Master thesis

Master in Energy Management and Sustainability

Microgrids:
A tool for a grassroots energy transition

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August 14, 2015
Lausanne/Paris

Thomas Vasco Mendes de Matos Guibentif is completing his Master degree in Energy Management and Sustainability, a program of EPFL Middle East, after a Bachelor in Physics at EPFL.

Dr. François Vuille is Director of Development of the Energy Center (CEN) at EPFL.

Acknowledgements

This work would not have been possible without the contribution of many and I am grateful to all of them.

In particular, my supervisor at EPFL, François Vuille, Director of Development of the Energy Center has provided me with the possibility of starting this project. The present outcome would not have been possible without his advice and patience over the 6 months of work. In particular, he secured the contact with most of the micro-Delphi respondents and even conducted a couple of interviews when I could not be physically present.

Indeed, for the second half of the project, I had the opportunity of moving out to Paris and work within the International Energy Agency. I could not be more grateful to my supervisor there, Simon Müller, Energy Analyst at the Renewables Energy Division. He not only selected my application for an internship but agreed to use the results of the project that was already starting and I enjoyed significant freedom during my stay. This provided a unique possibility to enjoy the experience of working in an international institution while conducting the Master project.

Next on the list are all those who collaborated on the project at EPFL, namely Mary Jean Bürer, Georgios Sarantakos and Lorenzo Reyes. At IEA, I received support and advice from Cédric Philibert, Emanuele Bianco, Yianqiu Bi and others. During the 6 months of the project, I had the opportunity to hear and speak with several panelists and experts, who all brought their expertise upon which I could reflect, in particular Evelina Trutnevyte, Chris Dunstan and Dr. Stephen Hall.

Of course, the interviewees who accepted the invitation to participate to the micro-delphi made a decisive contribution. Unfortunately, I shall not mention their names here. There were many others whose valuable and interesting contributions were made through various discussions which I had the privilege of undertaking. I noticed that energy issues easily trigger heated discussions and these are most inspiring, so I would like to express my appreciation to all of my "opponents" as equally as to those with whom I agreed. Many discussions arose during the Forum 2100, launched by David Gautschi.

I would also like to thank all my friends, those "from before" at EPFL and those I made among the interns at the IEA, who have always provided me with some kind of distraction from my work, slowing it down but most probably enhancing its quality.

Last but not least, my family and other friends outside of my studies who have provided me with opportunities for a bit of travelling and winding down; it was always comforting to think about or hear from them in the most tough moments of the project. A special thanks to Nessy (Vanessa Haines), who took the time to proofread this document.

This report was written with LaTeX*. The database, the meta-analysis results and part of the micro-Delphi results were treated in* Microsoft Office Excel *to increase portability, and* Office Word *was used for some documents to speed up contributions. Most figures were created using* Lucidcharts *(www.lucidcharts.com), some with* Power Point *and one with* MySQL Workbench.

Abstract

This document is a Master Thesis conducted under the supervision of the Energy Center at EPFL, as the conclusion of an MSc in Management of Energy and Sustainability. The aim of the work was to find out what contribution microgrids could bring to the energy transition currently underway.

Current trends First, a meta-analysis of the literature allowed us to identify current trends in microgrid diffusion and existing categorisations. Research on microgrids appears to be increasing, together with the interest they raise among the wider public. Actual implementation is concentrated in the US and India. "True microgrids" are distinguished from "utility microgrids", larger systems operated by utilities, and "virtual microgrids" which rely on remote assets.

New definition As a starting point, we extended the definition of the concept to go beyond the technical aspects that are usually considered. Microgrids are *the system resulting from a local approach to energy production and supply. Its aim is to provide energy services to a user or group of users delimited in space while interacting with the overlaying instances as a single node.*. This definition includes all types of energy, besides electricity and allows us to consider the economical and organisational design of the microgrid, besides the technical design.

Introduced frameworks To study the concept, we introduced frameworks that have not yet been used in this field, namely the flowchart, mapping energy, services and information flows from/to the microgrid; the "business case palette", mapping microgrid roles and associated value propositions; the value tree, linking value propositions with costs and other parameters; and the intelligibility diagram, mapping stakeholders and their motivations. These frameworks have been applied on data centralised in a database, populated based on a literature review. To help the conception and study of microgrids, we also propose a formal separation of technical, economical and organisational layers of the microgrid. We used this framework to describe some possible scenarios and support our policy recommendations.

Micro-Delphi To further explore the barriers and possible incentives to the deployment of microgrids did a case study for Switzerland. Interviews were held with 9 Swiss stakeholders in the field of energy, public and private and representing the whole value chain. Value propositions and barriers to the microgrid deployment were explored, and the respondents were asked to assess the place for microgrids in the future energy system as well as measures that could be taken to encourage them.

Results for Switzerland The current Swiss energy system is acknowledged to being in a state of change. New decentralised renewable sources (namely solar) are generalising, changing both the operation of the system and the business case for local utilities. In this context, microgrids could help to manage the distribution grid and achieve savings on the network costs. The potential for increasing Switzerland's energy supply security and network reliability, while nuclear reactors are to be stopped, could also be drivers for a microgrid deployment. The information on the users and increased sustainability seem to be less relevant value propositions. However, microgrids are not expected to spread in the medium-term (20 to 40 years) as technology is not completely mature and individuals are not sufficiently concerned by energy issues.

Medium-term limitation Aside from these findings, the vision and actions of the stakeholders appeared to be restricted to the medium-term due to political or technical reasons. However, the decreasing costs of microgrids and the fact that they enable the provision of energy services without relying on the electricity grid opens the door to new entrants. These would threaten the current model of incumbent public utilities, based on the sale of electricity. On the other hand, microgrid technologies are also an opportunity for this incumbent utilities, who could use them to lower their network costs and provide new services, increasing the competitiveness of their offer.

An action in the short term is recommended More proactivity, using the current favourable conditions would allow those utilities to consolidate their position. We found that a hybrid system, where local resources are privileged within microgrids while a central management ensures a coordinated and optimal use of these resources could be a interesting scenario to pursue. Evolving towards such a system requires measures at all levels:

- At a national level more planning and research would be needed, aside from existing objectives in terms of primary energy mix and network connectivity.
- At a regional level, utilities should prepare for the increase in self-consumption behaviour by developing new business cases, possibly using local markets and service-based offers.
- Collectivities (municipalities, cities, enterprises), would have to foster the discussion between all stakeholders, both to increase acceptability and exploit local potentials to the maximum.

Microgrids could provide a basis for this discussion, opening it to matters beyond electricity distribution, thus fostering interest. In that sense, they would pave the way for a grassroots energy transition.

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Introduction

Context The energy transition is usually associated with a shift from the use of non renewable primary energy sources to the harvesting of renewable energies, which is the starting point of most energy policies. Countries set targets for the share of renewable energy produced and issue measures accordingly (feed-in tariffs, public procurements...). In some countries, social protests following the Fukushima accident lead to the decision of abandoning nuclear, further putting the focus on primary energy sources change.

This push towards renewable energies is aligned with an objective of reduction of greenhouse gas emissions in order to limit global temperature rise of 2 degrees, a threshold deemed necessary to avoid likely irreversible planetary damages, according to the IPCC [49]. Other drivers are sometimes put forward: concerns on the sustainability and supply security arise not only from the physical finiteness of resources, but also from their uneven distribution and unstable price [58]; the impact on human health has been shown [67]; and the fairness of the current model has been questioned, where resources are extracted from developing countries under poor working conditions to be utilised in developed countries.

The focus on primary energy supply is now showing significant systemic limits. On the technical side, the characteristics of most renewable souces have posed diverse problems linked with the stabilisation and balancing of the electric system [28]. On the economic side, several utilities, including public utilities, have undergone major crises in several countries: faced, on the supply side, with a demand reduction combined with the obligation of buying electricity at retail price from the prosumers and, on the procurement side, with decreasing profitability due to falling electricity prices, some assets have become non-viable before even starting operation (stranded assets), causing large losses [13]. On the social side, large infrastructure projects are facing increased public opposition [68].

As a result, the policies have been complemented with new objectives for the transmission and distribution grids, as to increase capacity and stability. The underlying scenario is one of a strongly interconnected smart grid, covering an area wide enough to have a reasonably steady production from renewable sources thanks to an aggregation of several facilities. The remaining variability is to be compensated with balancing capacity, for instance gas power plants or storage. However, the reliability and security of such a centralised and interdependent system has been questioned [12], all the more in a context of climate change and increased frequency of extreme weather events. Moreover, this vision leaves unaddressed the economic and social challenges, which call not only for new technical solutions, but also for new financing schemes and more communication with the public.

Rationale In this work, we propose a bottom-up approach of the problem, where smaller entities cope with the local problems before aggregating remaining issues and passing them to the overlaying governance level. In the field of electricity, and energy in general, implementing this approach corresponds to deploying a microgrid. The main rationale of this work was to further explore the opportunities and issues associated with this technology.

Microgrids are defined in the literature as "[An energy system] comprising LV distribution systems with distributed energy resources (microturbines, fuel cells, PV, etc.) together with storage devices (flywheels, energy capacitors and batteries). Such systems can be operated in a non-autonomous way, if interconnected to the grid, or in an autonomous way, if disconnected from the main grid. The operation of micro-sources in the network can provide distinct benefits to the overall system performance, if managed and coordinated efficiently" [57].

Beyond the technical object, microgrids also materialise a grid management paradigm that is actually attracting attention for itself. Indeed, there is a decentralisation of the electricity system's governance taking place: the control of the grid is shifting from the transmission to the distribution levels. In parallel, the power economy seems to be moving towards a more user-centred, service-oriented model (on this other energy transition, see for instance [9], which handles the UK case). In particular, new players are entering the field of energy services through home automation and the spread of electric cars is increasing the decentralised (marketable) storage capacity available. This has implications on the political, economical and social (participation through DSM programs) levels. Microgrids could provide a support for this transition and help to address the challenges identified above.

First, thanks to the use of local resources, they allow to reduce the dependency on foreign fuels and increase the sustainability of the system. Moreover, the holistic and local perspective they require allows one to better consider local specificities and potentials, thus maximising the exploitation of these. Arguably, it would be easier to reach enhanced efficiency within small systems than considering a countrywide grid, as the complexity is reduced.

Moreover, the small size of the considered systems also reduces the impact of inadequate design or changed context. This reduces risk and thus stimulates investment and innovation, making the system more flexible and dynamic. From this point of view, a large scale solution would take much more time to develop, test, recognise and deploy, while any bug left during the process would be very costly to address in the future. Also, the partial decoupling between the components makes the overall system less vulnerable to failures of one part, increasing reliability, security and resiliency.

Lastly, as users are in principle more involved using this approach, behavioural changes could be expected, or at least a better acceptance, avoiding possible rebound effects. This would make the spread of the solutions faster, and opens the way not only to efficiency improvements (better building isolation, heat pumps) but also to final energy consumption reduction (accepted lower temperatures), ultimately increasing the impact on primary fuels use.

Specifying the scope: Switzerland Against the more agitated European context, Switzerland appears as an island of tranquility. Swissgrid, the transmission system operator (TSO) just concluded that the existing network could afford 16GW of unevenly distributed solar capacity, even in the event of a phase out of existing nuclear reactors [63]. However, hydro power plants have been facing profitability issues due to the European electricity market evolutions and wind turbines systematically face public opposition. Also, a possibly increased reliance on electricity imports due to the abandoning of nuclear power has raised concerns on supply reliability. Concretely, the path to the objectives set by the currently discussed Swiss Energy Law for 2050 [7] (one fourth of the electricity produced by renewable energy, other than hydraulic power, by 2035) is not yet clear, although a road-map has been set out for the implementation of smart grid technologies [20].

In addition, Switzerland shows interesting characteristics that may facilitate the deployment of microgrids. On the one hand, decentralised electricity production facilities are spread all around the country mainly, run-of-river hydro or biomass, while significant potentials for solar and wind have been assessed. On the other hand, the management of distribution networks is in the hands of a myriad of small companies, mostly publicly owned, with a strong trust relationship with their end users and relatively dynamic.

These local stakeholders could be empowered to deploy a microgrid, as to ensure the supply with local resources. Expectedly, this would reduce social opposition to infrastructure projects, all the more as a significant part of the population defends autonomy, thus self-sufficiency (at all administrative levels, from the confederation to the village). Economic issues would be addressed by the reliance on public funding and a stable local user base, while the technical problems for the transmission system would be handled at the distribution level, increasing capacity for international trade. At the same time, energy savings and an increase of the renewable energies share in the mix could be expected.

However, while the Swiss energy system is barely a few steps away from a network of microgrids, each with their own management entity and local generation sources, no claims have been made of a microgrid implementation[1]. This deserves further attention.

Report structure This report tries to answer the following central question: *In what contexts would microgrids contribute to a more sustainable energy system? In particular, could it become the paradigm for the future Swiss energy system?* The project tried to identify the benefits of microgrids, what are the barriers to their deployment and how the deployment of microgrids could be stimulated, with a focus on the Swiss case.

The first section of the current report details the methodology, data structures and assumptions used to address this question. In the second section an overview of existing literature is given, allowing to identify current trends, value propositions and possible business cases for microgrid implementation. In the third section we present the results of a Micro-Delphi conducted on Swiss stakeholders, which highlighted some barriers to the deployment of microgrids in Switzerland. Lastly, we discuss these results, proposing a frame-

[1] In 2014 only one DC grid in Zurich for one data center was reported in [4]. EPFL is conducting research on the subject, with a project for islanding the campus.

work for the consideration of the three facets of the energy system which allows to describe a couple of scenarios for the future energy system and of possible microgrids setups in Switzerland. Ultimately some policies are suggested based upon this scenarios which could lead to an energy transition based on microgrid deployment.

1 Approach

This section presents our approach to the subject. We tried to relate the socio-economic challenges faced by the energy system with the decentralisation solutions brought by microgrids. This is a relatively original approach, as most of the research on microgrids is done at a quite fundamental level for now, addressing technical aspects, although some research also exists on business cases for microgrids.

As presented in this section, the first step of the project was to redefine the microgrid concept. This provided a first framework to integrate findings from a literature review, which was the second step of the work. Other frameworks were also used, from different research domains, which are presented in this section as well. The last step was to reach the stakeholders who could play a role in the diffusion of the concept. The scope of this last step was Switzerland, as microgrids appear to have a very small presence, while they would apparently be an interesting solution. However, the methodology used should be applicable to other regions.

1.1 Problem definition

As other terms that left the engineering labs, the word "microgrid" has evolved into a concept broader than the initial definition. The first task is therefore to redefine the scope of study through a new definition of the word. In this section, we subsequently detail the questions addressed by this project, and the objectives which have guided it.

1.1.1 Microgrid, a proposed definition

Limitations of current definitions We take as starting point the definition given in the introduction. "[An energy system] comprising LV distribution systems with distributed energy resources (microturbines,fuel cells, PV, etc.) together with storage devices (flywheels, energy capacitors and batteries). Such systems can be operated in a non-autonomous way, if interconnected to the grid, or in an autonomous way, if disconnected from the main grid. The operation of micro-sources in the network can provide distinct benefits to the overall system performance, if managed and coordinated efficiently"[57]. This approach is illustrated by fig. 1. It dates back to 2009, but most definitions found convey the same technical view.

By itself, this definition carries some ambiguities. First, provided only a minimal storage capacity or the ability of curtailing non-essential loads, a local grid may be able to island from the larger grid for a few hours. A control

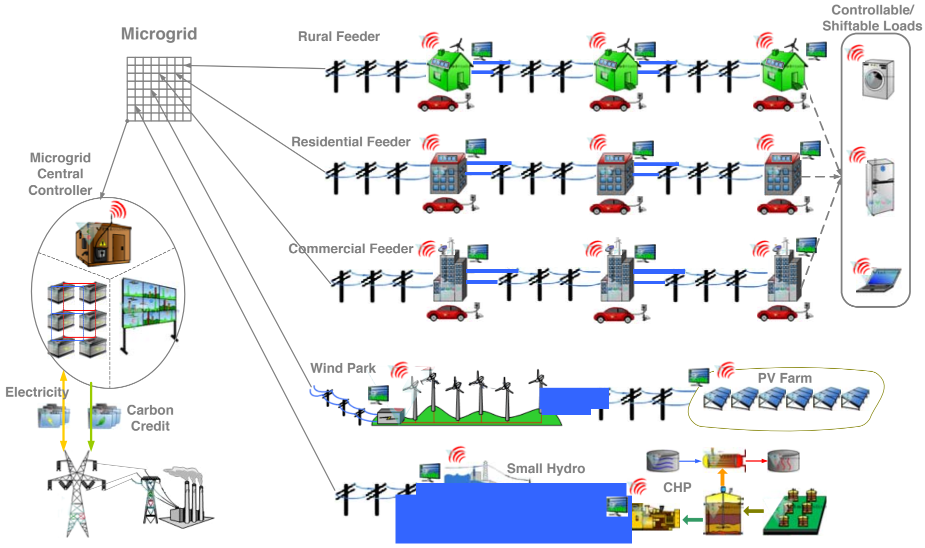


Figure 1: *Microgrid representation by [57, p. 15]. Note that for a full illustration of the given microgrid definition, the report also gives sample microgrid representations as a single LV feeder or even a single LV house. Here, the microgrid is assumed to be financed through "carbon credits".*

cell of a large smart grid can have this feature, for instance. Thus there is a blurring between the definition of a smart grid and a microgrid. Second, if we consider any distribution grid bellow a single point of common coupling (PCC), we observe a set of loads, and nowadays often also micro-sources, that could sometimes operate autonomously provided a minimum system adaption. This blurs the distinction between a microgrid and a conventional distribution grid.

Moreover, another definition is needed if we want to enable an analysis of economic, policy and social implications of the deployment of a local energy system. For the object considered in this study, we propose a broader, more flexible one. However, the continuum of possible system setups and the consideration of the different features of a decentralised energy system requires a more generic framework, that we present for the discussion, section 4.1.1.

Microgrid as a system *We define a microgrid as the system resulting from a local approach to energy production and supply. Its aim is to provide energy services to a user or group of users delimited in space while interacting with the overlaying instances as a single node.*

The approach conveyed by this definition is illustrated by fig. 2. Note that the microgrid system thus defined can include from household applications to a large power plant and from the end user himself to the microgrid operator, as well as the interactions between them. Thus it is composed not only of the energy system (electricity, heat, gas...), but also of the organisational structure and of the market design.

In principle, the overall operation of the microgrid system will be opti-

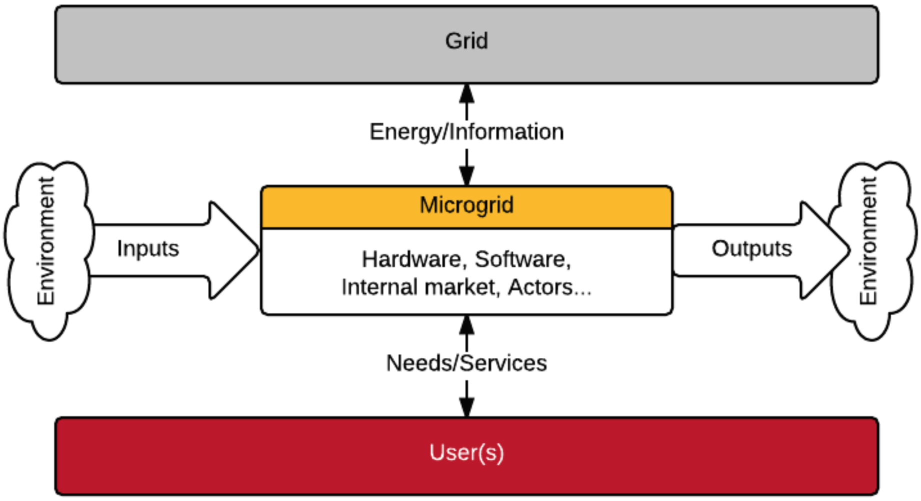


Figure 2: *Schematic representation of the microgrid system. This representation allows for the consideration of multiple technical, economical, managerial, political and social aspects.*

mised while satisfying the demand from the users in terms of energy services (rather than electricity supply). This optimisation can take into account multiple objective functions, beyond primary energy consumption (e.g. externalities, overall cost, noise...), depending on political and social choices. This requires an holistic conception of the whole system, which is at the core of our definition.

We acknowledge that such a definition may not be practical for a number of purposes, for instance the establishment of technical standards, but it allows us to take formally into account economical, political or managerial aspects beyond the technical ones.

Characteristics of a microgrid The definition given above suggest a couple of characteristics for a microgrid system, although not all are required at the same time:

- **Smartness** (i.e. use of computational and communication technologies) technically enables the communication with the overlaying grid, by aggregating acquired data and relaying instructions. It also enables the communication with the user as to collect needs and tolerable service changes. This can be implemented as an intelligent agent.
- **Enhanced metering** is required for the real-time optimisation and monitoring of the services provided. It allows to increase the supply quality, security and reliability.
- **Implication of local actors** has to be pushed as to match needs with offered services and increase responsive capacity so that the control agent has some latitude.

- **Priority to local resources** is given as to reduce grid dependence and improve resiliency. Often those resources are renewable, increasing the sustainability of the system.
- **Reduced impact on and from the grid** is almost a consequence, but actual islanding is used only in emergency situations. The interaction with the grid can take several forms, but has to be somehow controlled: no output/input flows, constant output/input, controllable output/input...

1.1.2 Other terms used in this work

Microgrid layers As to avoid ambiguities, we use the terms *microgrid energy system* to refer to all the hardware and software implemented in the microgrid scope and the inter-connexion infrastructure (*technical layer*), including the heat and gas distribution networks if applicable. This corresponds to the technical definition given at the beginning of this section. In particular, the denomination *electric microgrid* is used to refer to the electric grid that is usually the backbone of the microgrid energy system (including wires, smart meters, actuators...).

The structure of the engagement of the stakeholders participating into the microgrid (role(s) of the different stakeholders and flow of products and capital among them) is called the *microgrid business case*[2] (*organisational layer*). This engagement is determined by the *microgrid market design* (*economical layer*), which is the structure of possible cash flow exchanges (maketable products, pricing mechanisms, intermediaries...).

