GAIA

S1 | 2017

ECOLOGICAL PERSPECTIVES FOR SCIENCE AND SOCIETY
ÖKOLOGISCHE PERSPEKTIVEN FÜR WISSENSCHAFT UND GESELLSCHAFT

SONDERHEFT
RESILIENZ: ANALYSETOOL FÜR SOZIALE TRANSFORMATIONEN

oekom verlag

GAIA is available online at *www.ingentaconnect.com/content/oekom/gaia*
www.oekom.de | B 54649 | ISSN 0940-5550 |
GAIAEA 26/S1, 161 – 224 (2017)

"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
GAIA 26/S1 (2017): 199–206

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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https://doi.org/10.14512/gaia.26.S1.7

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

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[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

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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.

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[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 1b) 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.

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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.

We thank the Swiss Mobiliar for co-funding this research and the anonymous reviewers for their valuable feedback.

References

Baccini, P., H.-P. Bader. 1996. *Regionaler Stoffhaushalt.* Heidelberg: Spektrum Akademischer Verlag.

Bayerisches Landesamt für Statistik. 2015a. *Statistikatlas Bayern: 33111 Flächennutzung, Flächenverbrauch: Anteil der landwirtschaftlich genutzten Fläche: 31.12.2015.* https://www.statistik.bayern.de/statistikatlas (accessed February 2, 2017).

Bayerisches Landesamt für Statistik. 2015b. *Statistikatlas Bayern: 33111 Flächennutzung, Flächenverbrauch: Anteil der Waldfläche in %, 31.12.2015.* https://www.statistik.bayern.de/statistikatlas (accessed February 2, 2017).

Binder, C.R., S. Mühlemeier, R. Wyss. 2017. An indicator-based approach for analyzing the resilience of transitions for energy regions. Part I: Theoretical and conceptual considerations. *Energies* 10/1: 36. doi:10.3390/en10010036.

Böhm, T., M. Sambale, H.-J. Barth, F. Botzenhart. 2015. *Bericht: Energiezukunft Allgäu.* Kempten: Eigenverlag Energie- und Umweltzentrum Allgäu (eza!).

Böschen, S., C.R. Binder, A. Rathgeber. 2017. Resilienzkonstruktionen: Divergenz und Konvergenz von Theoriemodellen. Eine konzeptionell-empirische Analyse. *GAIA* 26/S1: 216–224.

Brand, U., A. von Gleich. 2015. Transformation toward a secure and precaution-oriented energy system with the guiding concept of resilience: Implementation of low-exergy solutions in Northwestern Germany. *Energies* 8/7: 6995–7019.

Büscher, C., J. Schippl. 2013. Die Transformation der Energieversorgung: Einheit und Differenz soziotechnischer Systeme. *Technikfolgenabschätzung – Theorie und Praxis* 22/2: 11–19.

Büscher, C., J. Schippl. 2017. Die Transformation der Energieversorgung: Einheit und Differenz soziotechnischer Systeme. In: *Die Energiewende verstehen – orientieren – gestalten.* Edited by J. Schippl, A. Grunwald, O. Renn. Baden-Baden: Nomos. 35–52.

Flick, U. 2009. *An introduction to qualitative research.* Thousand Oaks, CA: Sage.

>

Flick, U., E. von Kardoff, I. Steinke. 2004. *A companion to qualitative research.* Thousand Oaks, CA: Sage.

Freeman, L.C. 1978. Centrality in social networks conceptual clarification. *Social Networks* 1/3: 215–239. doi:10.1016/0378-8733(78)90021-7.

Gößling-Reisemann, S., S. Stührmann, J. Wachsmuth, A. von Gleich. 2013. Vulnerabilität und Resilienz von Energiesystemen. In: *Die deutsche „Energiewende" nach Fukushima. Der wissenschaftliche Diskurs zwischen Atomausstieg und Wachstumsdebatte.* Edited by J. Radtke, B. Hennig, Beiträge zur sozialwissenschaftlichen Nachhaltigkeitsforschung 8. Marburg: Metropolis. 367–396.

Grin, J., J. Rotmans, J. Schot. 2010. *Transitions to sustainable development: New directions in the study of long term transformative change.* London: Routledge.

Gunderson, L.H. 2001. *Panarchy: Understanding transformations in human and natural systems.* Washington, D.C.: Island Press.

Hinterberger, B. 2016. *Energy flow analysis on regional level: State of transformation towards a sustainable energy system of the Allgäu.* Master Thesis, Ludwig-Maximilians-Universität München.

Hodbod, J., W.N. Adger. 2014. Integrating social-ecological dynamics and resilience into energy systems research. *Energy Research and Social Science* 1: 226–231.

Kost, C., et al. 2013. *Stromgestehungskosten Erneuerbare Energien.* Freiburg: Fraunhofer-Institut für Solare Energiesysteme (ISE).

