowie der Politik, sollte ausserdem diskutiert werden, welche Rollen die Stadtwerke im zukünftigen Energiesystem übernehmen werden: *smarter lokaler Netzwerkbetreiber, smarter regionaler Aggregator oder smarter, voll integrierter Energieversorger*?

C - Information on thesis author

C.1 Curriculum vitae

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Current position

École Polytechnique Fédérale de Lausanne (EPFL),
Laboratory for Human-Environment Relations in Urban Systems (HERUS)
Researcher and PhD Student (March 2016)

- ➔ Social and technological resilience in regional energy systems (Austria and Germany)
- ➔ Transition, governance, urban utilities in the energy transition in Germany and Switzerland
- ➔ Didactical conceptualisation, lecture organisation "Sustainability assessment in urban systems"
- ➔ Didactical conceptualisation of interdisciplinary teaching programme "Design and build together"

Professional course

Ludwig-Maximilians-Universität München (LMU),
Research and Teaching Unit for Human-Environment Relations (HER)
Researcher and PhD Student, project coordinator for the third party funded project "Transition processes for a more sustainable energy system" (2015-2016)

- ➔ Social and technological resilience in regional energy systems (Austria and Germany)
- ➔ Transition, governance, pioneers in the energy transition in the Allgäu region, analysis of regional actor networks

Hessnatur Textilien, Butzbach
Corporate Responsability Department,
Master student and intern (April - September 2014)

- ➔ Development, implementation and evaluation of didactical programme on social standards for suppliers

Katholische Universität Eichstätt-Ingolstadt
Chair for didactic in geography, chair for economic geography
Research assistant (2010 – 2014)

- ➔ Supporting the design and coordination of lectures, research for and evaluation of lectures in didactics of geography
- ➔ Redacting textbook for economic geography

Education

M.A. Geography: Education for Sustainable Development (2012 -2014) Catholic University Eichstätt-Ingolstadt, Germany
Teaching for secondary schools, Geogrpahy/ Geman Language (Staatsexamen) (2009 -2014) Catholic University Eichstätt-Ingolstadt, Germany
B.A. Geography / German Language (2009 -2012), Catholic University Eichstätt-Ingolstadt, Germany

Projekt work and coordination

- Transformation processes to a sustainable energy system (TranE) (2015-2016)
- Pioneers of the energy transition in the Allgäu region – transdiciplinary reseach project in collaboration with the city of Kempten and the Umwelt- und Bildungszentrum Allgäu (eza!) (2015-2016)

Languages

German:	Mother tongue, full understanding of all swiss german dialects
English:	Full oral and written proficiency – EU C1 level
French:	Good oral and written proficiency – EU C1 level
Italian:	Basic knowledge

Professional networks

STRN – Research Network for Sustainability Transitions – steering group member, PhD & ECR representative
NEST – Network for Early Career Researchers in Sustainability Transitions – organisational board
ProClim – Forum for Climate and Global Change
FairBindung e.V. – Bildungsnetzwerk für Postwachstumsökonomie / Konzeptwerk neue Ökonomie e.V.

Teaching

- Lecture / seminar: sustainability assessment in urban systems – EPFL
- Transdisciplinary project seminar: pioneer oft he energy transition – Pioniere der Energiewende – LMU
- Seminar: resilience and adaption: climate change in the alps – LMU
- Methods seminar: education for sustainable development – KU Eichstätt

Personal Interest

Jazz music (saxophone, flute) in band and orchester, alpine sports, nordic sports, sailing, tennis, tailoring and carpenting.

Lausanne, 30. November 2018

C.2 Personal bibliography

Publications (peer-reviewed)

Mühlemeier, S. (under review). Dinosaurs in transition? A conceptual exploration of local incumbents in the Swiss and German energy transi-tion. *Environmental Innovation and Sustainability Transitions*.

Wyss, R., Mühlemeier, S., Binder, C.R. (2018). An Indicator-Based Approach for Analyzing the Resilience of Transitions for Energy Regions. Part II: Empirical Application for the case of Weiz---Gleisdorf, Austria. *Energies* 11(9), 2263.