Other grids We will use the word *grid* to designate the overlaying electricity grid the electric microgrid connects to and interacts with (can be a transmission or a distribution network according to the size of the microgrid). This can be structured as a *multi-microgrid*, an electrical grid which fits the definition of a microgrid (holistic approach, smartness...), but at larger scale, where every node is itself a microgrid. *Microgrid technologies* are all technologies that enable, directly or indirectly, the operation of the microgrid system (e.g. connected meters, communication protocols, controllable loads or plugs, decentralised sources...), including all *smart grid technologies*, which enable smart grids.

According to the IEA: "A *smart grid* is an electricity network system that uses digital technology to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Such grids are able to co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders in such a way that they can optimise asset utilisation and operation and, in

[2]During the project, a discussion arose on the definition of a *business model*, a term that was being used. We will not here detail the discussion, but for implementation purposes, the business model can be considered as a projection of the business case from the point of view of one of the stakeholders.

the process, minimise both costs and environmental impacts while maintaining system reliability, resilience and stability."[26]. We see that the *electric microgrid* is no more than a small smartgrid.

Scenarios for the future energy system The terms *microgrid based system* are used to design the large scale system that results from the bottom-up approach where every localised entity took in charge its energy supply and deployed a microgrid. This system is used a benchmark for this study, although a realistic scenario is what we call an *hybrid system*, which would have evolved from the current grid, thus where microgrids coexist with more global approaches to energy supply. The opposite scenario is that of a *centralised smart grid*, where loads and distributed generation are aggregated at large scale to reach capacities comparable with large centralised power plants, managed at a high governance level. We come back to these scenarios in section 4.1. In the next part, we specify the guidelines of our research.

1.1.3 Decomposing the research question

Structural problem solving approach As to objectify our approach, we take the point of view of a political decider. This is done using a Structural Problem Solving Approach, as to cover every relevant aspect. The overarching question is here, for a given context "Should microgrids be chosen as the solution for energy distribution?".

As shown on fig. 3, this ultimately breaks down to a number of aspects, of which we could only address a limited number in this project (in red). To ensure that the analysis developed can be used in a concrete situation, we will focus on the case study of Switzerland whenever a context has to be chosen to go further. Using this approach, we can determine the objectives of the project, presented in the next paragraph.

Objectives of the project Note that the goal of the project is not to provide an answer to the overarching question, but rather to provide as many tools as possible to answer it in a concrete situation. These tools can be used by all stakeholders, from microgrids implementors to high-level policy bodies. We try to give an example of application of these tools in the swiss context.

The first objective of the project will be to asses the impact of microgrid deployment on the local and global system. Positive impacts, or benefits, can be listed and categorised. Only if these benefits are sufficient should the microgrid solution be considered.

Negative impacts are part of the barriers. Other barriers arise from the interaction between the microgrid and the exterior, namely all relevant stakeholders, and from implementation complexity, with profitability and technical issues. Listing these barriers was the second objective of the work.

To do so, an appropriate mapping and characterisation of all stakeholders is also required. This allows to asses whether microgrids actually can be deployed. Indeed, only if enough stakeholders are willing to engage into a microgrid project will it become reality. Thus we also tried to identify

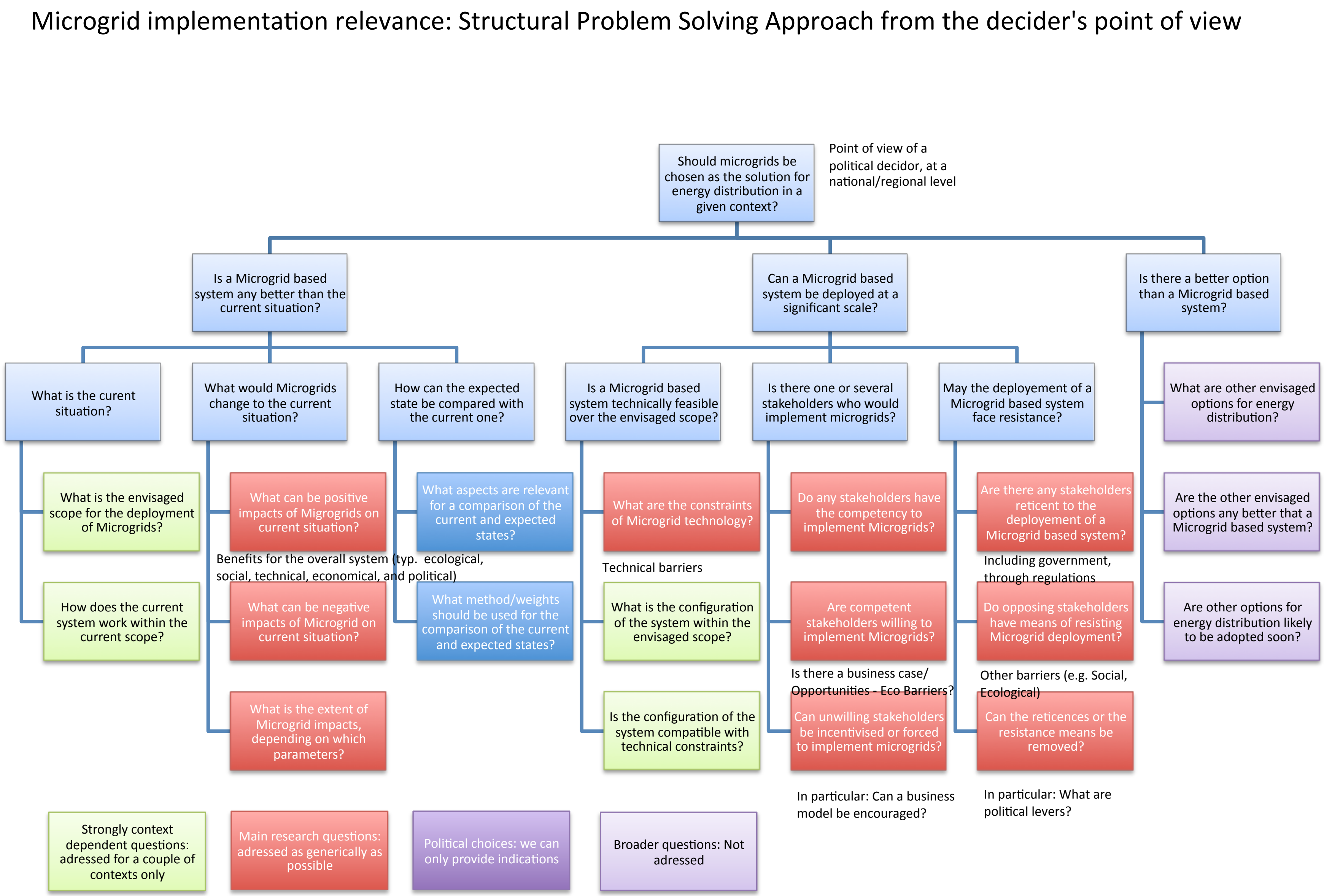


Figure 3: *Structural problem solving approach applied to determining the relevance of the microgrid concept for the energy transition. Each aspect outlined on a line is orthogonal to each of the others, in principle ensuring the consideration of any possible question. The graphical layout is also a starting point for discussion, allowing to take into account different perspectives.*

possible business cases, to see which stakeholders could be enablers of the microgrid.

Lastly, possible measures to favor the deployment of microgrids should be suggested, be it the leveraging of benefits to create incentives or the mitigation of barriers. The concrete case study of Switzerland was used to contextualise such measures.

Note that the technical and economical viability of microgrids is only marginally considered. Indeed, it is an aspect that involves only the technical layer of the microgrid. The fact that many microgrids already exist and are operated around the world (typically on islands, but also on campuses or hospitals) shows their feasibility. When deploying a microgrid, technical and economical barriers can be solved by finding trade-offs between required level of service and costs (e.g. trade-off between grid independence and cost of electricity). This is ultimately a political and social choice rather than an engineering issue.

1.2 A trans-disciplinary approach

In the previous section, we defined a quite broad scope for the study, but subsequently narrowed it down to a limited number of considerations. Adequate tools for its treatment are now introduced. Necessarily, given the multiple aspects of the microgrid concept, inputs from different fields had to be used, requiring the consultation of several laboratories and the consideration of a diverse literature, mentioned in the first part. Treating this material also required the application of mindsets from different origins, as described in the second part of this section.

1.2.1 Review

Collaborations The starting point of this project was a collaboration between the Energy Center (under the supervision of Dr. François Vuille) and the Management of Technology and Enterpreneurship (MTE) institute at EPFL (in the person of Mary Jean Bürer). A close contact was also established with the Distributed Electrical Systems Laboratory (DESL) for the consideration of technical aspects (namely Georgios Sarantakos and Lorenzo Reyes). The second phase of the project was conducted with the International Energy Agency (IEA), at the Renewable Energy Division (under the supervision of Simon Müller), adding the governance perspective.

Inputs from tenths of individuals with diverse backgrounds (economists, policymakers, engineers etc.) and from several countries have contributed to the reflexion presented in this report. Those are professors or post-graduates of EPFL, IEA officials and consultants, different stakeholders interviewed during the Micro-Delphi (see below) as well as panelists of presentations at EPFL and IEA with which a discussion was engaged. Most of these interactions were informal (apart from the interviews), thus their proper referencing and systematic presentation is difficult, but will be mentioned whenever relevant.

Literature Apart from these personal interactions, an extensive literature was consulted to determine the state of the art, ongoing research and development perspectives on the microgrids field. Around one hundred documents were consulted: reports from private and public institutions, scientific publications, chronicles and newspaper articles, many of them published during the period of the project. In this paragraph we try to give an insight into some of the more relevant ones.

The exact sourcing of every element mentioned in section 2 would have been fastidious as many points are evoked by several sources under different forms. Finding primary sources in the domain (considerations made for smart grids, distributed generation, grid decentralisation, local economy etc. are all relevant for microgrids) is often impossible. Only apparently original ideals are properly referenced, although with no guarantee that original sources were found. However, the content of the two last sections (3 and 4) results from the work conducted during the six months of the project (unless otherwise stated), thus are in principle original contributions of this report.

Meta-research First, some meta-research was done using common search engines: ScienceDirect [16] and Google trends [21]. This was to assess the scope of existing studies on microgrids and the popularity of the concept (smart grids were also studied for comparison). Another source was the Navigant Microgrid Deployment Tracker 2Q14 database [4] that gave us an overview of existing projects around the world.

The portal Science direct, by Elsevier [16], allows to search for books or articles in a wide range of journals in different fields, from engineering to social sciences. This diversity is important as it makes results, namely associated concepts, more relevant. A search was done for the terms "microgrid" and "smart grid" (with the quotes), in the title or abstract. Most biases, such as plurals, hyphenation and caps, are handled by the search engine.

Google Trends [21] in turn gives the number of searches for a given keyword, along time and with geographical dispersion. The results give an idea of the interest raised by a concept in the population, which can be related with the interest among the scientific community studied in the previous paragraph. We used the same keywords as in the previous part. This tool does not handle plurals and hyphenation that well, but manual trials with "microgrids", "smart grids", "smartgrid[s]" yielded relatively low values, with the same patterns than their counterparts.

Reports A first base for the reflexions were the reports published under the European Commissions project "More microgrids" [57, 60], which although a bit outdated (published in 2009) provide interesting business case suggestions and a complete assessment of microgrids profitability. Reports from the IEA also provided important contributions, and some work is ongoing to relate the results of this project with existing research on renewable sources integration [27, 28]. The How2guide for smart grids [26] is a tool for an actual implementation of smart grids aimed at high-level policymakers. Finally, the reports of the Realising Transition Pathways project [9, 24] provided valuable reflexions on the changing power utility structure structure and the need for a mutation more profound than simple technical adjustments[3].

Articles Beyond this background information, several articles have already studied microgrid value propositions beyond economic profit as well as barriers to deployment. A quantitative analysis of value propositions is found in [29], while other sources provide a framework for consideration of such values [11, 37, 64].

Technical literature was also taken into account as to determine the technologies that compose the microgrid and understand related limits [30, 69]. One particular study, the Danish Cell Controller Power Project draw our attention for the very complete implementation of a microgrid based system that was achieved over a large territory [17, 32, 33]. Finally a few articles were published that take a more open perspective than the techo-economical aspects, be it regulatory [36, 56], or, without specifically focusing on microgrids, discussing the socio-political impact of energy system decentralisation [2, 38, 39, 70][4].

1.2.2 Used frameworks

The informations sourced come from different mindsets and therefore have to be bundled into an unifying structure as to answer the questions presented in 1.1.3. This section presents the frameworks used and justifies their choice. To the best of our knowledge, they are either original or have not yet been applied in studies on microgrids. Their formalisation is therefore an important contribution of the present work.

The data used to create them, centralised in the database, is mostly not original[5]. The result of the application of these frameworks is not expected to be definitive and has evolved all along the project (consistency was ensured as much as possible, but some incoherences may remain). Their reuse is wished.

Database Most of the relevant elements collected during the review and micro-delphi were summarised in a database answering the main questions of the project: what are the value propositions, the stakeholders and the barriers to implementation of microgrids. Fig. 4 presents the structure of this database. For portability purposes, it was implemented as an Office Excel file. The state of the tables at the end of the project is given in the appendices, while section 2 points out the most relevant results.

The work on the frameworks below has been strongly based on the data gathered in this database. This underlying structure enables a systematic integration of any new element found in the literature. Drawing the synthetic diagrams presented hereafter based on this data allows to ensure their

[3]Stephen Hall gave a presentation at IEA when he introduced these documents.

[4]Chris Dunstan Gave a presentation at IEA when he introduced [38, 39].

[5]The exact formulation or distinction between some elements are our own choices.

completeness. As further explored in 2.2, this structure could be the starting point of a business case generator.

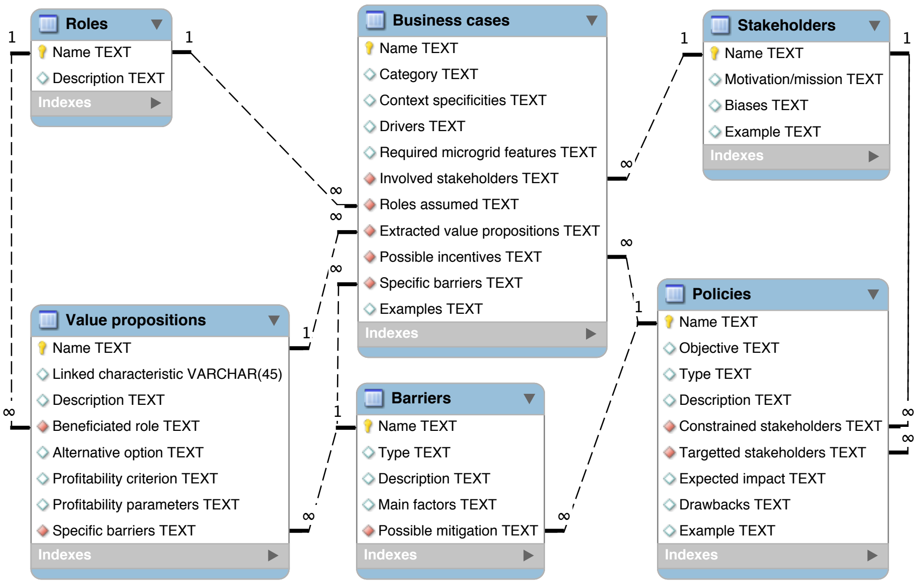


Figure 4: *Structure of the database used to bring together all the relevant information extracted from the literature. It presents in particular value propositions, barriers and stakeholders, which brought together form possible business cases. The cardinality of relationships is not formally respected in this representation, as some relationships are many-to-many.*

Flowchart This framework builds upon the systemic approach introduced by the proposed microgrid definition (fig. 2), dissociating the flows of energy (and more generally material resources), information and services between the microgrid and the other three main components it interacts with: the downstream user(s), the upstream grid and the environment (comprising natural environment, markets, society...). Cash flows are left aside in this representation, as they happen directly between stakeholders, without processing by the microgrid (although cost and profit allocation may be done by the control algorithm).

This representation allows to have a broad idea of where benefits are provided and what resources are needed. To complete the state-of-the-art overview, we also include microgrid technologies. This information is in principle enough to design a microgrid for any given situation.

Business case palette This representation is introduced as a way of formally distinguishing between the *roles* that have to be endorsed within a microgrid and the *stakeholders* who ultimately play those roles. This framework could be used for other technologies and may have been suggested in other contexts, but no reference was found to it. The distinction is not explicitly done in the literature that was covered, except for [20, p. 79] (in the

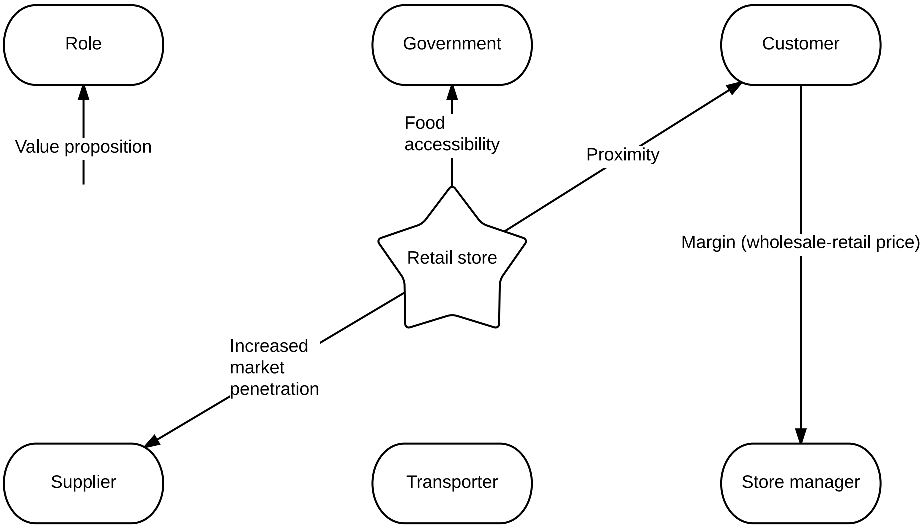


Figure 5: *Example of a business case palette for a retail store (simplified). We map the roles that have to be ensured for the store to work and the values added by the store.*

context of smart grid implementation). Instead, business cases are directly proposed, whereby stakeholders endorse one or several roles. Our contribution was to systematically make the distinction between stakeholders and roles.

The "palette" shows the roles that have to be endorsed for the microgrid to run and the values propositions that can be extracted by endorsing this roles, as is illustrated on Fig. 5. These can remind the elements of the value chain function (as formalised by Porter's Value chain framework [51]) associated with the supply chain elements, whereby every component is unbundled and can be attributed to a separate entity (unlike in Porter's representation, which originally provides a framework for the description of value creation within a single enterprise). Every role can be the object of a competition. Again, the outcome is subject to discussion and further work.

On this palette, we can then place the "color pools", that is the stakeholders, who will assume one or several roles, as is illustrated on Fig. 6. Using the stakeholders mapping presented below, we can associate the motivations of the stakeholders with value propositions of the microgrid as to determine what stakeholders are most likely to endorse some roles. To complete the business case, incentives must be provided to remaining stakeholders for them to participate in the microgrid and endorse remaining roles (share the added value). This enables the corresponding value propositions.

This framework is a generic support to the conception of business cases. It avoids to have to detail all possible options. In this project, we used it first to illustrate a couple of business cases found in the literature (2.2.3), which were then transposed to the case os Switzerland (4.2).