Leipprand, A., C. Flachsland, M. Pahle. 2016. Energy transition on the rise: Discourses on energy future in the German parliament. *Innovation: European Journal of Social Science Research* 30/3: 283–305. doi:10.1080/13511610.2016.1215241.

Mayring, P. 1991. Qualitative Inhaltsanalyse. In: *Handbuch qualitative Sozialforschung. Grundlagen, Konzepte, Methoden und Anwendungen.* Edited by U. Flick. Munich: Psychologie Verlags Union. 209–213.

Mühlemeier, S., T. Knöpfle. 2016. *"Pioniere der Energiewende". Bevölkerungsbefragung im bayerischen Allgäu.* Edited by Bayerischer Forschungsverbund *ForChange*. *ForChange* Working Paper 4. https://f.hypotheses.org/wp-content/blogs.dir/1945/files/2016/03/Muehlemeier-Knoepfle-2016-WP4.pdf (accessed July 11, 2017).

Mühlemeier, S., R. Wyss, C.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.* doi:10.1007/s12398-017-0205-z.

Mühlemeier, S., R. Wyss, C.R. Binder. Forthcoming. Ein indikatorengestützter Ansatz zur Analyse der Resilienz in Transitionen von Energiesystemen: Theoretische Konzeptualisierung und empirische Anwendung im bayerischen Allgäu. In: *Resilienz. Neue und alte Perspektiven zu Wandel und Transformation.* Edited by M. Karidi, R. Gutwald, M. Schneider. Wiesbaden: Springer.

Olsson, P., V. Galaz, W.J. Boonstra. 2014. Sustainability transformations: A resilience perspective. *Ecology and Society* 19/4: 1.

Roege, P.E., Z.A. Collier, J. Mancillas, J.A. McDonagh, I. Linkov. 2014. Metrics for energy resilience. *Energy Policy* 72: 249–256.

Rohracher, H. 2001. Managing the technological transition to sustainable construction of buildings: A socio-technical perspective. *Technology Analysis and Strategic Management* 13/1: 137–150.

Rotmans, J., R. Kemp, M. van Asselt. 2001. More evolution than revolution: Transition management in public policy. *Foresight* 3/1: 15–31.

Schilling, T., R. Wyss, C.R. Binder. Forthcoming. Beyond the threshold – Seven thesis to conceptualise the resilience of sustainability transition processes. *Ecology and Society*.

Späth, P. et al. 2007. *Energieregionen: Wirksame Leitbildprozesse und Netzwerke zur regionalen Gestaltung sozio-technischen Wandels.* Berichte aus Energie- und Umweltforschung (BMVIT) 29. Vienna: Bundesministerium für Verkehr, Innovation und Technologie.

Stirling, A. 2007. A general framework for analysing diversity in science, technology and society. *Journal of the Royal Society Interface* 4/15: 707–719.

StMWi (Bayerisches Staatsministerium für Wirtschaft und Medien, Energie und Technologie). 2016. *Energie-Atlas Bayern.* http://geoportal.bayern.de/energieatlas-karten (accessed July 3, 2017).

StMWi. 2017a. *Energie-Atlas Bayern (Kartenteil): Abfrage zu Anteil EE am Gesamtstromverbrauch, Landkreise Kaufbeuren, Kempten, Lindau, Memmingen, Oberallgäu, Ostallgäu, Unterallgäu.* http://geoportal.bayern.de/energieatlas-karten (accessed July 3, 2017).

StMWi. 2017b. *Energie-Atlas Bayern (Kartenteil): Windenergie – Potenzial – Windgeschwindigkeit – Mittlere Windgeschwindigkeit in 100 m Höhe.* http://geoportal.bayern.de/energieatlas-karten (accessed July 2, 2017).

Strunz, S. 2014. The German energy transition as a regime shift. *Ecological Economics* 100: 150–158. doi:10.1016/j.ecolecon.2014.01.019.

Stührmann, S., A. von Gleich, U. Brand, S. Gößling-Reisemann. 2012. Mit dem Leitkonzept Resilienz auf dem Weg zu resilienteren Energieinfrastrukturen. In: *Der Systemblick auf Innovation. Technikfolgenabschätzung in der Technikgestaltung.* Edited by M. Decker, A. Grunwald, M. Knapp. Gesellschaft, Technik, Umwelt N.F. 16. Berlin: edition sigma. 181–192.

Verbong, G.P.J., F.W. Geels. 2007. The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy Policy* 35/2: 1025–1037.

Verbong, G.P.J., F.W. Geels. 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change* 77/8: 1214–1221.

Walker, B., C.S. Holling, S.R. Carpenter, A. Kinzig. 2004. Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society* 9/2: 5.

Wasserman, S., K. Faust. 1994. *Social network analysis: Methods and applications.* Structural Analysis in the Social Sciences 8. Cambridge, UK: Cambridge University Press.

Weimann, G. 1982. On the importance of marginality: One more step into the two-step flow of communication. *American Sociological Review* 47/6: 764–773.

Submitted July 3, 2017; revised version accepted July 7, 2017.

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