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Mühlemeier, S., Wyss, R., &. Binder, C.R. (2017) Und Aktion! – Konzeptualisierung der Rolle individuellen Akteurshandelns in sozio-technischen Transitionen am Beispiel der regionalen Energiewende im bayerischen Allgäu. *Zeitschrift für Energiewirtschaft* 41(3) 187-202.

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Non-peer-reviewed chapters and contributions:

Mühlemeier, S. (2018). "A particular species" urban utility companies in Germany and Switzerland. *Network Industries Quarterly*, 20 (1).

Mühlemeier, S.; Wyss, R.; Binder, C.R. (2018). Ein indikatorengestützter Ansatz zur Resilienzanalyse von Energiesystemen in Transition. In: Resilienz: Springer, S. 293–326.

S. Mühlemeier and T. Knöpfle. „Pioniere der Energiewende" Bevölkerungsbefragung im bayerischen Allgäu Akzeptanz, Wahrnehmung und Verhalten der Bevölkerung in der regionalen Energiewende, *ForChange Working Publications*, 2016.

Talks and Workshops

Mühlemeier, S. (2018). Good Governance – sind die Schweizer Gasversorger "richtig" aufgestellt?. Presentation at *VSG Werkleiterseminar*, Brunnen, Schweiz, 23. November.

Mühlemeier, S. (2018). Große Stadtwerke in der Energiewende Deutschlands und der Schweiz – eine grenzüberschreitende Studie über die aktuelle Situation und die Rolle(n) eines föderalistischen Akteurs. Presentation at *Konferenz Kommunales Infrastruktur-Management*, Berlin, Germany, 06. September.

Binder, C.R. and Mühlemeier, S. (2018): Wie wird der einzelne Akteur der Energiewende? Presentation at *Alpenforce Sommertagung*, Zürich, 01. July.

Mühlemeier, S. (2018). Public incumbent actors in network industries Investigating urban utility companies in the German and Swiss energy transition. Conference paper presentation at *9th International Sustainability Transitions (IST) Conference,* Manchester, 14.-17. June.

Mühlemeier, S. (2018). Torn between international competition and the city's claims: Analysing key influence factors on urban utilities' business strategies in the German and Swiss energy transition. Presentation at *3rd NEST Conference*, Utrecht, 15.-16. March.

Mühlemeier, S. and Wyss, R. (2018): Resilience Thinking in Sustainability Transitions. Workshop at *3rd NEST Conference*, Utrecht, 15.-16. March.

Mühlemeier, S. (2018). Poster presentation at *International Conference – Infrastructure Resilience 2018 RESIL2018*, 12.-14. February.

Mühlemeier, S. (2018). Sozialwissenschaftliche Forschungsagenda zur Energiewende in alpinen Regionen. Workshop at *Energieforschungsgespräche Disentis* 2018, 24.-26. January.

Mühlemeier, S. (2017). Analysing Swiss energy companies´ strategies embedded in their socio-political, economic and physical environment. Speed-Talk at *Transformations2017*, Dundee, United Kingdom, 30. Ausgust - 01. September.

Mühlemeier, S. (2017). Rusty dinosaurs and the surviving species in the new energy system? Analysing urban utilities in the German and Swiss energy transition. Poster presentation and speed-talk at 8th *International Sustainability Transitions (IST) Conference,* Göteborg, 18.-21. June.

Mühlemeier, S. & Wyss, R. (2017). Resilience of Energy Transitions. Presentation at *Energieforschungsgespräche Disentis*, 26.-28. January.

Mühlemeier, S., Binder, C.R., Wyss, R. (2016). Indicators for measuring the resilience of energy transitions. Speed-talk at 7th *International Sustainability Transitions (IST) Conference*, Wuppertal, Germany, 06.-09. September.

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Mühlemeier, S. (2016). Development of a holistic framework for structures and processes of urban energy supply systems in transition. Presentation at *1st PhD in Transitions Conference*, Greenwich, UK, 28.-29. April.

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