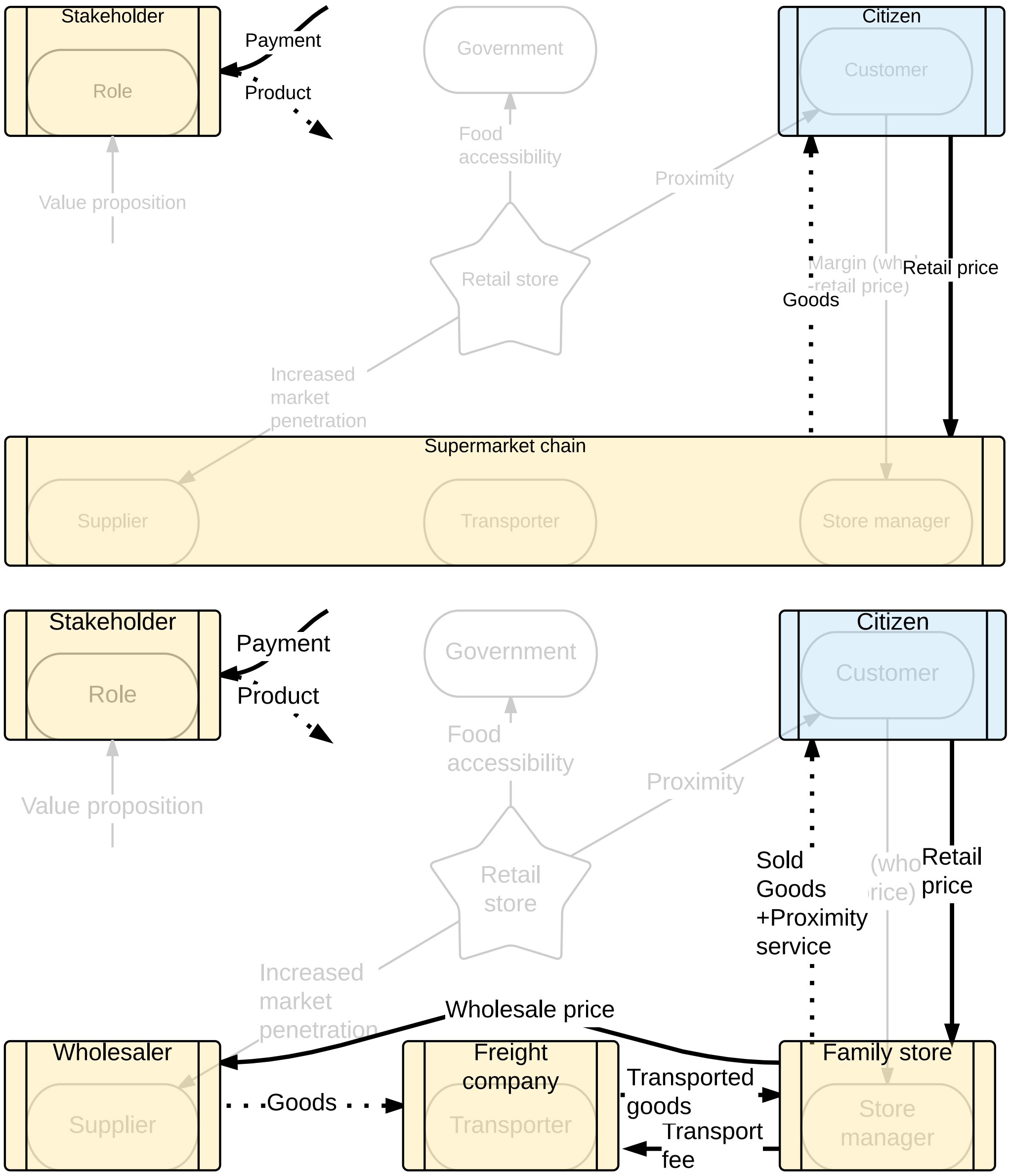


Figure 6: *From the retail store business case palette, two business cases can be illustrated. In the first one (top) a supermarket chain endorses all the roles, extracting the values through the payment of the customers, normal citizens. In the second one (bottom), the supply chain is completely unbundled, whereby a family enterprise managing the store has to pay a freight company in order to provide an incentive for this one to endorse the role of transporter. The wholesaler not only receives the payment but also benefits from the increased market penetration.*

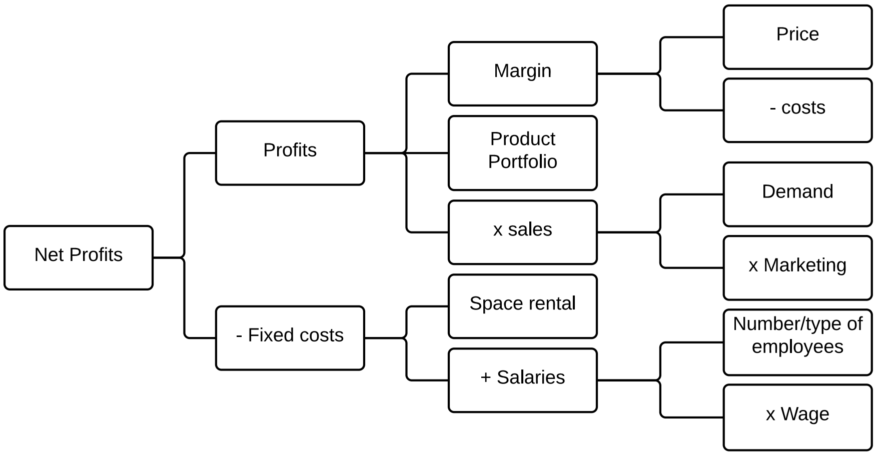


Figure 7: *Simplified example of a Return on Assets Tree for a small retail company. Applying the same type of systematic break down of value can allow to identify favorable contexts for microgrids.*

Value tree This framework is inspired by the Return on Assets Tree sometimes used to break down the sources of revenue and costs of an enterprise into measurable, actionable bricks[6]. A simple example is given on Fig. 7. In business, this allows to identify core components and activities of the revenues of a company as to focus on them. In our case, it relates the main features of microgrids with their value propositions (not necessarily monetisable), further connected with different parameters that define the microgrid.

The value tree will allow us to underline the elements that are most crucial for the microgrid to be beneficial. It also shows external elements that may influence these benefits. In this project, we choose to point out elements that are particularly unpredictable, and we broke down any technical parameter into quantifiable costs.

Even under the relatively simple form used, this value tree should allow to identify in what contexts a microgrid may be profitable. It also shows, for an existing microgrid, how the benefits can be increased. As it is a evolving output, it also allows for the further consideration of other aspects through discussion. A more precise characterisation of the relationship between the elements (usually simple additions or multiplications, but more complex functions can also apply) would allow to create a full model computing the extractable value based on a given microgrid setup.

Stakeholders mapping This framework is inspired from the “intelligibility diagram”[7], based on a tool used in social sciences to map stakeholders according to their position concerning a given social object [66]. We added

[6]Deloitte, in particular, has been using this framework for its consulting activities.

[7]Boris Beaude introduces this tool for his teaching *Internet, enjeux sociaux, enjeux mondiaux*

a typology to distinguish public and private stakeholders as well as incumbents and entrants. The motivations of the stakeholders are separated as rather being a driver for implementing a microgrid or rather a deterrent. Ultimately, it allows to see which stakeholders would be more likely to engage first in a microgrid deployment, and what would be the drivers for this deployment. Matching those drivers with the value propositions in the business case palette allows to determine which roles these stakeholders are most likely to take in the implemented business case, thus deduce which roles will still be vacant. The mapping also provides an insight into possible conflicts and synergies between stakeholders. This allows to understand possible barriers to the spread of the concept, while showing possible levers to mitigate this barriers or incentive stakeholders.

1.3 A pragmatic approach – Micro-Delphi

To complete the literature review, we approached a number of stakeholders, focusing on the Swiss case. Indeed, as we will present latter, microgrids have been found not only to be potentially profitable, but also to face no significant regulatory barriers in Switzerland. This makes the fact that almost no microgrid exists in Switzerland curious. We tried to adopt the micro-Delphi format, as developed by Rossel[8] and Finger [53].

1.3.1 Methodology

Experiment design The experiment was designed to test tree overarching hypothesis:

Beyond technical constraints, microgrids mainly face the lack of participation from the stakeholders, be it because:

- *They lack information about or neglect the "energy management" aspect, beyond simple energy production and consumption (co-generation, energy distribution...).*
- *They are reticent given the technical or contractual complexity of a microgrid implementation, or do not have time to study it.*
- *They have no profit in it, given the uncertainty on the investments required, on the benefits and on the actual profit sharing among participants, due to the lack of a standardised solution.*

The micro-Delphi is a method derived from the Delphi protocol. The Delphi itself is a future studies tool that aims at assessing the possible evolution of a given technology through a two or three round consultation of a few hundred experts, which in principle allow to converge to a couple of scenarios considered plausible by all stakeholders. The micro-Delphi targets a more restricted number of interviewees with fewer questions, but the answers are pushed deeper as to understand the actual position and reasoning of the

[8]Pierre Rossel's advice was seek for the elaboration of the questionnaire.

stakeholders. The outcome is in principle also a better understanding of the technology's future and possible scenarios.

The interview protocol is based on the review, and comprises possible answer elements. These elements are used to orient the discussion during the interviews, designed to be face-to-face. This format allows to bring up ideas that the interviewees might not have thought of at first while also making the cross-comparison of the answers easier. The drawback is the introduction of a possible bias as interviewees might be tempted to acknowledge one element while it was never really considered. This bias should be taken into account when processing the answers.

Roll-out The interviews are recorded, with the approval of the respondent, whose anonymity is explicitly guaranteed, together with the anonymity of the institution they belong to. Based on these recordings, two main outputs can be produced.

The first is one table of all answer elements and corresponding adhesion from the stakeholders (evident, spontaneously mentioned, approved when suggested, minimised when suggested, denied when suggested and not discussed). This table allows for a quick identification of diverging or converging opinions and of controversial elements.

The second table is a less rigid summary of the answers to each question, structured around the points made by the interviewee. Any relevant comment made by the stakeholder is here taken into account (sometimes comments done within the answer to a question were relocated into another question for consistency). This allows for a more qualitative identification of converging and diverging points, and the integration of new elements.

From this processing we obtain an intermediate summary, given in the appendix. This can be in principle be further reduced to give a personalised feed-back to every respondent, as to collect a new round of opinions. This was unfortunately not possible for this project due to the fact that the last month of work coincided with holidays for most respondents.

1.3.2 Interview protocol

The full interview protocol is given in the appendix. We recall here only its structure and the purpose of each part.

- *Future of the energy system*: The first part serves two purposes. It allows the respondent to speak about familiar issues, thus helping the discussion to be free-flowing, and it gives an idea of how issues addressed by the microgrid concept are actually acknowledged (which can then be related with the value propositions asked later). However, as the stakeholders were aware of the scope of the project (that had to be disclosed for credibility), the answers here may have been biased towards challenges linked with microgrids.

- *Microgrid concept*: We here ensure that the interviewee is aware of the technical concept and collect different definitions, as well as a couple of examples. The acceptability of our proposed definition was implicitly tested.

- *Microgrid value propositions*: This part is based on our own value proposition database. The objective is to see whether identified value propositions are acknowledged or denied and which ones would be more actionable.

- *Microgrid stakeholders and business models*: Besides collecting ideas for possible business cases, this section implicitly assesses the willingness of the stakeholders to appropriate the microgrid concept, under which conditions, and evaluates possible barriers in terms of communication, contracting or perception divergences. Ultimately, it should allow to understand whether the spread of microgrids is possible in the considered scope.

- *The role of the end user*: Is the object of a dedicated section. Indeed, citizen movements have had significant impacts on the energy landscape (namely the closure of nuclear plants), while changes in behaviour do not seem to be a priority for them. Therefore we want to evaluate what degree of engagement is expected and how it could be triggered.

- *Microgrid barriers and alternatives*: This part completes the barrier list already established. Expectedly, new elements should be added and identified elements may be concretely specified according to the context. Also, solutions may be mentioned, which gives an idea on their acceptability.

- *The role of public institutions*: Other action levers can be explicitly suggested here. This part explores what is the expected degree of involvement of governments, underlining possible divergences in the definition of the public service itself.

- *Microgrids future*: This part tracks elements typically considered in future studies: perceived trends, weak signals and possible "black swans". The perspectives for microgrids can be explicitly assessed and compared with the implicit potential mentioned in the previous answers (further indicating whether barriers can arise from mis-perception of unwillingness to involve).

1.3.3 Scope and sampling

Given the structure of the interview and the limited amount of time and resources, only a restricted number of interviewees is realistic. However, the answers should give an insight into the positioning of all relevant stakeholders. The scope is restricted to the Swiss case, although the protocol can in principle be applied to a broader sampling. Clearly, with such a limited number of interviewees the answers cannot be expected to be statistically representative. However, as we address qualified respondents, some reflexivity can be expected, thus the representativity of their position on important points can be explicitly assessed. More specific or personal comments can be used either in parallel with other sources to estimate their representativity or taken as a measure of the variety of opinions.

We did 9 interviews:

- 3 academics, as experts: one electrical engineer, post-graduate, working on microgrids; one professor of economy and business development, currently working on the elaboration of business models for microgrids; and one professor in business administration with a strong personal interest in energy issues. These interviewees are expected to have an out-of-the-box view that may be completely different from the one of the "*ground stakeholders*".

- 2 DSO senior executives: one DSO operates a city grid, the other runs several grids in different setups, rural or urban. Both DSOs accommodate self-consumption, purchasing surplus production from customers, and own relatively decentralised generation facilities (MW range).

- 1 TSO senior executive: The company operates a dense and reliable national grid.

- 1 policymaker: from an legislative body, left winged and with a focus on energy within his party.

- 1 senior executive of a manufacturing company: the company is a multinational hardware provider and we interviewed the head of a division in charge of microgrids.

- 1 manager of a pension fund: pension funds manage a large housing stock and their engagement is therefore required if neighbourhoods are to be transformed as to allow the deployment of a microgrid. The interviewee also has a background in energy in buildings and energy governance. This interview was done later, thus it was not possible to integrate its results into the "intermediate summary", but some elements are presented in the results and used for the discussion.

The interviewees were reached through existing contacts of the CEN.

2 Review outcomes – a promissory concept

This section summarises the results of the literature review. The first part presents a meta-analysis on data from search engines and from a microgrid database. This shows trends on the use of the term microgrid and on the actual implementation of microgrids, together with associated study fields. Later a brief overview of microgrid categories is given, and finally all proposed microgrid characteristics are integrated into our flowchart. The second part goes into the detail of identified value propositions and suggested business cases. Instead of presenting all the relevant sources and comparing different contributions that have been done, we try to give an insight into the overall picture, by displaying all collected elements into a the business case palette. Finally, we come back to the geographical scope of this study by briefly presenting the Swiss energy system.

2.1 "Microgrid" in the literature

The first step of the work was to determine the state-of-the art in the field of microgrids worldwide. This declines to a couple of questions: Since when and where are microgrids studied? What are the most explored aspects of the concept? How do microgrids work? Answering those questions will also help to focus further efforts on less explored aspects of the concept.

The answer to the first question is better presented with a meta-analysis of the literature and microgrid data, showing trends in the use and implementation of the context, in time and space. It also allows to identify some fields microgrids are associated with. We then found out that often microgrids are categorised according to some of their characteristics, and chose to show these categories. Lastly, we used our microgrid flowchart to summarise the operation of a microgrid: input and output flows and elements used to process these flows.

2.1.1 Metainformation

This section presents the metadata on research results with the word "microgrid" in Science direct (using the research filters) and Google trends. For comparison purposes, we also give the results for the words "smart grid", that is assumed to be a more widespread concept, more technologically, ecologically and economically neutral. The Navigant Research database of microgrid projects around the world is also used as metadata source.

This metadata is an objective way of presenting the current trends in the field of microgrids, instead of citing selected articles. It allows to identify what aspects of microgrids are already studied, where the concepts attracts most interest or has been implemented and whether the trend is one of growth or decline. This allows to see what questions we want to address might have already been answered, and which ones deserve further attention.

Science Direct The research was done as presented in 1.2.1, for "microgrid" and "smart grid". This yielded 614[9]., resp. 913 results (as of the 8$^{\text{th}}$ of July 2015). Fig. 8 gives the date of the articles found and associated topics.

Interestingly, the first article yielded by this research [36] is on economic and policy issues, exploring regulatory barriers to the concept of local electricity supply rather than the technical object. Associated topics are "business

[9] An unavoidable bias is that the term microgrid designs as well an element in electronic microscopy. The first use of the term microgrid as a power system element is in [36], from 2002, and from then on the results treating of electronic microscopy are a negligible number.

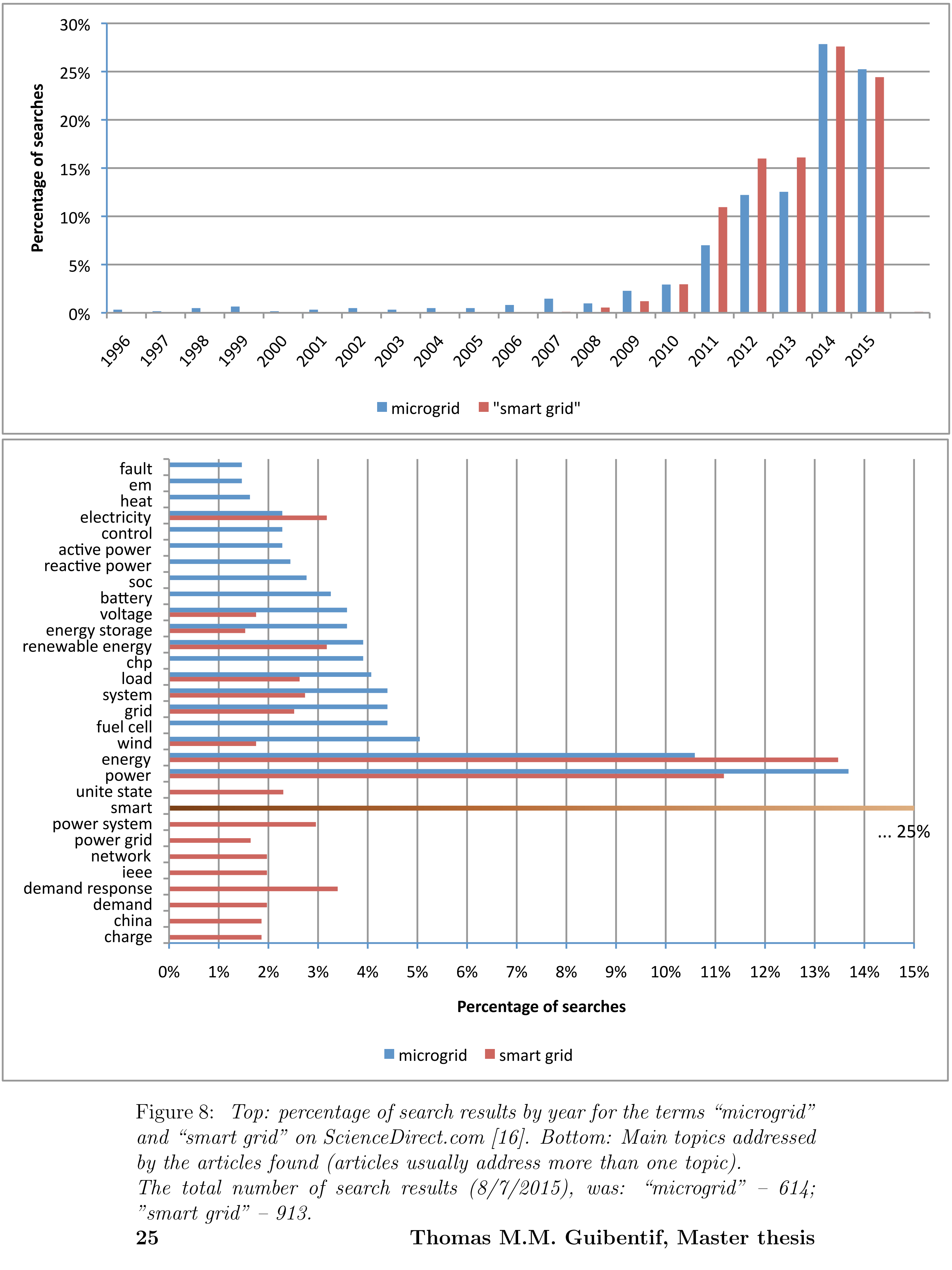


Figure 8: *Top: percentage of search results by year for the terms "microgrid" and "smart grid" on ScienceDirect.com [16]. Bottom: Main topics addressed by the articles found (articles usually address more than one topic). The total number of search results (8/7/2015), was: "microgrid" – 614; "smart grid" – 913.*

model”, “distribute generation”[sic], “minnesota” and “regulatory environment”. The meta-analysis shows that, later on, those aspects were much less addressed, while the focus shifts to topics related with micro-generation (chp, soc, battery, fuel cell, wind), power system control (fault, control, active power, reactive power, voltage) and energy management (em, heat, chp). Smart grids instead show more association with large scale systems (network, power grid, power system, china, unite state [sic]) and demand side management (demand response, demand, charge).

It appears that both concepts have been attracting a comparable attention at the same pace among the scientific community, although smart grids only start to be studied in 2008, 6 years later than microgrids. Interestingly, the two themes do not overlap significantly, with only 10 topics out of 30 in common of which 7 are trivially related with the electricity system (energy, power, renewable energy, electricity, system, grid, load).

In practice, this suggests that supporting research on the field of microgrids will foster innovation for microsources and small scale control/management strategies while research on smart grids is more likely to provide solutions to large scale system control and demand response. Both fields are likely to provide solutions for the integration of renewable energies.

Most relevant for this project, the results show that economical, social and policy aspects of microgrids do deserve further research. On the technical side, progresses are expected to be fast as research is very dynamic. A missing element is the geographical scope of the research on microgrids, when any, and the actual use of the results on the field. These elements can be provided by Google trends.

Google trends In a next step, we use the tool Google Trends [21], using the same keywords as in the previous part: “microgrid” and “smart grid”.

The results show much more searches on smart grids than on microgrids, although the interest for smart grids seems to be declining while microgrids apparently attract more and more attention. This contrasts with the situation in the scientific world, and is most probably linked with an asymmetric representation in the media and the political agenda. Also, it is possible that the simple installation of “smart devices”, that is generalising, makes the “smartgrid” palpable, while the deployment of microgrids is not yet envisaged as a practicable solution in most countries.

This is relevant for the project, as some suggested microgrid benefits require the involvement of several stakeholders, besides utilities. If those non specialised stakeholders are not aware and not interested by the concept, as it seems to be the case according to the results, they will not be able to take the initiative and may be reticent to adhere to this new concept. Such a lack of willingness to involve and awareness could become a barrier to the effective deployment of microgrids. Thus, if they are to be deployed, the research that is being done on the field should be more communicated to the wider public and be introduced in the political agenda.

The relationship between proximity and interest can be tested by comparing the geographical dispersion of the searches with the places where mi-

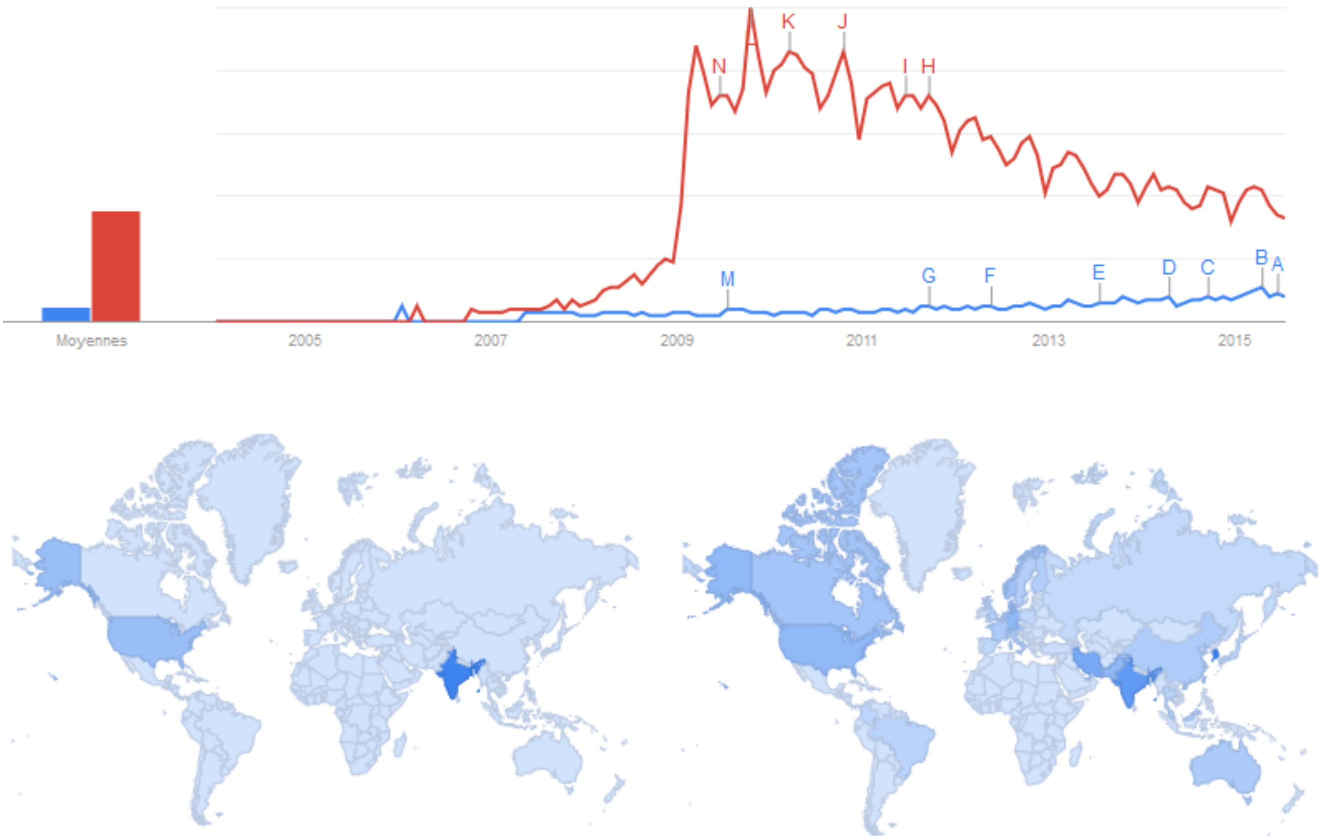


Figure 9: *Relative proportion of searches for "microgrid" (left) and "smart grid" (right) on Google [21] (the tool does not provide absolute values, the maximum value is always taken as 100%). Top: evolution in the past years, bottom: geographical dispersion. Results as of 8/7/2015.*

crogrids have actually been deployed. As for the geographical dispersion of searches, microgrids are nowadays a topic mainly in the US and India, while smart grids attract some attention in several more countries, with South Corea being the country with the more searches. India, together with Iran and Pakistan also show relatively high number of searches for the term "smart grid", as well as North America and Europe. We relate the results with the actual deployment of microgrids in the next paragraph.

NR Microgrid Deployment Tracker Navigant Research Inc.,has been been following the expansion of the microgrids market since 2009 with its Microgrid Deployment Tracker [4]. They have witnessed a very fast expansion of operated and planned microgrid capacity, with an increase from 4393MW to 12031MW between the second quarters of 2014 and of 2015 alone [6][10]. The database is not expected to be exhaustive, and Navigant Research explicitly

[10]The capacity identified in 2013 was 4148MW, making the evolution from 2013 to 2014 less impressive.

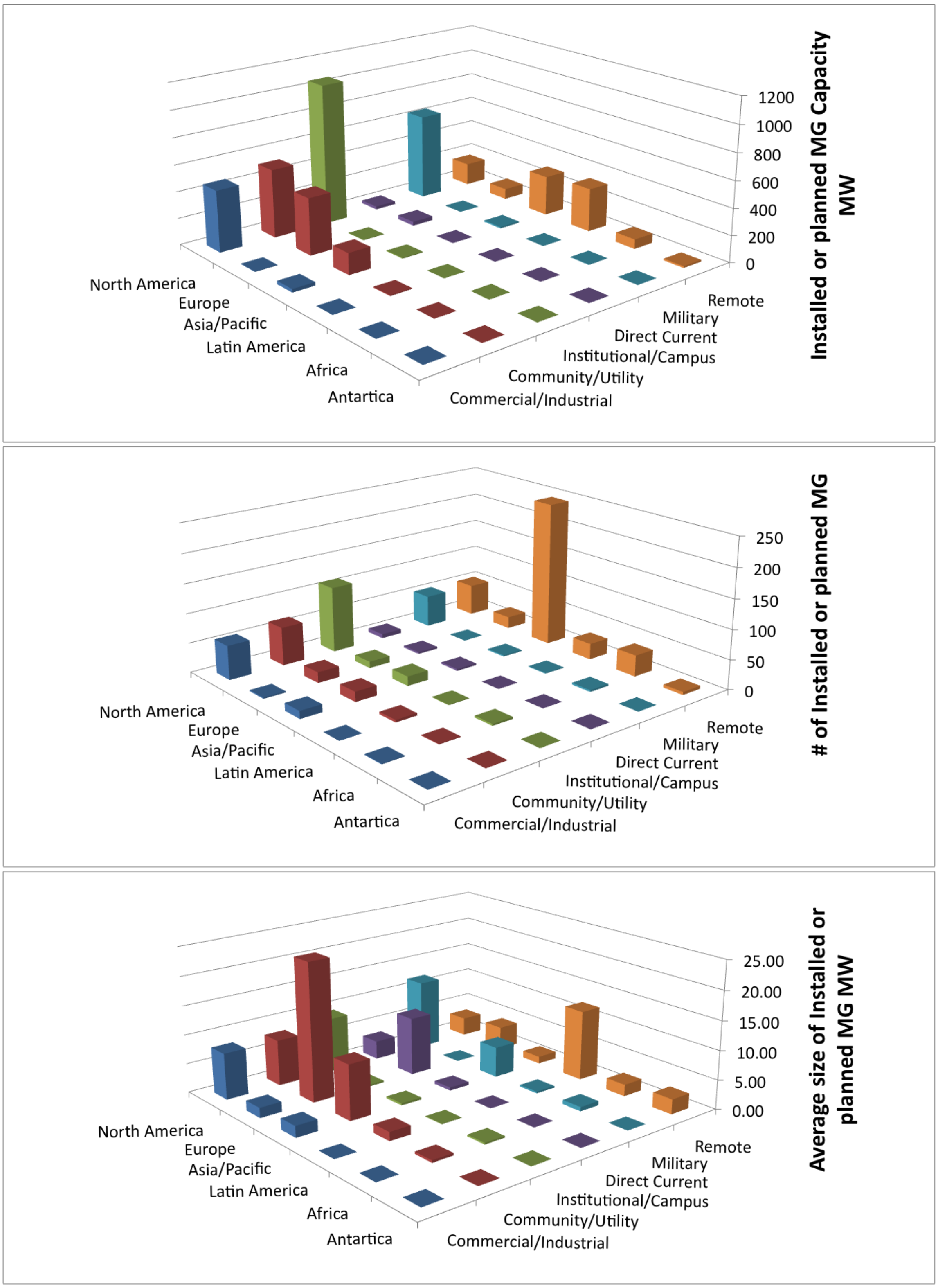


Figure 10: *Installed and planned microgrids around the world, according to the 2Q14 Microgrid Deployment Tracker of Navigant Reasearch [4]. A separation along 6 broad microgrid categories is done. Installed/planned capacity (top) and number of projects (middle) are displayed. Dividing one by the other gives the average size on deployed microgrids (bottom). Total capacity is 4393MW over 712 projects, yielding a 6.2MW/project average capacity.*

mentions that the results may be biased by their own focus. For instance there was a focus on remote microgrids for the 2014 edition. In the presented figures, we only took into account projects with a rated capacity.

Fig. 10 aggregates the data from the 2014 version of the Tracker database, giving the number and capacity of microgrids according to their geographical position and market segment. The segmentation is made by Navigant Research in 6 categories: Commercial/Industrial, Community/Utility, Institutional/Campus, DC, Military and Remote. Apart from a few exception, only systems that integrate some renewable generation are taken into account.

The results show most of the capacity being deployed in North America, mainly institutional and military microgrids but also community and commercial microgrids. Those are mostly small scale projects (less than 10MW[11]). This predominance of North America is drove back by Navigant to the "declining reliability of its distribution grid". The other leading segment is the remote microgrid in Asia/Pacific, for rural electrification, a closer insight yielding that most of these projects are installed in India (the new 2015 edition [6] mentions a strong growth in China, both for remote and grid-tied projects).

The results on the geographical dispersion of microgrids (in terms of number of projects) do correlate with the results of searches dispersion on Google Trends, suggesting that people search for technologies that they are close to. In Europe, a couple of large projects are being deployed, but have drawn little attention and had little visibility in the media.

This analysis already allows to point out two microgrid drivers: power reliability and remote electrification. However, overall, microgrids exist in a variety of sizes and purposes, with no clear microgrid benchmark. In the next section, we detail a couple of microgrid categories that have been studied in the literature, as to give a better understanding of this diversity.

2.1.2 Microgrid categories

This section presents some categories of microgrids proposed in the literature, relying mainly on technical considerations. This not only facilitates a better understanding of what can be a microgrid, but also shows some drivers and archetypes for their implementation that have already been studied. We have picked some references that in a way or another try to categorise microgrids and provide a reflexion on the concept (rather than on specific technologies or values).

Technical categories In chronological order, the first article featuring microgrids [36] proposes that a microgrid would be an infrastructure "serv[ing] about 20 customers in a new commercial and industrial park", using combined heat and power generators, generating revenues from the increased

[11] How small this is can be understood comparing with the typical capacity of an onshore wind turbine: around 2MW.

efficiency of this technology. The generation would be determined by heating, resp. cooling needs, selling and buying electricity from the local utility whenever needed (thus assuming an under-utility scale). Benefits could also arise from increased power quality and reliability, namely for high-tech firms. Such a microgrid could be either run by a for-profit firm or a customer co-op.

This could be considered as the benchmark microgrid. In a review of microgrid projects around the world [25], Hossain *et all.* call it a "facility microgrid", and suggest that renewable sources are integrated in such grids. Those microgrids are mainly complement systems to ensure energy supply to critical facilities (North America is mentioned as the host of this kind of microgrids). The same article then uses the terminology "utility microgrid" for a larger scale microgrid, grid tied, built to support the power system (improve overall reliability and resiliency), found in Japan, Europe or China. Finally, the "remote microgrid" provides electricity to a more or less large area, featuring no connexion to a larger grid, typically an island or distant zones in developing countries.

The same categorisation is done by the Berkeley lab [18], under the names "customer or true microgrid", "utility or community microgrids or milligrids" and "remote power systems". They add a fourth category, of "virtual microgrids", covering several distributed resources in distant places, coordinated as to be presented as a single entity to the grid.

The categorisation can be further broadened with the segments proposed by Navigant Research [4], based on the users of the microgrid. This splits the first category into "Commercial/industrial", "Institutional/campus" and "Military" microgrids. "Community/utility microgrids" are retained, as well as "Remote systems". A purely technical distinction is done for "Direct Current systems", a special type of microgrid, used for very specific applications as they require a non standard adaptation of all connected devices (data centers are a typical example).

Economic categorisation These distinctions are mainly technical ones, or based on the purpose of the microgrid. The European More microgrids project [60] further explores the economic aspects of the microgrids and categorises corresponding business cases. It distinguishes the "DSO monopoly model", which can apply to a utility microgrid, the "prosumer consortium model", applying to a customer microgrid and "free market microgrid model", a category that recoups the two preceding ones, where the microgrid is seen as an economic tool to enable new, local markets. Note that these economic distinctions do not take into account technical specificities, nor the purpose of the system. We come back to these business cases in 2.2.3.

Finally, a discussion of the governance structures of energy systems was done in the Realising Transition Pathways project [24]. Microgrids are not explicitly mentioned, as the discussion is purely political and does not treat technical aspects. Many "archetypes" are proposed, some of them being relevant for microgrids: the "local aggregator archetype", corresponding to a customer microgrid run by a third party, and the "municipal utility archetype". Other archetypes are not detailed here as they do not refer directly to microgrids.

Retained categories Other papers more or less implicitly evoke categories of microgrids that can be drawn back to one of the above. For clarification purposes, in what follows we will consistently use the following typology:

- *True microgrid* is a small scale energy system managed by a single entity who benefits from the services provided, be it an enterprise, a private, a public institution or a consortium of those. They can serve a variety of purposes (cost savings, power reliability, sustainability image...). We include *remote microgrids* in this category, those having the particularity of not being grid connected.

- *Utility microgrid* is grid connected and managed by an overlaying entity, while typically inserted into a multi-microgrid managed by that same entity. Its aim is usually to make the operation of the system easier (improve stability, integrate renewable sources...). Such a setup may enable local electricity markets. It will typically be larger than a *true microgrid*.

- *Virtual microgrid* is a true microgrid from the ownership point of view, but has physically distant components (i.e. energy has to flow through the conventional grid to connect those elements). This disables part of the technical benefits of the microgrid, but may be required if not enough resources are available locally. The management paradigm of multiple virtual microgrids is equivalent to a larger scale aggregation, which would rather be called a *virtual power plant*.

- *Franchise microgrid* is a true microgrid from the technical point of view, but designed and operated by a third party who captures the benefits drawn from the microgrid operation (which is ensured by a decentralised "franchise", unlike in the utility microgrid case). This category is inspired by the "local aggregator" archetype but has not been explicitly found in the literature on microgrids.

Section 4.1.1 builds upon these categories, providing a framework to map them and making explicit the continuum between the different categories. In what follows, we come back to the general concept of microgrid to present the features and technologies that are being studied.

2.1.3 The microgrid flowchart

Regardless of their category, microgrids share some characteristics derived from their technical concept (set of decentralised devices, managed together). These features may or may not be enabled according to the technical completeness of the microgrid, the regulatory framework and the economic conditions. Almost all studies done on microgrids summarise some of them, more or less formally, so that a precise sourcing of every element is difficult. To present these features, we use the microgrid flowchart, as presented in 1.2.2.

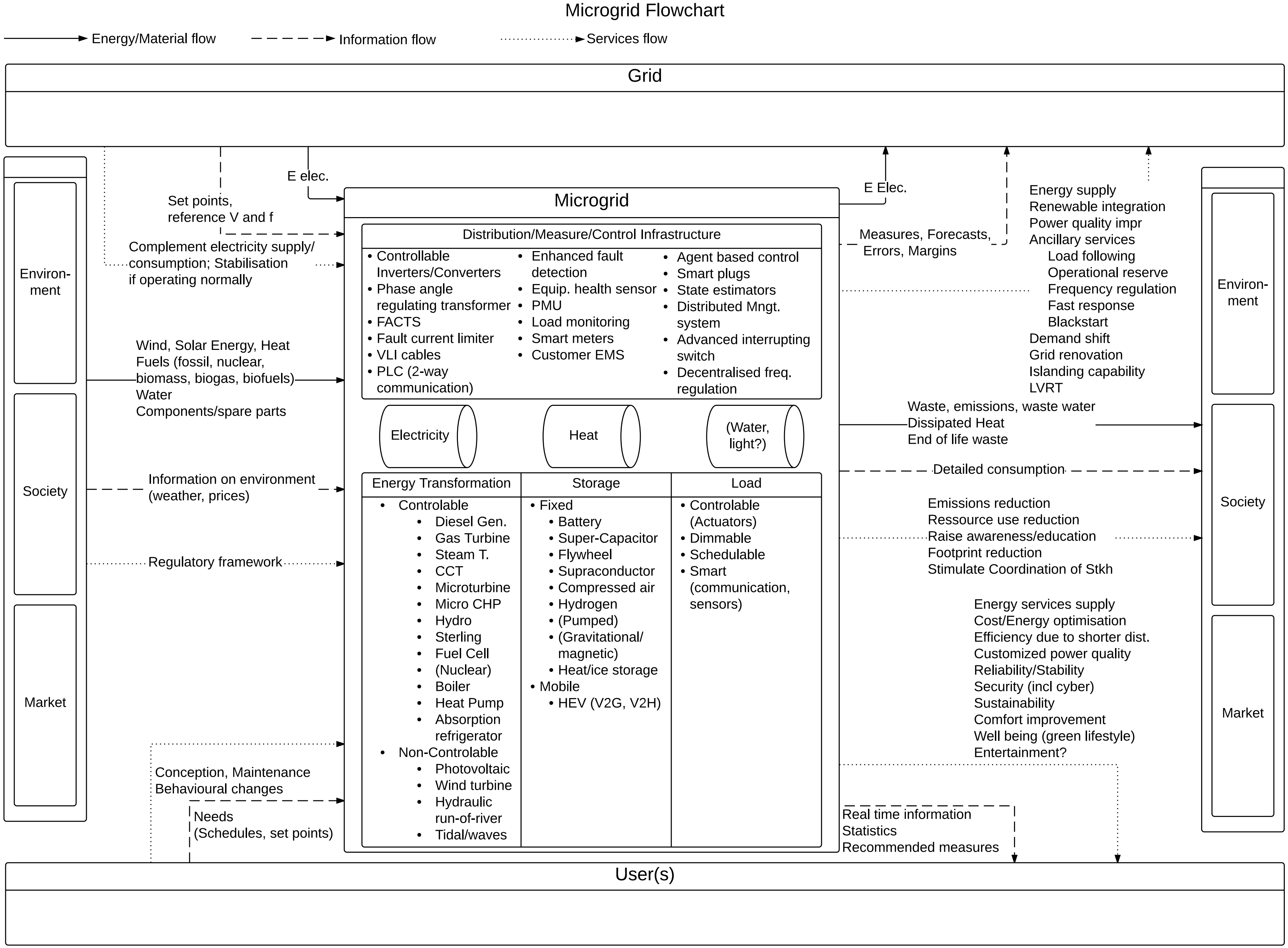


Figure 11: *Microgrid flowchart, featuring energy (and materials), information and service flows between the microgrid object and surrounding components. Many sources have contributed to this result, so we do not try to detail them all. However, [11] contributed significantly for the listing of control technologies, and [26] or [57], among others, list smart grid, resp. microgrid benefits (outward service flows).*

Fig. 11 presents the state of this flowchart at the end on the project.The necessary trade-off between readability and completeness led to the aggregation of some elements. This representation can be read under different angles, presented hereafter.

Microgrid as energy processing tool From the purely physical point of view, the flowchart shows the microgrid as an energy processing tool, getting energy inputs and transforming them to provide services, the energy itself being ultimately dissipated as heat. Note that we included other "fluids" than electricity into the microgrid: hot liquids can also be used to transport energy, as well as gas, or even water (either through gravitation or heat). A fully integrated microgrid would manage all these flows as to optimise the overall operation of the system.

From the user(s) point of view, the microgrid is an infrastructure that has to be designed, implemented and maintained as to provide energy services to the community. According to the features of the microgrid, services beyond those linked to the energy supply can be provided, namely those derived from data management (e.g. controllability and efficiency improvement).

Furthermore, from the utility point of view, the microgrid is a single node, easier to handle than a disaggregated set of loads and sources, which can provide services to the grid, namely predictability and ancillary services, while consuming or producing energy according to the needs or technical constraints of the system.

Microgrid technologies Lastly, from the engineering point of view, the microgrid is a set of technologies working together to conciliate all the previous points of view and needs. Without going into the details of the technologies, some elements can be more precisely sourced.

First, the inclusion of nuclear into the energy sources may be surprising. However, research on small portable nuclear reactors is going on, and several start-ups proposed reactor designs suitable for a MW scale generation [31][12]. The viability of such solutions is disputed [52]. Less controversial, but not yet harnessed neither, are technologies based on tidal and wave energy [40].

Storage technologies face large, although decreasing, costs and environmental concerns. However, it has been suggested that the spread of electric cars may be an enabler for microgrids as it makes decentralised storage resources available. Increasing the use of the batteries to provide services to the grid would increase their profitability [35].

From the informatics point of view, smart loads an new kinds of actuators and meters are being developed by enterprises working on network management or house automation. This is enabling research on new control algorithms and state estimators, relying on the increasing amount of data collected [30]. The speed of these algorithms is of crucial importance, as to comply with the power electronic requirements, but is hindered by the

[12]However, no primary sources were found on these technologies and for instance the website of Upower, one reportedly promissory start-up, does not display any information.

complexity of the system. New, decentralised, control strategies have been proposed, relying on the local regulation of frequency, but are still at theoretical stage [55].

The review has shown the variety of solutions for implementing a microgrid. The technical challenges posed have been solved for a variety of contexts and multiple examples of operating microgrids exist. Research is still very active to improve reliability, speed, efficiency, inter-interoperability... The microgrid flowchart allows to integrate new element in a structured way and can help to the technical conception of a microgrid.

Another research focus is now attracting more and more interest: the financing of such a microgrid and the extraction of the values it proposes, together with the governing structure of the microgrid. These are the aspects where this work brings the main contributions. In the next section, we review existing studies on those topics and integrate their findings into our own frameworks.

2.2 Creating a business case palette

This section presents the research that has been done on microgrid business cases. As defined in 1.1.2, a business case is the structure of the engagement of the different stakeholders and the flows of value (products, cash) among them. For it to be viable, all stakeholders within this structure should be able to extract some of the total value added by the microgrid. Also, most of the roles should be assumed by at least one stakeholder, or some features of the microgrid will not be enabled.

We first integrate proposed roles and values propositions of a microgrid into a "business case palette" which allows to represent a wide range of business cases, as presented in 1.2.2. The actual profitability of microgrids is then assessed, based on the literature. Lastly we present a couple of business cases found in the literature, illustrating them with our framework.

2.2.1 The microgrid roles: unbundling value propositions

Microgrid business case palette implementation The first step towards the understanding of possible business cases is the identification of all value propositions of the microgrid. Those values can be mapped as inherent to certain roles within or around the microgrid, as explained in 1.2.2.

The inventory of value propositions (found e.g. in [26, 57]) and associated roles is stored in the database (see appendix), and presented on fig. 12 using the business case palette framework.

For readability purposes, we took the same overall structure than the microgrid flowchart. It appeared that the different roles can be categorised into internal roles, roles endorsed by entities downstream and upstream of the microgrid and roles to be played by other entities. We also separated value propositions associated with internal, resp. external roles, by introducing the "thermoelectric microgrid" at the core of the microgrid, as the object actually

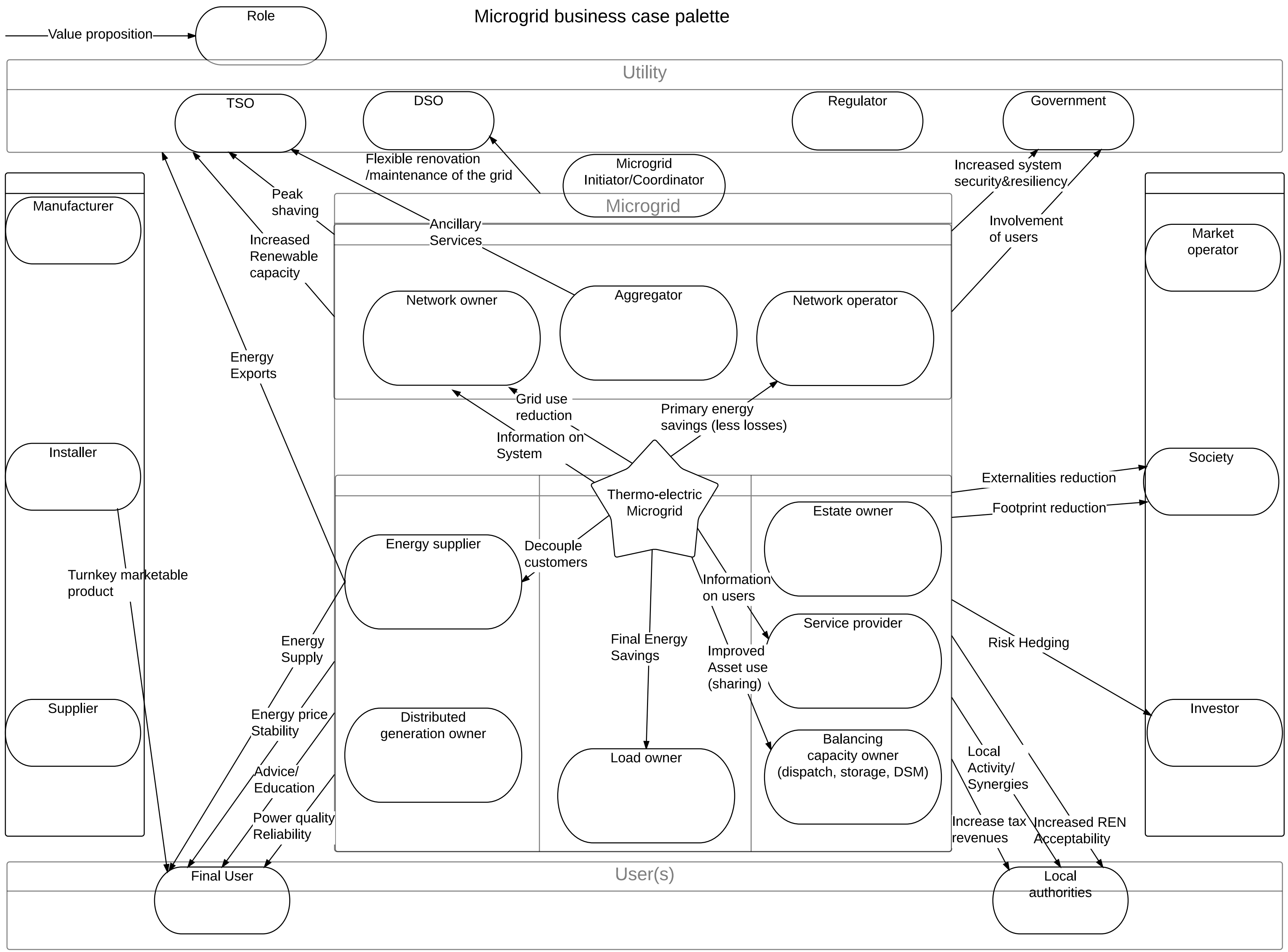


Figure 12: *Microgrid business case palette. It maps the roles that have to be endorsed by a stakeholder for a microgid to run and the associated value propositions. The exact sourcing of every element is difficult, although [26, 23, 11] are important references. For a description of the elements named, refer to Tab. 3 and 4 in the appendix.*

producing value. Not all roles are indispensable, so that value propositions may not be enabled according to the microgrid configuration.

Interpretation Some stakeholders endorsing only one role may have no interest in the microgrid. For instance distributed generation owners have no direct interest in deploying a microgrid, as they can as well sell the energy into the grid, either through wholesale price or at feed-in tariffs. For a business case to be viable, it will therefore have to provide an incentive (or a legal obligation) for the distributed generation owners to connect to the microgrid. Another solution for a stakeholder wanting to enable the microgrid would be to bundle this role with another, profitable one.

Furthermore, very few added values can actually be traded (between two roles), as is the case of ancillary services or the microgrid itself (as a turnkey product). Indeed, most added values are inherent to the increase in operational efficiency (both energy and economic efficiency). This is important, as it means that new entrants will likely face very large barriers to enter.

In the electricity distribution industry, these barriers are particularly high. Create a brand new infrastructure providing the same services at a better price than the existing utility is not a practicable business model (for both cost and regulatory reasons) – the electricity distribution is a natural monopoly. On the contrary, incumbents, who already ensure network operation, energy supply etc, would benefit from cost reductions or profit increases if they install a microgrid.

Those values that can be traded are those that have already enabled new entrants. In Switzerland, telecom companies are playing the role of aggregators to provide ancillary services [61] (rather as a virtual power plant than as a microgrid). Also, an uncountable number of startups or larger companies are endorsing the role of installers, operators and energy suppliers in remote regions, providing access to electricity.

2.2.2 Microgrid profitability

Qualitative approach – the value tree The quantification of each value proposition is alone a field of study, and strongly depends on the context (connectivity of existing network, cost of failures...). As this work aims at being general, our contribution to this matter is limited to the mapping of possible impactful parameters on the value tree, fig. 13.

Among others, this representation shows the central role of the control latitude of the microgrid, linked with the total installed assets and actuators. Those impact the most value propositions, but are also responsible for most of the costs.

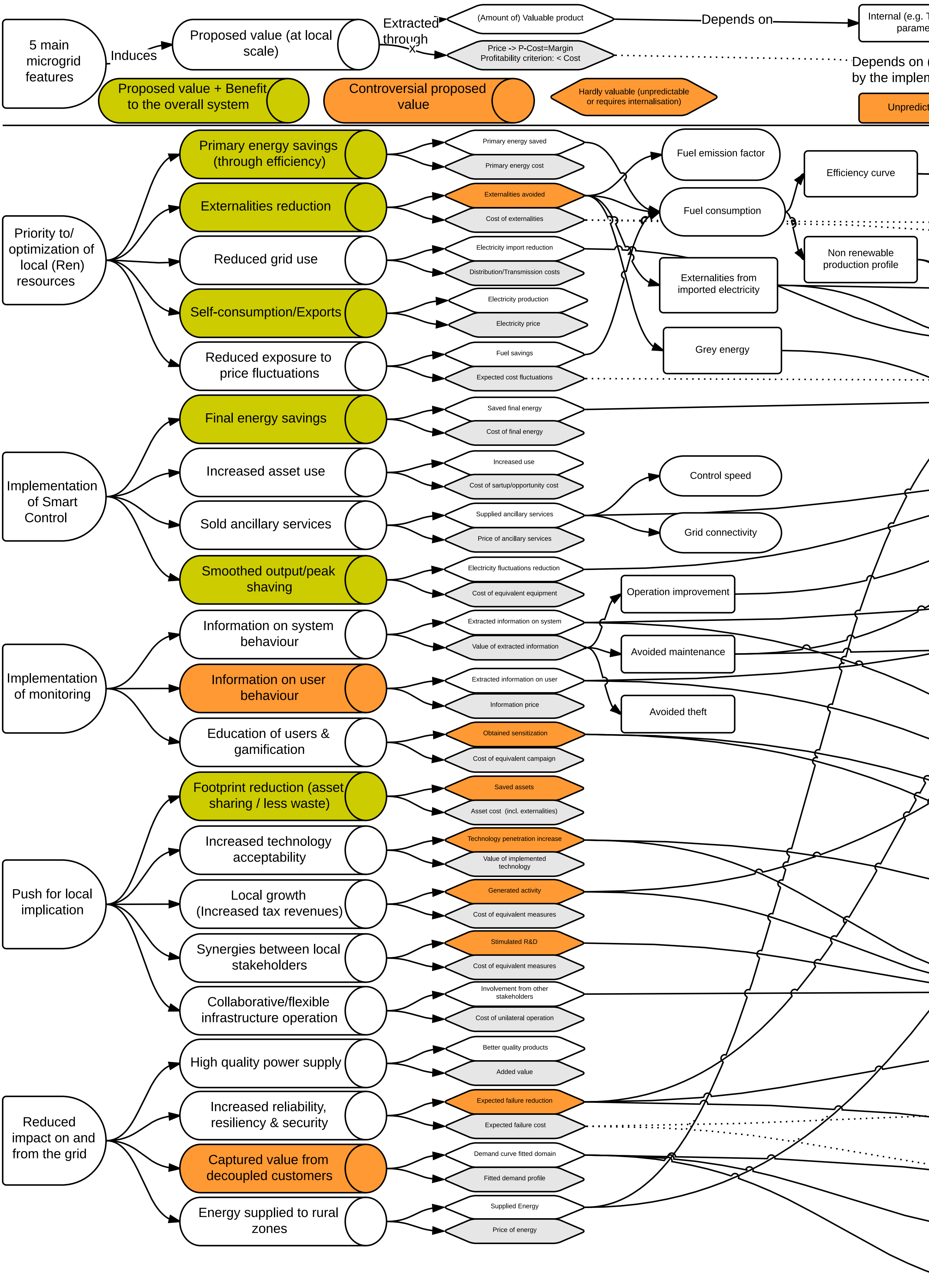
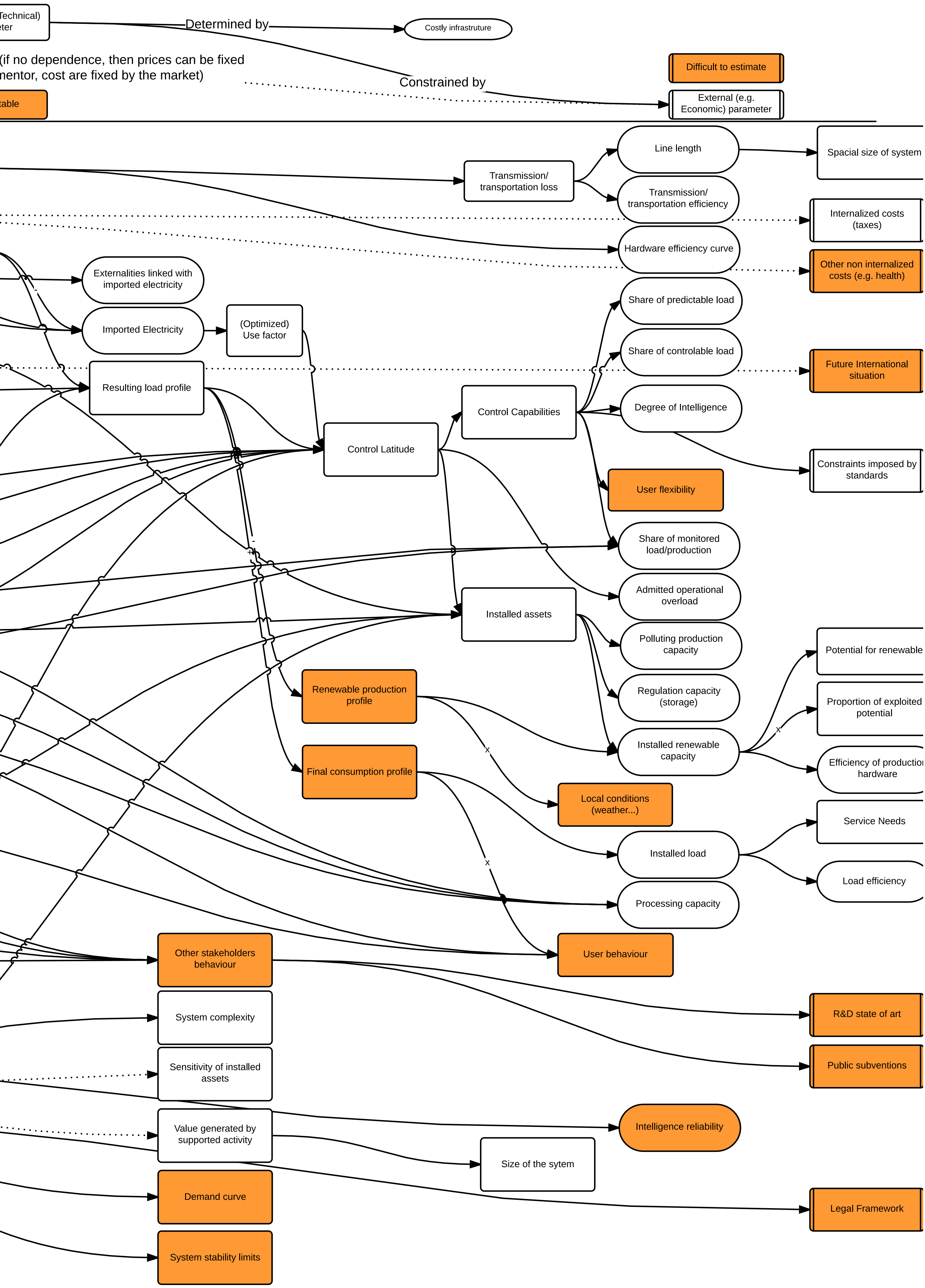


Figure 13: Microgrid value tree. It links the value propositions of a microgrid with its features and external parameters.


Technical)
eter
Determined by
Costly infrastruture
(if no dependence, then prices can be fixed
nentor, cost are fixed by the market)
Constrained by
table
Difficult to estimate
External (e.g. Economic) parameter
Transmission/ transportation loss
Line length
Spacial size of system
Transmission/ transportation efficiency
Internalized costs (taxes)
Hardware efficiency curve
Other non internalized costs (e.g. health)
Externalities linked with imported electricity
Imported Electricity
(Optimized) Use factor
Share of predictable load
Share of controlable load
Future International situation
Resulting load profile
Control Capabilities
Degree of Intelligence
Control Latitude
Constraints imposed by standards
User flexibility
Share of monitored load/production
Admitted operational overload
Installed assets
Polluting production capacity
Potential for renewable
Regulation capacity (storage)
Proportion of exploited potential
Renewable production profile
Installed renewable capacity
Efficiency of productio hardware
Final consumption profile
Local conditions (weather...)
Service Needs
Installed load
Load efficiency
Processing capacity
Other stakeholders behaviour
User behaviour
R&D state of art
System complexity
Public subventions
Sensitivity of installed assets
Intelligence reliability
Value generated by supported activity
Size of the sytem
Demand curve
Legal Framework
System stability limits

For the case of Switzerland, the imported electricity is another interesting node of this diagram. As the externalities generated by electricity production in the country are low, it is *a priori* more profitable from the point of view of environmental added value to import electricity than to burn fuel on site. However, if the efficiency is improved (e.g. through cogeneration), there may be an ideal tradeoff between importing electricity and burning fuel on site. Finding this optimum requires to turn the diagram into an actual quantitative model, which was not the aim of this project.

Quantification From the pure cost of energy point of view, the cost of energy produced within a microgrid is usually larger than the wholesale price of electricity due to the investment required for the infrastructure. It is but but decreasing as used technologies reach maturity (e.g. solar PV or storage). However, if the electricity is consumed locally, network costs could be avoided, making the overall cost potentially lower. Already in 2009, taking into account this element together with other values within a complete model, the More microgrids project [57, p.136] concluded that microgrids “can be profitable to invest and operate given the current market situation in Europe. However, a suitable regulatory framework including proper policy and financial support need [sic] to be available”.

Also, Morris *et all.* [37] do a modeling of some microgrid values (emissions reduction, locality, reduced peak loading and improved reliability/power quality) and taking the example of an existing Canadian microgrid concludes that “despite the comparatively high cost of electricity from distributed generation units, microgrids can be a valuable investment opportunity”.

Nevertheless, in other setups microgrids were found to be unprofitable. For instance, Khalilpour and Vassallo [29], studying a microgrid at building scale, operated by a end user, conclude “that leaving the grid is not a feasible option even at low PV-battery installation costs, at least for the types of household electricity consumption and demand profiles used”.

Anyway, it is likely that a trade-off between the level of service provided and the cost of the system can be found to make the investment viable. Indeed, this last study also finds that a “PV-battery” system can be profitable for some cost factors of the battery, although not enabling a full autonomy from the grid. Conversely, the More microgrids project considers “microgrids” with a self-supply level of only around 20%.

The main economic barriers are more the ones of the transaction costs of designing the microgrid, the cost of capital to engage the initial investment (which is capital intensive) and the capture and distribution of the profits made, especially as, for now, each microgrid project appears to be unique and very complex [5]. Thus not all stakeholders will have the same incentive to engage into a microgrid deployment, according to their desired supply quality, already owned infrastructure and profitability of the current model. In the next section we present 3 possible business cases with typical stakeholders.

2.2.3 Bundling value propositions: three baseline business cases

Having collected all the necessary elements for the construction of business cases, we will now apply the framework to some cases that have been proposed in the literature. Further analysis of the implementation of this business cases in Switzerland is done in section 4.2.

The case of *remote microgrids* is specific, as they essentially bring energy where it is needed, which overshadows any other value proposition. The provider will typically also own and ensure the operation and maintenance of the microgrid, resulting in a "franchise microgrid", although some research is also done to ensure that the local users can undertake these tasks. They can offer energy or energy services as the final product. This model is fairly common in developing countries [3, 19].

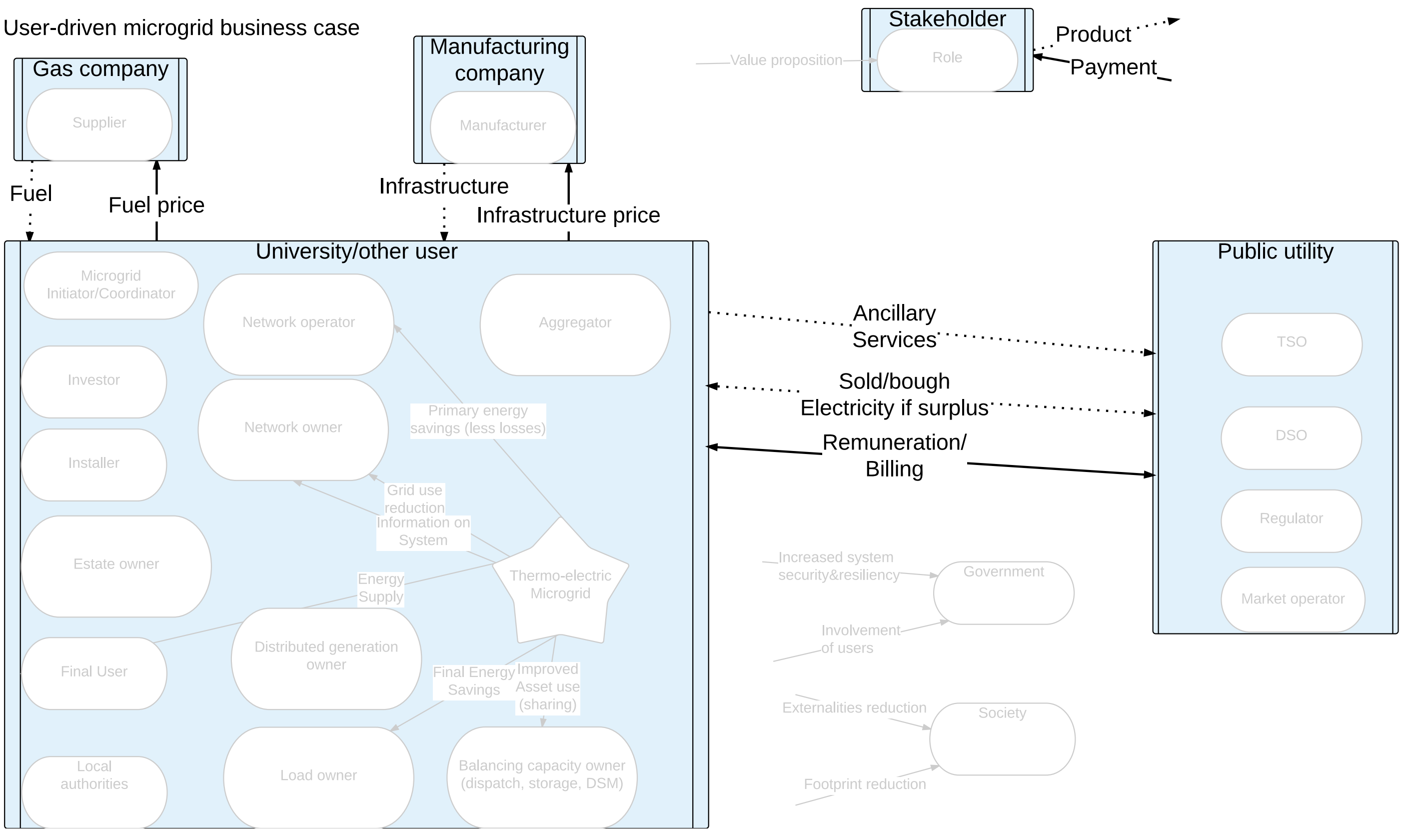


Figure 14: *User-driven microgrid business case. One end user owns and operates the microgrid to reduce its costs.*

User-driven business case Apart from that special case, a first business case is the one of the *user-driven business case*, illustrated on Fig. 14. In this setup, the user installs, maintains and operates the microgrid, drawing its profits mainly from the energy savings, and possibly from energy sale to the grid.

The user will typically not be a single citizen, for whom the transaction costs are too high. However, if the user is a larger entity, for instance an university or an energy intensive enterprise, then the transaction costs are relatively lower, and the infrastructure may become viable.

The resulting microgrid will be typically a “true microgrid”. It has several known instances, listed among others by the Berkeley lab [18], namely university campuses, as the New York university, which was able to island from the city grid during the Sandy storm and has “proven its benefits”.

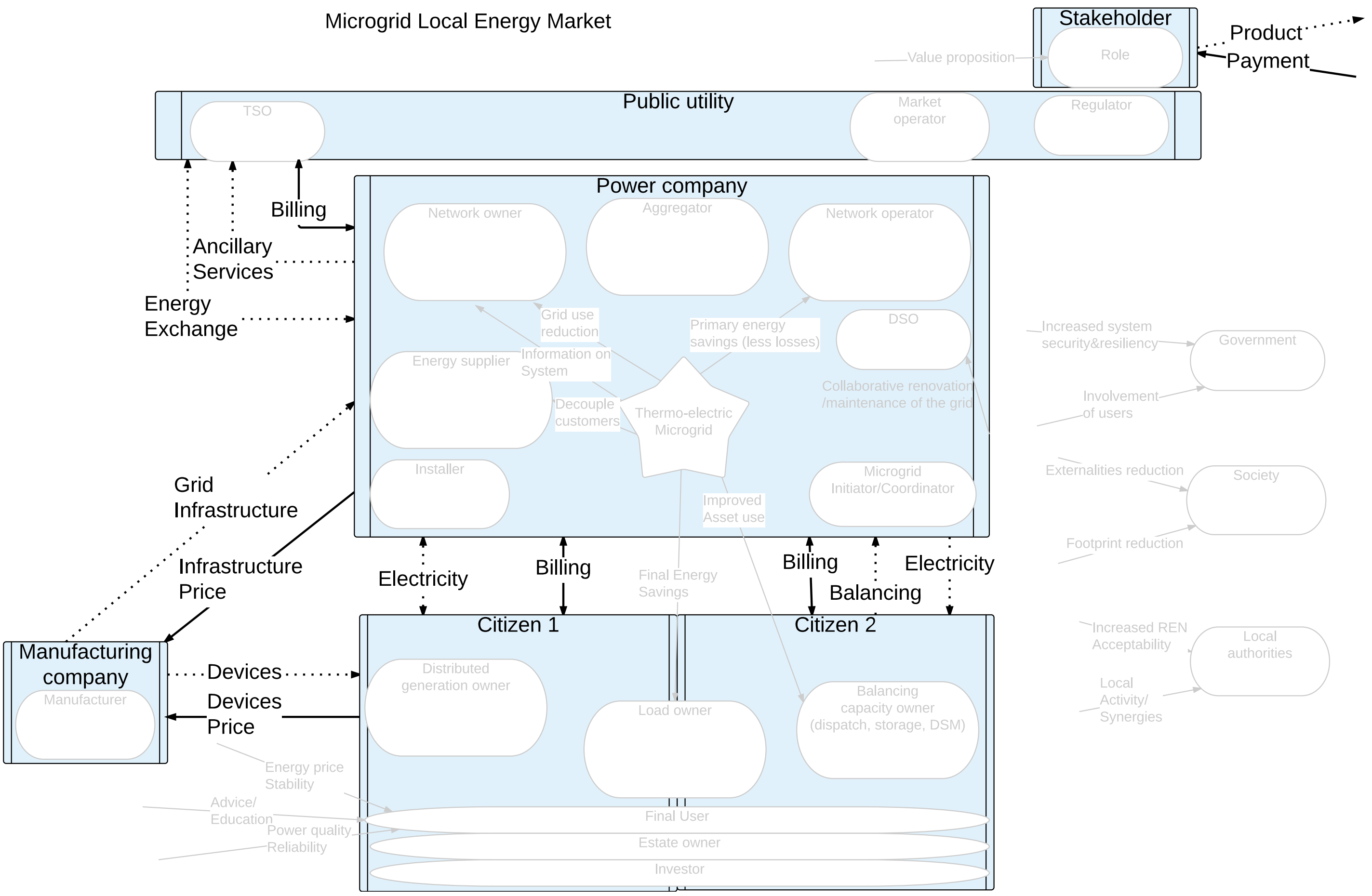


Figure 15: *Local market operator business case. One stakeholder, typically a local utility, operates the grid while energy and balancing capacity is supplied by prosumers.*

Local energy market The second business case family is the enabling of a *local energy market*, as shown on Fig. 15. It is based on the overall reduction of network charges (thanks to grid use reduction, peak shaving and final energy savings), and is explored by [60]. Indeed, around half of the retail electricity price is usually due to network charges (this depends on the countries, and in some countries the producers also contribute to network charges). The reduction of distribution network constraints and the reduced use of the transmission network result in a margin that can be distributed to the users.

One model for capturing this value is the setup of an independent microgrid operator, who buys energy above wholesale prices to local producers and sells it below retail prices to local consumers while managing a profit margin. This supplier also buys balancing capacity to sell it to the network operator. In this layout, all the stakeholders have an incentive to participate and the relative unbundling of the roles is supposed to enable some competition and innovation. The result will usually be a "utility microgrid". The Cell Controller Project, in Denmark, enabled such a local market during test periods, although only the technical aspect was explored [33].

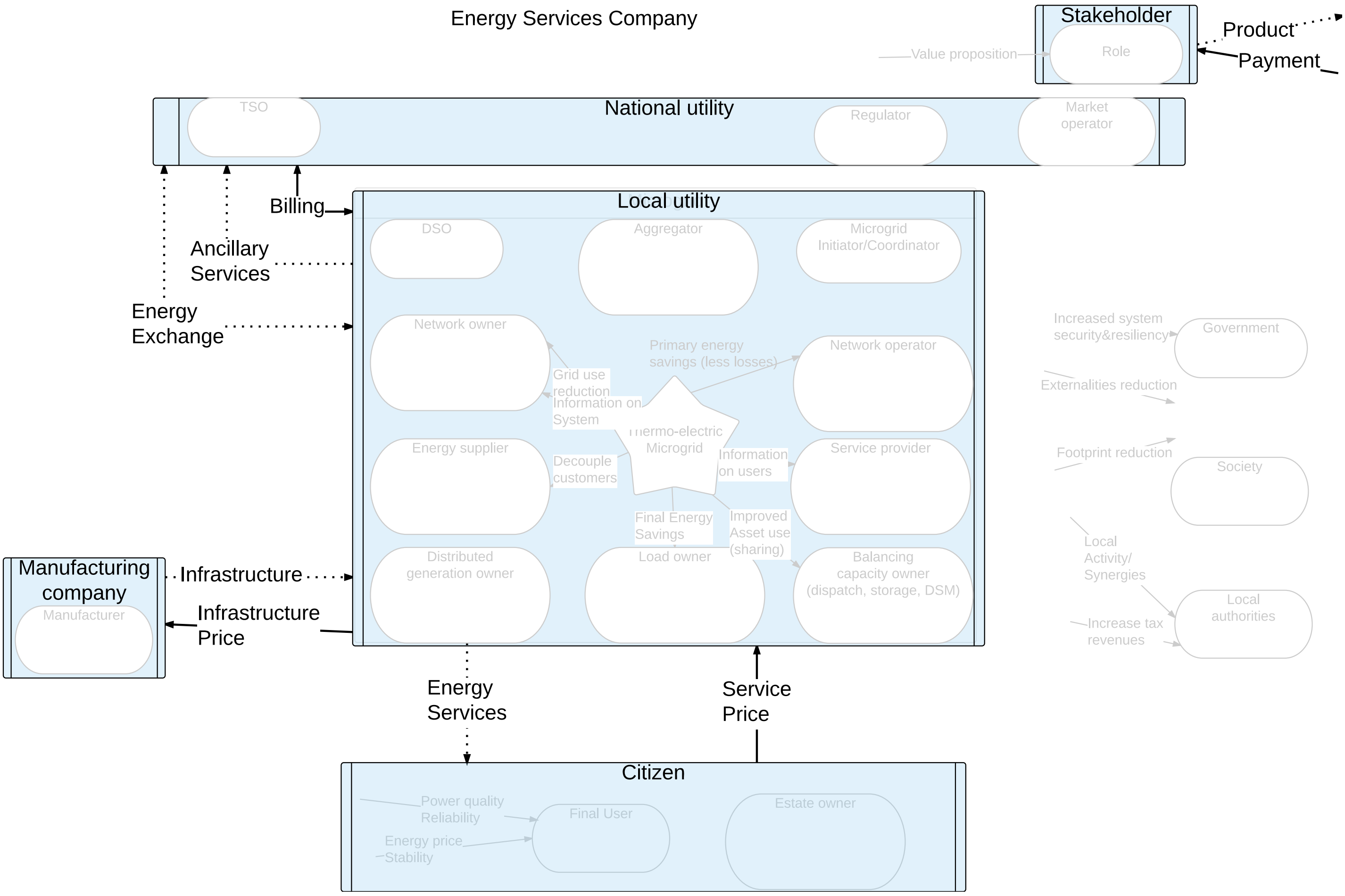


Figure 16: *Energy Services Company business case. One stakeholder, typically a local utility, owns and operates not only the grid but also connected devices. He then sells energy services (heating, cooling, lighting...) rather than energy.*

Energy services company A third business case family relies on both energy savings and network charge reduction, whereby an *Energy Services Company* (either a utility or another company) supplies energy services instead of direct energy, drawing it's profit from increasing the system efficiency. This is shown on Fig. 16. It is studied among others in [24].

This business case has the advantage that the profit of the *Energy Services company* stems directly from the reduction in energy consumption and operations optimisation, thus it incentives the reduction of externalities and footprint. Moreover, as energy services are differentiable (speed, design), the company can extract more of the willingness to pay of the consumers and even propose new products based on the metering and control features (remote control, building automation). However, this differentiation may result in high differences in service quality, which can be socially unacceptable, thus imposing the company to be publicly owned or mandated to supply a minimal legal service.

Such a business case can result in any type and size of microgrid. Several examples of such ESCos can be found, although they usually do not offer explicitly the installation of a microgrid, but rather offer other services (monitoring, energy management, maintenance... [10]). The microgrid products offered nowadays by some large manufacturers can be assimilated with Energy Service Company offers, although their revenue is not tied with the savings achieved.

2.3 The case of Switzerland

Having sketched the frameworks for both a technical and an economical design of a microgrid, it would be interesting to address the problem of an actual implementation. This can face regulatory issues, resistance from incumbents, dysfunctions due to user misbehaviour... Those factors are highly dependent on the context, and to simplify the analysis we will therefore focus on the case of Switzerland. Our study used a micro-Delphi to understand the position of the stakeholders in the country. Before presenting the results of that experiment, an overview of the current swiss energy system is given in this section. Future perspectives are subsequently described and lastly we focus on existing regulation.

2.3.1 The current energy system

The Swiss Federal Office for Energy does provide annual statistics on the energy [46] and electricity [47] consumption and production mix. This reports are good references for further reading and we here only provide an insight into some aspects relevant to the discussion on the microgrid concept applications.

Energy balance Switzerland has a high primary energy consumption per inhabitant compared to other countries (313TWh or 38MWh/inhabitant[13] in 2014). However, its overall efficiency is high, as it has achieved ever higher levels of PIB without increasing its consumption in the last decades.

Fig. 17, from the first report, summarises the primary and final energy consumption components of the country for the year 2014. The diagram

[13]Using the numbers of the STATPOP [59]: 8'236'573 inhabitants in 2014, up from 7'204'055 in 2000

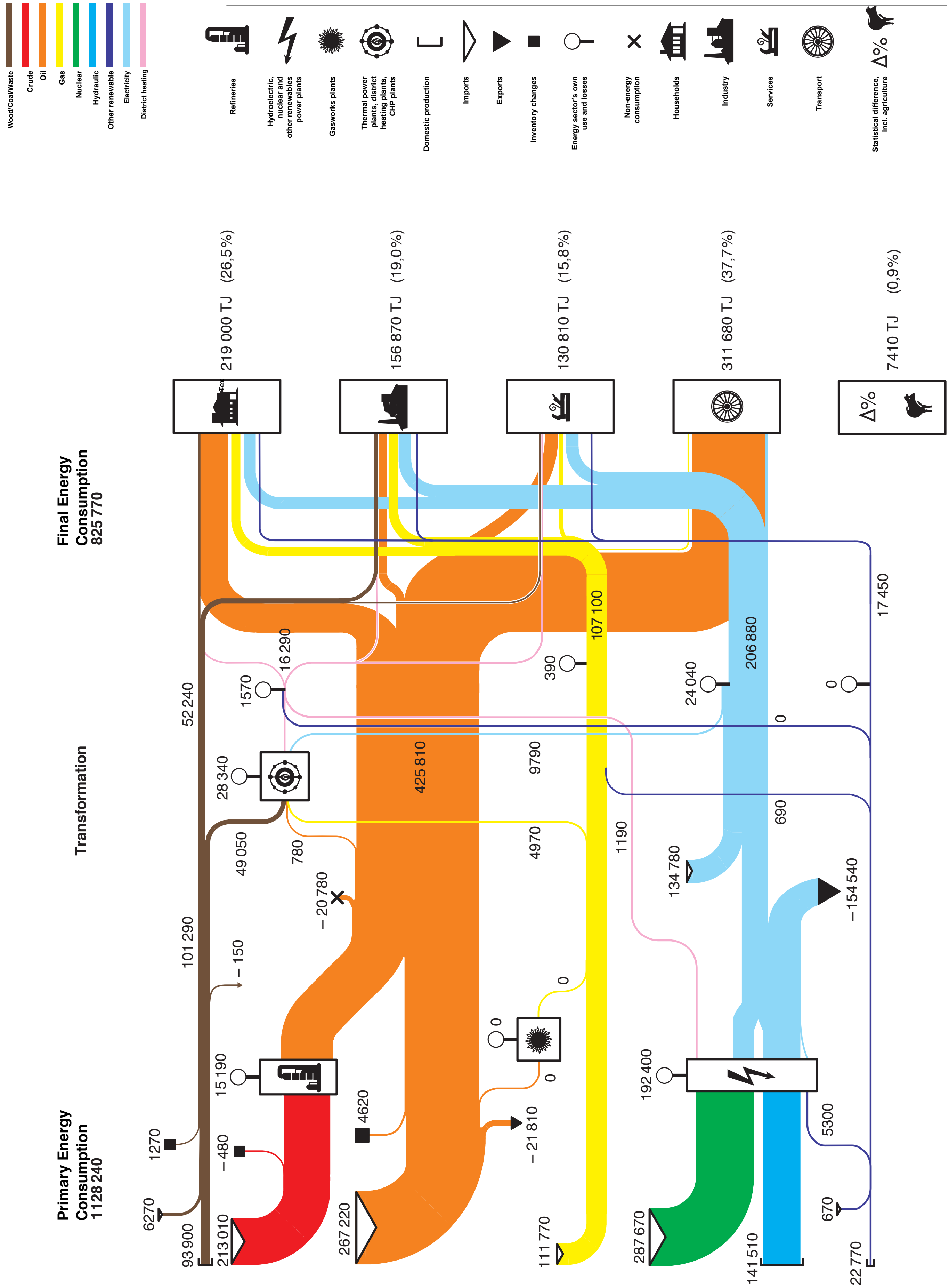


Figure 17: *Switzerland energy balance in 2014. The large dependency on fossil fuels is evident, mainly for transportation but also heating. Electricity represents about one fourth of the final energy consumption. Translated from [46] (all numeric values and methodologies are available in the report).*

shows an heavy reliance on primary fuel imports. However, electricity, which represents roughly a fourth (28% or 57TWh, that is 7,0MWh/inhabitant) of the final energy consumption, is produced mainly (56%) from domestic hydro-power plants, the remaining being supplied essentially (38%) by 5 nuclear reactors around the country.

As for the daily operation, the power requirements are supplied by a base load from nuclear power plants (constant output), complemented with variable run-of-river hydro-electricity, the balancing being ensured by reservoir hydroelectric power plants. Variable renewable energies (solar and wind) have, as of today, negligible impact on the load curves.

Internal and external markets Switzerland has usually been a net electricity exporter in the last years (except 2010 and 2011), but this hides significant annual fluctuations [47]: in winter, when the consumption is the highest, the country imports between 5 and 26% (data from 2004 to 2014) of its electricity consumption. Those needs are mainly supplied by French nuclear power plants, while exports are done to Italy.

Imports are mainly (54%) secured by long term (more than 5 years) contracts, the rest being ensured by shorter term contracts. Exports on the opposite are negotiated (for 97% of traded amounts) on shorter time-frames, either through short-term contracts (less than 2 years) or on the spot markets.

The internal market is liberalised for large consumers and producers since the 2008 energy supply law. A full liberalisation (free choice of the electricity supplier for all end consumers) is scheduled for 2018. As of today, [47] identifies 313 enterprises producing 90% of the electricity and supplying 79% of the total demand.

These enterprises are mostly publicly owned by “communes” (municipalities, 29% of the capital) and “cantons” (regions, 57% of the capital) as of 2013. The benefits they drawn are redistributed and constitute a significant revenue source for some municipalities.

The operation of the transmission system is ensured by a single TSO, Swissgrid, which is in turn mostly owned by the smaller, mostly publicly owned, distributors and energy producers. Energy and ancillary services are traded on federal markets regulated by a national authority, Elcom.

A centralised electricity system Overall, the electricity system is technically quite centralised (more than half of the hydraulic power plants are storage plants in the Alps, far from the consumption centers). However, from a governance point of view it is very decentralised, with small companies, themselves often owned by a number of institutions, ensuring the electricity supply of a limited number of consumers. In some places, these DSOs also provide heat and other energy services, being closer to ESCos (see 2.2.3).

However, on the electric part, they nowadays only ensure that the dimensioning of the wires within the distribution network is large enough to avoid overloading. All the stabilisation of the network is done centrally, by

Swissgrid, using the existing centralised capacity. This could become more difficult as decentralised production capacity is spreading, as exposed below.

2.3.2 Trends and objectives

The country is undertaking a energy transition. This is to be guided by the Swiss Energy Law for 2050, which is currently under discussion [48], and would replace the current law with more ambitious objectives. Meanwhile, other measures are been taken under the broader "Energy Strategy for 2050". Those are based on a study mandated by the confederation on the energy perspectives for 2050 [42].

Objectives This study foresees a decrease of the primary energy use of about 6% between 2010 and 2020 and up to 21% by 2050 if current policies are maintained. However, the electricity demand would then be expected to increase 5%, resp. 18% (due to the population increase and the increasing share of electric transportation and heat pumps).

Instead, the energy law would set an objective of reduction of primary energy consumption per person of 16% between 2000 (43,7MWh/hab) and 2020 and 43% by 2035, while electricity demand per inhabitant (7,3MWh/inhabitant in 2000) should decrease 3%, respectively 15%. Moreover, following the Fukushima accident, the decision of not renewing the nuclear power plants was taken, which could mean a banishment of domestic nuclear electricity production by 2044.

Together with increasing the hydraulic production, for which a target of 37'400GWh/year is to be set for 2035, the exploitation of the renewable potential would therefore be needed, and a target is set to 14'500GWH/year[14]. In such a "full renewable" scenario, still part of the future demand would have to be covered with imports (due to annual and daily variations). To avoid this, the construction of gas power plants (CHP then CCT) is envisaged.

Obstacles The governance structure of Switzerland is the first challenge to overcome for this transition. Indeed, local authorities usually have large competencies, and referendums are often organised (at the municipal, regional or national scale) for important decisions. This has already led to the rejection of several projects and laws.

On the technical side, a recent study by Swissgrid has shown that the existing transport infrastructure would afford the introduction of enough renewable to cover the overall swiss production, provided some reinforcements [62]. However, this analysis does not take into account possible overloads on the distribution lines. To face this possible challenge, the swiss federal department of energy has proposed a smart grids road-map [20]. This document underlines the maturity of most required technologies, although it

[14]Due to the uncertainty on the population evolution, the actual targeted mix is not defined. An online calculator allows to explore different configurations for the future energy system: www.energyscope.ch

acknowledges that their penetration rate is not very high due to technical difficulties and the lack of actual needs for the moment.

Decentralisation of the electricity system Overall, the Swiss energy system is likely to evolve towards a more decentralised system, in the sense that small renewable generation sources could be implemented. This, together with the full liberalisation of the market, could have significant impacts on the electricity landscape of Switzerland.

2.3.3 Regulatory context

Information and incentives Swiss authorities give a significant importance to communication as to ensure the success of the energy transition. All the legislation on energy issues can be found on the confederation website [15], as can be all the aforementioned reports. For non specialised public, the institution SuisseEnergie does communication campaigns and promotes energy efficiency all around the country. Lastly, electricity suppliers are required to label their energy, giving the detailed mix.

In parallel, research on energy-related fields and on energy standards is financed. The application of the developed technologies is encouraged, as well as their diffusion to the greater public.

Efficiency is also promoted, both through national and local subventions. There is a tax on CO2 emissions[15]. Feed-in tariffs are in place for solar installations and small hydraulic turbines. These have had such a success that nowadays tenths of thousand of projects are on the waiting list, in the meantime benefiting from regional subsidies when available.

Self-consumption Besides feed-in tariffs, self-consumption is enabled in Switzerland, including for prosumer consortiums [43]. The only condition is that all the users are below a single point of common coupling with the distribution grid. In fact the conditions are particularly favorable for prosumers. On one side, this right to self-consumption does not deliver the DSOs from the obligation of purchasing surplus electricity, and does not prevent the user from establishing certificates of origin (which can be traded, thus enabling additional benefits) for the renewable energy produced. Local storage is also authorised. On the other side, "the injection of current is not considered as constituting a technical disturbing factor for the grid", implying that any costs require to accommodate this injection are to be endorsed by the distributor [44].

Therefore, true microgrids (i.e. managed by a client or consortium of clients) do not face significant regulatory barriers. The fact that they are absent from the energy landscape deserves further research, which has motivated the micro-Delphi that we present in the next section.

[15] 60CHF/ton, levied on combustibles directly – energy intensive industries are exempted to ensure competitiveness, but the most polluting ones participate in an Emissions Trading System

3 Micro-Delphi results

The review presented in the previous section has allowed to reach two important conclusions: first, the deployment of a microgrid can be profitable, provided that a trade-off between grid dependence and cost is found, and second, it does not face significant regulatory barriers, at least in Switzerland. However, no example of microgrid is know in Switzerland at the moment. It is to understand the reasons of such an absence that we launched the micro-Delphi, as presented in section 1.3. A synthesis of obtained answers is available in the appendix, this section gives an analysis of these results.

The structure of this part is slightly different than that of the questionnaire, as the later was conceived to allow a fluent conversation. We first present the stakeholders' visions of the future, then the business models that they propose for microgrids and lastly the barriers to their deployment that they perceive and the policies envisaged to mitigate those or increase incentives.

3.1 Scenarios for the future

The first focus of the experiment was to evaluate the perception of the stakeholders of the future energy system, namely in terms of decentralisation. This was to understand what room they implicitly see for the microgrid concept.

3.1.1 Decentralisation is ongoing

Unanimity on an hybrid electricity system All stakeholders agreed that there is a decentralisation taking place, in particular through the growth of distributed renewable sources and the increase of prosumer behaviour. New, relatively standalone nodes are appearing according to most stakeholders, energy intensive industries, but also individuals. One DSO sees some prosumer consortia already forming and selling energy to the grid, while the liberalisation of the market would facilitate this process even more.

Therefore, from the technical point of view, the electric system is expected to get closer to an "hybrid system", where standalone nodes will plug-in to a larger grid. The later is not expected to disappear, as existing facilities are reliable and sufficient according to all stakeholders. This is corroborated by the recent Swissgrid report, mentioned by several respondents. The pension fund manager goes further, envisaging a decoupling of the decentralised system, dedicated to small loads with low quality requirements and a centralised, strongly interconnected system for large applications

From the institutional point of view, this inter-connexion requires the continuation of the central authorities, regulator and TSO, in charge of regulating the energy flows (the policymaker sees them as a sort of "central bank") and ensure a fair market operation. This market would be open to DSOs, whose number is projected to decrease (one DSO by region). Local markets or locational signals are not envisaged by any respondent, although one academic underlines the value of locality for Swiss consumers.

Communities are expected to mandate DSOs for the satisfaction of local needs (including microgrids if they decide to choose this solution), rather to rely on other offers. Indeed, DSOs have the technical expertise and are trusted by the consumers. According to demand, DSOs may start offering solutions to increase decentralised production and self-consumption, as one of them points out.

Possible threats on current assets Centralised generation sources, namely large dams could be threatened by the competition from these decentralised sources, as well as by perturbations on the European electricity market. The future of these infrastructures is still uncertain and controversial. While most stakeholders would see the existing hydro-power plants remain (and the policymaker advocates that they should even be protected), the TSO does envisage their abandon if they become non profitable, which could be the case if subsidised decentralised solutions generalise. The policymaker also fears the spread of delocalised storage solutions, which would compete with pumped hydro.

The TSO also mentions the possibility of a major failure on the transmission system, considering it as not impossible. As was mentioned by some respondents, the power reliability is primordial in Switzerland, so that such a large scale failure could trigger a movement towards decentralisation[16].

Other elements No respondent evoked the consequences of climate change and the associated glacier retreat on the situation for hydro power plants. This could change considerably the situation, namely for reservoir dams (a quarter of Swiss production), creating new risks and opportunities [22]. These issues are complex as they impact not only the power system, but also other domains, according to the diverse functions of dams (flow regulator, drinking water reserve etc). They create an uncertainty that increases the hedging value of local resources on the long term.

Moreover, only one academic envisaged new solutions based on nuclear power, possibly smaller reactors, even in Switzerland. Such technologies could make decentralisation much easier technically (small fission reactors) or on the contrary push for centralisation (large fusion reactors).

Another element that was not taken into consideration is the long term cost of entertaining the transmission system, which might become non-affordable in some places if DSOs start evolving towards a more proactive role, regulating their own grid and reducing their dependency on the transmission grid (aligned with the users self-supply share increase). Such changes in the electricity system structure have already impacted the grid planning in the past. For instance [62] mentions the abandon of 8 project which were programmed for 2015, some of them because of a change in the supply mix.

Some other challenges are seen by the respondents, rather in the shorter term, which we present in the next part.

[16]The push for "community resiliency microgrids" after the Sandy storm and associated blackouts, in the US, is one example of such a trend and could be replicated elsewhere.

3.1.2 Perceived challenges

As could be expected, the challenges are perceived more differently according to the type of stakeholder than the envisaged future energy system.

Self-consumption and bidirectionality DSOs see the greatest challenge in the increase of distributed renewable resources, as it implies more bidirectional flows in the grid, requiring changes in the operation, and possibly technical adaptations. Two specific technical problems mentioned by these stakeholders are the interference of inverters with other devices and the problem of ensuring that lines are not powered by decentralised devices during maintenance. These problems require the creation of new standards. On the contrary, the consulted policymaker denied quite vehemently the problem of bi-directionality, arguing that there is still a long way to go before the flows in the lines are actually reverted.

The possible economical problems that could arise from the increase in self-consumption are mentioned as possibly requiring to increase tariffs of energy. However, the expected price increase is only around 10% according to one DSO. Should it go further, measures would have to be taken. Under the current legislative framework (operators have the obligation of buying surplus energy at retail price), the operation of the grid could possibly become highly unprofitable[17].

Changing business cases The problem of the sustainability of current business cases, which ultimately also relates to the integration of new decentralised generation sources, is mentioned by several stakeholders, namely the TSO, the manufacturer and the academics. New business cases are required not only because of the self-consumption, but also to serve consumers seeking new products (information, off-grid supply...).

Furthermore, a possible change in the control paradigm of the grid (e.g regulate voltage together with frequency), required by the diminution of inertial capacity, may require the introduction of new ancillary service products and the corresponding regulation adaptation. DSOs would have to adapt to this change, which is already seen by the manufacturer in some countries. Solutions that compensate the producer for self-consumed energy withing a prosumer consortium while managing a profit margin for the DSO is one promissory solution according to the policymaker. This ultimately is equivalent to enabling a local market.

Technical challenges Linked with the problem of grid stabilisation is the challenge of finding new storage solutions, on which one DSO, the pension fund manager and the policymaker focus. As explained before, such solutions would be double-edged, requiring a careful framing according to the

[17]Switzerland has a share of only 2% of "new renewable energies" in the electricity mix, with an objective of multiplying the installed capacity by around ten by 2035, mainly solar PV, of which a good part could be privately owned given the current incentive schemes – which has already lead to large difficulties for utilities abroad, for instance in California.

policymaker, to protect large scale pumped storage. This could become a barrier for their deployment in Switzerland if protective measures are taken.

As one academic points out, the research on this field is very active, and a range of solutions is expected for soon, which will have to be handled properly[18]. The same happens in the field of smart grid technologies, namely smart metering and actuators, which are emerging and will bring major changes in the energy field, raising issues such as privacy protection, mentioned by several stakeholders, and health concerns, not mentioned by any stakeholder but illustrated by recent polemics on the installation of smart meters.

Other challenges linked with decentralisation were discussed within the context of microgrids and we present them further below, as possible barriers to implementation.

3.1.3 The medium-term limitation

The first results tend to show that even high-level stakeholders have a short to medium-term horizon. They are actually aware of this limitation, as most stakeholders mentioned a time horizon of 5 to 10 years, acknowledging that uncertainty is too high on longer periods. This may be a bit surprising given the time horizon of the Swiss energy law, which sets objectives for 2035 up to 2050.

Passive utilities For the DSOs, this short range is justified by the fact that they have a public mandate to ensure electricity supply. They therefore consider that it is not their role to introduced large operational changes or changes in the control paradigm. They could potentially be the main actors of the change if they started acting more proactively, but they consider that it is “too early” (taking the words of one of them). Moreover, they are constrained by existing regulations.

Indeed, on the national level, the regulator has precise standard that make it difficult to certify non-conventional, innovative, solutions, as pointed out by some respondents. Similarly to DSOs, TSOs have precise mandates to ensure the security of supply that impose that they take into account current technologies, with small consideration for breakthrough technologies. Similar biases have been found in other large instances, who are sometimes not allowed to take into account possible disruptive events in their forecasts.

This “thick present” view (only consider the prolongation of current trends) is required as to provide a stable ground for decision-making. It also allows to reduce perceived uncertainty, which fosters investment. Nevertheless, it has also led to some failures[19] that call for a more long sighted energy sector.

[18] During the period of the project, a couple of innovative battery solutions were marketed, which could well be the first step of more technological developments. Actually, some offers also include the installation of PV panels as to make the household as autonomous as possible, increasing self-consumption.

[19] An emblematic example of those is the construction of modern gas power plants across Europe, which have become stranded assets before even starting operation because of the

Non-expert policy makers The short-sight of ground stakeholders is propagated to the policy makers. These, as mentioned by the manufacturer, are reticent to try to influence utilities. They may even be more conservative, as illustrated by the contradiction between the policy-maker and the DSOs on the challenges posed by bidirectionality. Indeed, one academic deplores their lack of technical expertise, which further reduces the margin for innovation. More generally, the lack of interest for energy issues is illustrated by the recent debates on the Swiss energy law, when only the most specialised deputies where present, which in turn makes energy related issues appear as less interesting and important for the larger public.

Moreover, policy making is constrained by elements beyond technical considerations and by electoral deadlines. Although in Switzerland the political landscape is more stable than in other countries, some decisions may not be taken because of their implications on the cost of electricity or other factors. This is all the more the case as the populations themselves, as pointed out by most respondents, are not concerned about energy issues "as long as they can watch the World Cup" (according to one DSO).

This medium term vision is likely to make this stakeholder slower to adopt new solutions, such as microgrids. Nevertheless, they do see some added value in them, and envisage some business models, as we present hereafter.

3.2 What business for microgrids?

In this section we focus on opportunities and value propositions of microgrids, as they are perceived by the respondents. In general, they were able to enter the discussion about microgrid deployment without being inhibited by the fact that they considered it as a non viable solution, at least for the coming years.

Indeed the term microgrid is accepted as designing more than an electric system that can operate islanded from the grid. Apart from the manufacturer and the pension fund manager, the respondents considered the islanding feature as accessory. Moreover, the microgrid is expected to be serving a determined user or user community, except by the manufacturer. The definition that we propose is therefore likely to get their adhesion.

We first present the value propositions acknowledged, or not, by the respondents. Note that some of them were mentioned spontaneously, others only upon suggestion, which we tried to take into account in our analysis. Later, we try to understand what business models are envisaged, with a particular focus on the role of citizens and public bodies.

3.2.1 Testing the value propositions

The value of locality The increase in energy independence that microgrids may bring was spontaneously mentioned by almost all the respondents, except by the policymaker and one academic. This is particularly valuable, according to some respondents, because of the Swiss culture of autonomy

electricity price reduction induced by a falling cost of carbon and oil [13].

and the value given to locality, also found in [65]. Actually, according to an experiment conducted by one academic, citizens of a Swiss city showed more motivation and involvement in an energy savings program if this benefit was put forward, rather than environmental or even economic incentives. The pension fund manager goes beyond this view by suggesting that a microgrid may foster a feeling of membership which would be valued.

As pointed out by the TSO, a disruption in the electricity supply due to a failure of the transmission grid could further accentuate this facet, making also the security and reliability improvements important values, although they can not be monetised.

Pricing services to the grid The technical added value, in terms of control, grid use reduction and efficiency increase, both for the distribution (e.g. investment deferral) and the transmission (e.g. ancillary services) grids are acknowledged by all stakeholders as well, although the pension fund manager sees it as accesory. Nevertheless their actual profitability is controversial. Indeed, they cannot be priced yet at a small scale, and some services that microgrids could provide (beyond frequency regulation) are simply not acknowledged as products, as pointed out by TSO. This could change, as envisaged by the TSO himself, and depends a lot on the political willingness. The current trend towards liberalisation and the push for new operational models required by the introduction of non inertial devices would be enablers of this value.

The DSOs also mention that microgrids would not be competitive against the services provided by the existing infrastructure that is amortised, but recognise, together with the policymaker, that in the case of an aging or under-dimensioned infrastructure the deployment of a microgrid to spare the wires could be more efficient than the replacement of some hardware (e.g. transformer). It therefore appears that this is a relevant value in the medium to long term.

Sustainability left out In contrast, the reduction in final energy consumption and sustainability improvement seem to be less probable drivers for a microgrid implementation (in Switzerland). Actually they are not even mentioned by most respondents. Indeed, as pointed out by one academic, the Swiss electricity is already almost “carbon free” (from hydro-power). Even if savings where achieved, the same academic points out they may be wiped out by rebound effects. However, security improvements achieved with the closure of nuclear power plants would be valuable.

This may be neglecting the integration of heat into the microgrid, with the possibility of replacing polluting oil furnaces (three fourths of the energy consumption of households are fossil fuels, mainly for heating). The discussion on the consequences of dams on the ecosystems are also forgotten, although it could be revived once the nuclear polemic slows down.

Controversial information The value of information for the users would be low, according to the policymaker backed by the DSOs and one academic, given the low willingness to involve of the users. The DSOs and academics base this opinion on conducted experiments that provided to the users their real time consumption, or tried to confront them with the consumption of their neighbours, with little impact on behaviour. Moreover, as said by one DSO, successive studies have concluded lower and lower values for the savings expected from user awareness (from some tenths of percent to some percents).

On the contrary, an actual change in mentalities towards a more aware energy consumption is envisaged by the TSO and one academic, enabled by this information. Indeed, in the aforementioned experiments, information was provided without levers for action, while this may make it more valuable, for instance to control the comfort level of secondary residences, as mentioned by one DSO, or if real-time price signals are applied and broadcast, as proposed by one academic. Information could be used to provide enhanced energy services, as pointed out by one academic and the pension fund manager.

The value of this information for the DSOs themselves, as to help the maintenance and operation of the system, was not explicitly mentioned by any respondent. One DSO did mention that the microgrid is a more concrete object and "sounds simpler to manage" than a simple distribution grid, but without referring to information. The decoupling of customers and the multiplication of new services, enabled by the same information, are mentioned by the manufacturer and one academic. They are but are not envisaged by the other stakeholders, because of the lack of interest from the end users.

Uncertain profitability Overall, half of the respondents (two academics, one DSO and the TSO) estimated that often enough monetary value is produced by a microgrid to finance its deployment, thanks to the decreasing price of energy. The other five rather think that a microgrid is often not profitable. All respondents agree on the fact that the profitability is very case specific, requiring a careful design of the system. In any case, non monetary values would not be enough to trigger a large scale dissemination of microgrids according to all respondents but one academic, although those values are acknowledged to be the main drivers in specific cases.

The second DSO argues that should the deployment of a microgrid be systematically profitable most large enterprises would have entered the field. Precisely, the manufacturer affirms that its enterprise is entering the field, considered as very promissory, and making microgrid products development a priority – the head of microgrids section is very close to the top of the hierarchy. Other large manufacturers can be found, who propose microgrid solution even for individuals, including in developed countries, a trend seen by the pension fund manager.

However, publicly owned companies for now are prevented from extracting most of the monetary value, as they point out themselves, for the reasons explained below. For them as for other stakeholders, new business models still have to be conceived and enabled to capture these values, which we present next.

3.2.2 Envisaged business cases

The turnkey product The most consensual business case is the one of a company selling a turnkey microgrid product to different categories of clients. This is what the manufacturer affirms to be doing, while the TSO acknowledges this business case as one of the most viable ones. Less complete offers are the ones from new entrants, selling plug-and-play products or providing new services based on existing infrastructure, as is foreseen by all respondents, except the policymaker who would rather consider these products as non marketable "gadgets". A comparable business case is the one of a third party platform providing the tools to bring together and coordinate stakeholders, lowering transaction costs and possibly freemium, as other existing platforms of the "collaborative economy" (ebay, airbnb...). It is mentioned by one academic and also found in [5]. He points out that the design of such products and of new business cases is currently the object of intense research.

For these products to be profitable, they must be valued by the end user. As pointed out by the manufacturer, different categories of end users exist who already have specific needs that may be satisfied with microgrids: military or hospitals require high power reliability, energy intensive companies require efficient supply, companies wanting to show corporate responsibility need renewable power... Normal citizens are less involved, but their interest could be triggered through the development of attractive products to address new "created needs" (in the words of the TSO) and. The three academics mention this possibility and yet propose little concrete solutions, apart from a real-time pricing which would be an incentive to use some customised automated solutions. This may but face oppositions, for instance on data privacy issues. Also, as it proceeds from a rather consumerist point of view, it might make fear a rebound effect, as one academic points out.

Utilities sharing profits Another possible business case is the one of DSOs sharing the benefits drawn from the microgrid with the users enabling it. Such benefits could arise from the network cost savings, as mentioned by the DSOs, or by the sale of subsidised solar energy, as mentioned by the policy-maker.

Other more specific models could be profitable. For instance, as exemplified by a DSO, the owner of a variable renewable energy based power plant could want to smooth its output using the flexibility of existing loads, and would share its profits with all participants. Another example, acknowledged by the policymaker, is one of special communities of loads that could take advantage of peak load reduction, such as electric transportation networks or cooling facilities.

The business case for individuals In general, the expected and desired degree of involvement of individuals (*a priori* only end users) in the microgrid business case is controversial. According to half of the respondents (two academics, the TSO and the policymaker), avoiding network costs would be a possible key value for this end users, who would take the lead. It is assumed that they would rely on third parties for the implementation, as they have no technical expertise, except if microgrid components were made available as turn-key products, as envisaged by one DSO.

DSOs see themselves as this third party, but on a push basis, i.e. they would respond to demand, but not take the lead. The policy maker, the pension fund manager and the manufacturer instead see rather the DSOs taking the lead, with little involvement from the users. However, most respondents mentioned the lack of interest from individuals as the main barrier to microgrid deployment, or more generally to deep changes in the energy system, as presented below

3.2.3 The problem of inertia

Most respondents mentioned the complexity of the setting up of the business cases above given the relatively high number of stakeholders involved, with different interests and motivations. These are summarised on Fig. 18, using the framework described in 1.2.2 and the respondent answers together with some elements from the literature. This representation allows to underline a couple of important elements, that are hindering the development of microgrids

The indifference of individuals Households (representing one third of the Swiss electricity consumption), have little interest in deploying a microgrid. Indeed, according to stakeholders close to public bodies (policymaker, but also DSOs and the TSO) Swiss citizens are not interested in energy matters. This is because the share of energy expenses for a Swiss household is very small (some percent), while the service quality is very high. Their priority is to obtain a reliable energy supply in a steady context. Most of them would be unwilling to incur any transaction costs related with energy, even if it could be profitable on the long run.

However, the economic driver was acknowledged to be usually the main one by all respondents but two academics, but even once some profitability becomes possible, other non-monetary drivers would have to be put forward to motivate action. Those could be the main drivers for 10% of the population, estimated by the TSO. One academic also points out that for wealthy populations – 60% of the swiss population is considered to be “middle class” – economic drivers become less relevant. Those drivers could be either the feeling of contributing to a more sustainable world (acknowledged by the TSO and one academic) or the social pressure/community feeling (acknowledged by two academics and a DSO, but disputed by the other stakeholders). These are currently not actioned, due to the inertia of public bodies.

Public bodies constrained by duty The lack of interest from the citizens results in a low willingness to change from public bodies, which adds up to their medium-term vision mentioned in 3.1.3. Indeed, the priority of public bodies is to sustain the present situation, all the more as the current business case of DSOs (electricity sale) relies on the little involvement from

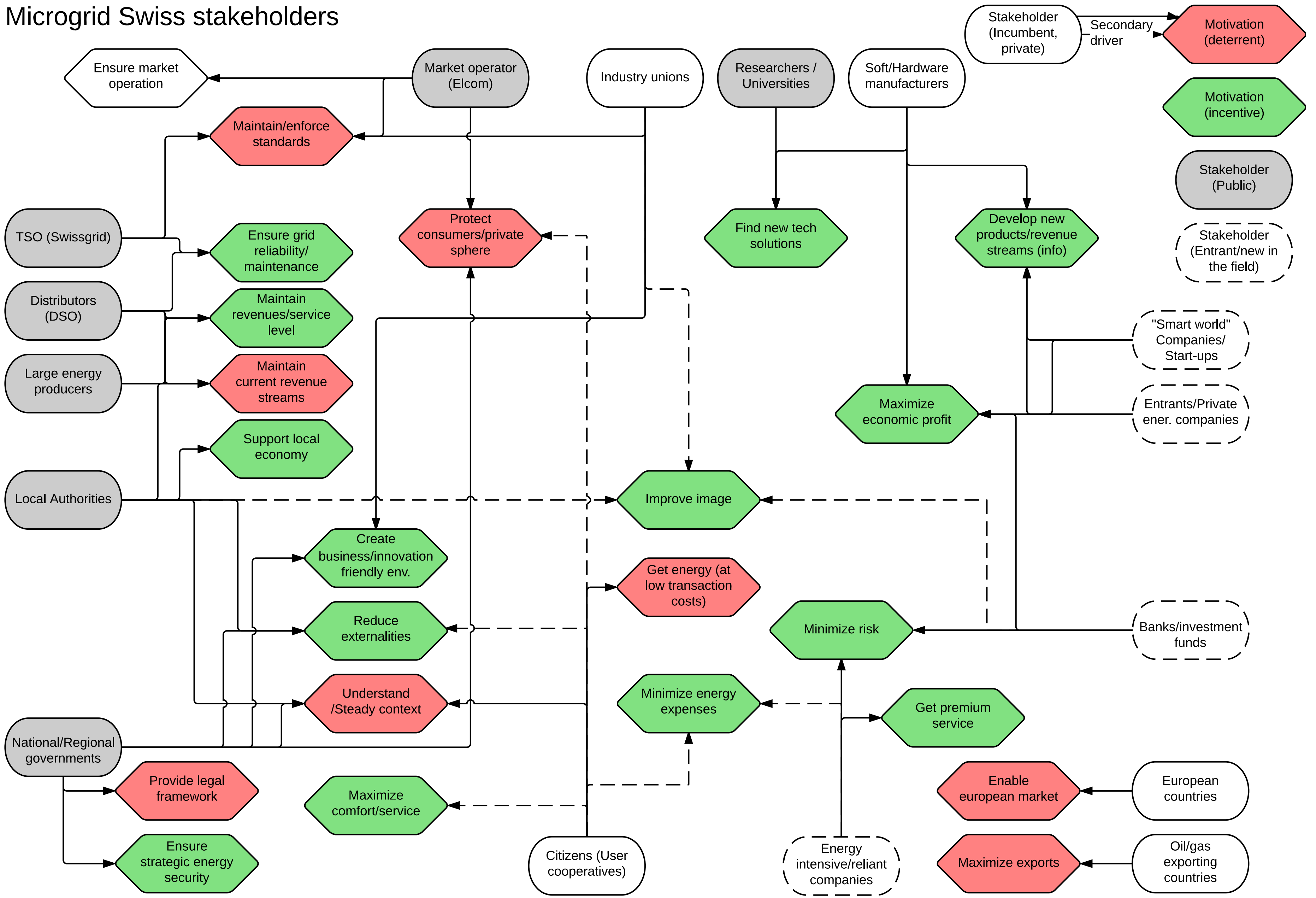


Figure 18: *Mapping of the Swiss Energy stakeholders and their main motivations. It features the different stakeholders implicated in the field of energy management (production and distribution) as well as local stakeholders and others. For a description of each element, refer to Tab. 5 in the appendix. The elements are mainly derived from the answers to the micro-Delphi.*

the end users (low self-consumption rate and little willingness to increase it), which is deemed to continue. Moreover, DSOs expect end users to turn to them in case of new needs, given the trust they enjoy in Switzerland, which is mentioned by the policy maker as well.

Institutionally and legally, this situation is supported and legitimated by the fact that energy supply is a public service, submitted to reliability standards and regulated prices. As long as existing utilities provide the expected service, it is difficult to motivate changes from the political point of view. As a consequence, DSOs remain legally bound to provide a minimal energy service to the population, as they recall. This obligation to serve was found in other sources as well [5]. They are also entitled to take any measure necessary to ensure this service, as pointed out by one of them, which could lead to slowing down the diffusion of new technologies, as feared by the pension fund manager and two academics. Furthermore, the current regulatory context makes it difficult to adopt innovative solutions, as mentioned by one DSO, which disables, for public utilities, most of the investment savings in principle brought by microgrids (the old dimensioning has to be maintained in parallel, by law).

On one side, such an inertia is required to give time for opposition to raise and possible disadvantages of new technologies to be identified. On the other side, it puts utilities under the threat of being by-passed by private companies installing microgrids below the points of common coupling, which is already legal in Switzerland. This calls for a more proactive public sector, both at national and local levels, as to guarantee the continuity of the public service.

The threat of new entrants Indeed, if we look at the other respondents' answers, the research on new opportunities for new entrants and existing providers appears to be a fast moving field. Actually, another contact stated that utilities already see telecoms as possible competitors. Some respondents suggest that large customers already have an economic interest to adopt these solutions (for security or other reasons), while end users could arguably be attracted by new products, either by direct bill reductions or other reasons (early adopters).

The full liberalisation of the electricity market and the decreasing technology prices will facilitate the entry of these new players. However, the policy maker does not observe nor expect a significant impact given the current context of indifference from the public. DSOs, on the contrary, see liberalisation as a threat and consider it unwelcome, given the fact that private companies would work for profit rather than for the common good, threatening the power quality,

If competitors actually start growing, they would leave public utilities facing a dilemma: these could take the lead, design new products and deploy smart solutions at distribution scale, probably provoking controversy on different grounds (price increases, privacy, role of the public sector...), or let end users take the lead, in which case those may opt for solutions from other providers. In any case, as pointed out by the DSOs themselves, increased network maintenance costs or reduced revenues due to self-consumption would have to be fed back to all customers, which poses social fairness problems. This calls for regulatory changes and new measures, which we explore in the next part.

3.3 Microgrids in practice

This part presents whether microgrid generalisation could start in the near future, and what prevents their deployment. Some microgrid barriers are mentioned in the literature, but as they are strongly dependent on the context we chose to present them only now. However, they are integrated in the database, and a table of identified barriers is given in the appendix (Tab. 6). Possible policies are also listed in the appendix (Tab. 8) and treated more qualitatively here.

3.3.1 Perceived barriers

Competing with the current system Most of the barriers appear to be linked with the existence of the current system. This system, as underlined by one academic, is only "accidental", and stems form an epoch when the electricity supply was centrally ensured by a state utility, and centralised production facilities were technologically more efficient and less costly. These barriers appear on three levels.

From the economic point of view, the existing system is amortised, making transaction costs (technical design, contracting between participants) for the installation of a microgrid high in comparison, as mentioned by the TSO, the policymaker and one academic. However, the two other academics, the DSO and the manufacturer see a significant research effort and the emergence of new tools that allow to cope with the complexity of the conception stage, reducing the height of this barrier.

On the institutional level, incumbents may oppose to the emergence of new solutions if they threaten their economic model as foreseen by most respondents. Indeed, DSOs affirm their will to impose any measures required to secure their revenues in order to continue to ensure the legal reliable electricity supply. In Switzerland, this opposition will be all the more efficient as utilities are publicly owned and have a non-negligible weight on policy decisions. They could put forward the possible impact of microgrids on the technical infrastructure to trigger political action.

Indeed, on the technical level, microgrids could disturb the electricity system according to the TSO, the policy maker, the manufacturer and one academic. Moreover, the separate optimisation of microgrids across the country could lead to a non-optimal state at the national level. Yet any reduction, or suggested reduction, in the supply quality would be unacceptable in Switzerland, given the reliability of the current system, as pointed out by the policymaker, one DSO and the pension fund managers. Protective measures could therefore be taken, with the risk that they overshoot and hinder the deployment of any kind of microgrid.

Fear of the unknown – the polarisation of the debate Independently from the technical performance, if microgrids were involved in other kinds of controversies (price, political exploitation, landscape, privacy, health[20]...), they could come at the center of a very polarised debate, which would be prejudicial to their deployment, as pointed out by two academics. This is all the more a threat to a spread of microgrids as the existing system provides a satisfactory service and microgrid implementation relies on acceptation/willingness to participate by the end users. According to one academic, it should be prevented by ensuring complete transparency.

The most typical example of such a controversy is the data handling issue, acknowledged by one DSO and one academic. The DSO pointed out the paradox, for the operators, of having to operate their system optimally (in the future, using meters and actuators in households), while billing the energy consumed, which may lead to conflicts of interest and subsequently disputes. Privacy issues are also mentioned, but minimised by a second academic on the ground that anyway people already accept to use internet tools that exploit their personal data. Also controversial is the possibility that the differentiation enabled by smart technologies results in a 2-tied electricity supply: wealthy clients receiving enhanced service and being proposed efficiency measures – enabling more savings – while less fortunate customers would pay blindly for their electricity consumption, which may even become more expensive if network costs have to be increased[21]. One academic acknowledges this possibility, while another academic minimises it.

On the opposite, the current indifference of the users (including commercial or industrial users) for energy issues reduces their willingness to involve in microgrid projects, a view shared by most of the respondents as was discussed in 3.2.3. This could be a barrier to a large scale deployment. One DSO sees it but as an opportunity, since it would allow the operators to deploy a microgrid without public involvement. Based on the discussion in the previous paragraph, this could raise a fierce opposition if the initiative gains visibility, and would not be a recommendable path.

Techno-economical barriers due to the context Pure technical (feasibility) and economical (profitability) barriers to microgrids are raised by one academic, one DSO and the TSO, due to the the current situation, which prevent some values from being extracted. On one side, DSOs can not take advantage of the investment deferral value of microgrids as the dimensioning of their system is set by regulation, regardless of the energy management structure within the network. On the other side, feed-in tariffs make it useless to maximise real-time self-consumption, disabling the network cost savings value for end users (but also resulting in additional costs for the distribu-

[20] The discussion around the possible impact on health of the waves emitted and the use of data collected by smart-meters in other countries is one example of polarisation of the debate on the energy system because of issues unrelated with energy.

[21] Fereidoon P. Sioshansi, president of Menlo Energy Economics and representative of E-CUBE in California, during a presentation at IEA on the situation of Californian utilities, evoked this problem as well.

tors). This is not explicitly mentioned but is implicit when several of the respondents mention network cost savings as one main driver for a microgrid implementation.

The other DSO and the other two academics note that new affordable technical solutions will soon enter the market. One academic also points out that the capital intensive nature of the investment (and associated risk) are reduced by the fact that funds are sourced locally, on the users of the microgrid who will benefit from and finance its operation. In this context, the diffusion of microgrids could become possible, or at least first signals of it, which we tried to detect through the last questions of the interview.

3.3.2 A future for microgrids?

Overall trends The evolution expected by the DSOs, as mentioned in 3.1.3, is a "thick present", the continuation of current trends with no large disruption. They exclude large microgrid deployment in the coming years. On the other hand, the policymaker already sees a shift of the stakes from the TSO to the DSOs, implying a change in the governance of the grid. Together with the national instances, international institutions also have a significant impact in Switzerland, namely the setup of the European market, pointed out by the TSO, which requires a strong transmission system and paves the way for a system interconnected at large scale.

Most stakeholders acknowledge the research being done on the field of microgrids related technologies, namely storage, and expect cost reductions. However, as one DSO points out, the impact of these reductions on microgrids is uncertain. Indeed, cheaper technologies would induce a decrease in the electricity price, thus an increase of supply security. This disables some values added by the microgrid concept. Anyway, most respondents call for continued effort on research at all levels, including on new standards.

Possible disruptions However, trends at the scale of end users are also pointed out, as the growth of new renewable energy sources. This could be a trigger for more proactivity in the distribution side, as acknowledged by the DSOs themselves and the manufacturer. Other technologies could also change the situation, for instance electric cars, mentioned by one academic, which are already seen to impact the load profile on the Norwegian grid. These decentralised facilities, for now acting only as pure loads or sources seen from the grid, could be an enabler or even a driver for microgrids, or smart grids in general, if their flexibility is harnessed.

This requires a change in the regulation. Indeed, on the governance level, a trend to phase out from subsidies is seen. This would increasingly enable the network cost savings value of microgrids for end users, as opposed to the direct sale to the grid at feed-in tariff. One DSO mentions a push for a softening of the regulation, for now as to be able to bundle their electricity distribution activities with heat distribution. Further work on the regulation could enable the investment deferral savings for the utilities.

3.3.3 The necessary debate

This section has made explicit how the short sight and inertia mentioned in 3.1.3 and 3.2.3 are obstacles to the deployment of microgrids, all the more as the current system is relatively efficient and reliable. It is interesting to see that in countries where the existing system is less reliable (US) or inexistent (India, China), microgrids are actually growing fast, as studied in 2.1.1 and acknowledged by some respondents as well.

The weight of policy This makes the decision of entertaining and developing a strong transmission system, as opposed to switching to a more locally oriented electricity supply, a quite political decision rather that a technical one. Indeed, the barriers identified are more social, political and regulatory barriers than economical ones, at least for the public utilities – private companies are still struggling to find business cases, but this could be rather due to the lack of marketable values in microgrids, as proposed in 2.2.1.

For now, these decisions on the energy future of Switzerland are been taken with relatively low involvement from the citizens, and even from their representatives (the weak participation to the debates on the Swiss energy law is illustrative of this situation). Some of the respondents, representing public bodies (DSOs and policymaker) see this as a rather inevitable fact, while other stakeholders are more optimistic on the possibility of an increased awareness (which may be triggered by an unexpected event, as was the case of the Fukushima accident, or by a campaign from some stakeholders).

Energy supply vs. Energy services This involvement could, according to some of the respondents (namely one academic and the manufacturer, but also one DSO), be fostered through the "creation of new needs" and the development of new attractive products, which is ongoing and could be fostered by the market liberalisation. Those could be based on the smart technologies and the information and control they provide, which may trigger controversies as explored in 3.3.1. Those problems on information management and differentiation are not new, and currently it is assumed that users will choose the degree of privacy they require as a function of the service they desire and the amount they are ready to pay. The problem is that the product considered here is electricity supply, which by itself is non-differentiable and, in Switzerland, mostly a public service.

However, microgrids do enable the development of such new products, expanding energy supply, without relying on a large costly distribution network infrastructure. Their marketisation, if driven by private companies, will be profit-oriented, as pointed out by one DSO. It would also destabilise the incumbents, as they see it themselves, with a risk that the overall reliability of the system ultimately decreases, and makes fear a rebound effect in consumerism is encouraged. DSOs therefore prescribe the continuation of the current public service, with a focus on efficiency. Other solutions are for now difficult to envisage, as, for public utilities, proposing differentiated energy products (beyond the current differentiation, relying mainly on the amount of information provided to the user) would be, politically, a very controversial decision.

Redefine the public service Nevertheless, the reflection on these matters may become indispensable, given the current opening of the markets and the growth of decentralised solutions. To engage this reflection, more proactivity would be needed. Comparing with other countries, Swiss utilities would but be in a good position to introduce changes as unbundling regulations are not as constraining as in other places, allowing them to own not only the distribution infrastructure, but also production infrastructure. Moreover, as publicly owned institutions they could take advantage of synergies with other public services, which is already taking place for instance with the installation of solar panels on the roof of public buildings, mentioned by one DSO.

As a starting point, a debate on the definition of the public services itself may be needed soon, as to give utilities the flexibility needed to cope with future perturbations. This discussion is also called by one of the academics, as to align energy efficiency goals with other objectives and gather public adhesion and participation. One DSO acknowledges that a microgrid is "easier to manage", which suggests that the concept might make it easier also for the wider public to handle energy issues as it provides a fresher, more comprehensive and localised, view on the energy nexus, to base the debate on. The pension fund manager suggests that microgrids allow for a "feeling of membership", fostering the acceptance of the solutions.

We suggest that the deployment of microgrids, by regrouping the users into communities and providing a basis for the discussion, would help the redefinition of the essential needs and associated products beyond electricity supply. The outcome could be the basis of a new model for DSOs, who would have to provide new offers to answer this demand, as they see themselves. In the next section, we further discuss how the microgrid concept, and the decentralisation that it implies, could contribute to deep changes in the energy system.

4 Discussion and recommendations

In section 2, we presented the state of the art in the field of microgrids, showing the diversity of applications and possible business models and concluded with their applicability (enabling regulation) in Switzerland. Section 3 explored the position of different Swiss stakeholders in the field of energy, with the observation that the Swiss energy system is mainly controlled by public bodies, which have a large inertia and are constrained by existing regulations, but might face important challenges in coming years due to the development of solutions which enable increased levels of self-sufficiency – although the speed of the actual diffusion of this solutions is uncertain, and would deserve more research, for instance with a survey conducted over a representative sample of the population. These challenges are not only technical, as observed by most stakeholders, but also inherent to a possible change in the market structure and revenue streams, requiring a restructuring of existing institutions.

In this last section, we suggest some policy measures based upon the microgrid concept. These could help to the restructuring of the energy system while enabling primary energy savings and an increased involvement from the end users that could help to reduce final energy consumption. As to make explicit the place expected for microgrids, we base these recommendations on a couple of scenarios, both for the overall system and for the microgrid systems that would be implemented ("microgrid templates"). An original framework, which makes explicit the technical, economical and organisational aspects of microgrids, is first proposed to describe these scenarios.

4.1 Determining a long-term goal

Currently, policies are more and more underpinned by a range of scenarios[22], which policy-makers try to reach through adequate measures. They are believed to be a sounder basis for policy making than an approach based on trying to inflect current trends (e.g. try to decrease carbon emissions), as those trends are usually strongly interrelated and the effect of policies on them is difficult to model.

These scenarios allow to give a clear vision and goals for the future to all stakeholders, facilitating the understanding and acceptation of measures while allowing to coordinate different policies. In the field of energy, in particular, debates tend to be easily polarised as soon as they reach the attention of them large public (pro and against nuclear, pro and against wind turbines, pro and against "fracking"...). The clear delineation of (hopefully) consensual scenarios should allow to avoid such a polarisation on the subject of decentralisation.

This subsection first proposes a framework for the creation and evaluation of scenarios for the (de)centralised energy system and better underline paths leading to these scenarios. We use this framework to propose a couple of scenarios representing two opposed visions of the future, and then try to conciliate them.

4.1.1 Three dimensions of (de)centralisation

All along the sections before, it was mentioned that the creation of a microgrid has to be undertaken not only from the technical point of view, but also from the economical and organisational ones. Also, existing microgrids have been shown to have different degrees of decentralisation, not only because on their scale, but also because of their governance structure ("true microgrids" vs. "utility minigrids"...). In the same way, the overall energy system

[22]The most known policy scenario is probably the 2 degrees scenario, which federates all the climate policies of the last years around a common goal: restricting the global warming to 2 degrees, a threshold beyond which the stability of the current natural system is believed to be seriously threatened [49].

has technical, economical and organisational components which all must be taken into account.

Presentation We formalise this separation by considering an energy system as a superposition of a technical infrastructure, a market design and a institutional hierarchy. It is therefore a superposition of three networks, as illustrated by Fig 19. The first is the energy grid, where nodes are sources and loads and edges are the energy flows (namely electricity flows, but other fluids can be considered); the second network has market participants as nodes and cash flows as edges; the third network is one of management instances connected by information flows.

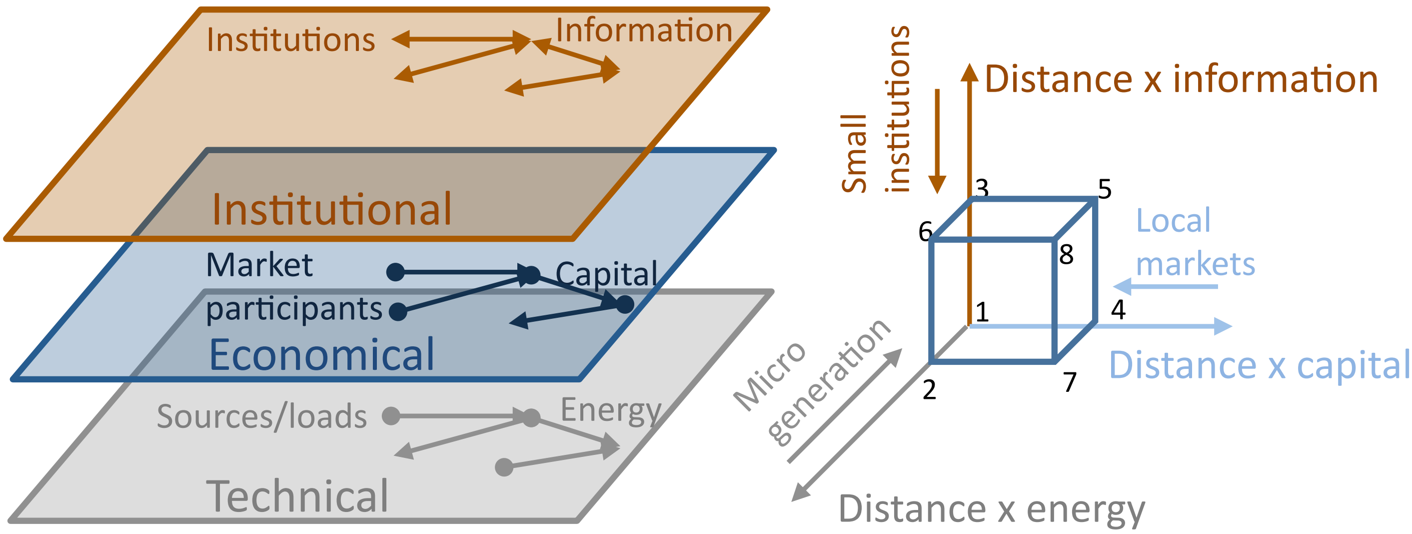


Figure 19: *The 3 layers of an energy system, and associated "centralisation dimensions": the more centralised the system, the more the flows will travel large distances. As examples, we place the 4 microgrid categories presented in 2.1.2. The "true microgrid" (1) is a fully decentralised energy system component; "the virtual microgrid" (2) has to rely on distant energy sources; the "utility microgrid" (3) is managed by an overarching institution; and the "franchise microgrid" (4) has his values extracted by an external enterprise.*

We propose that the system can be decentralised on each of these layers independently. It can therefore be placed on a tridimensional space where each axis corresponds to the degree of centralisation on one layer. Objectifying the degree of centralisation deserves further research, based on extensive data analysis, but it will depend on the size of the nodes (capacity of the plants, wealth of the investors, geographic extension of the power of instances) and/or the distances (that can be defined as physical distances, but also as any length measure within a network) between them. For instance, a decentralisation metric could be the volume of the flows times the Cartesian distance traveled by those flows as a measure of centralisation (kWh×km, \$×km, kB×km).

Note that this framework can be applied to an entire energy system or to one of its components (microgrid). Moreover, it can describe the design/creation of the system (in which case hardware, investment, resp. decision should be considered) or its operation (energy, cash flow, real-time data). In both cases the relevant measures might change.

Application We use this framework to characterise our scenarios and motivate the assignment of the proposed measures to the different governing levels. Later on, it could also be used to help the design, implementation and evaluation of the new energy system, or, at local scale, of microgrids. In a domain where the focus is still mainly on technical issues, it gives more place to other stakeholders than the utilities, and it facilitates the consideration of stakes beyond energy supply (social fairness, confidentiality...).

For the scenarios and system conception, the separation of the three layers provides a clearer understanding of the resulting system (although interactions between the layers must be taken into account). For instance the technical complexity of a microgrid implementation, which might be a deterrent, can be decoupled from the business case conception and subcontracted. The modelling of those layers by a network of flows allows to evaluate the system. For instance a component of the system is standalone and sustainable if it receives no inward flows on any layer (meaning that it relies solely on local energy sources – provided that these sources are renewable, on local capital and on local competencies for the processing of the information). Enabling this standalone components fosters the use of local, small resources which may otherwise be neglected given the large capacity of main nodes. This ultimately may increase the resources available, as illustrated by Fig. 20, and is to be balanced with the possibly lower efficiency of smaller nodes (more costly maintenance, lower economies of scale...).

This framework is also relevant for policy-making as it provides a support to define the appropriate level and timescale of policy measures. The technical layer has large lead times, thus any action on it has to be planned on the long-term. The market layer needs some stability to avoid creating uncertainty and risk for investors, thus can only be changed gradually. Anyhow, small state intervention is expected on this layer in liberalised economies. The institutional layer can be changed more often, although the readability must be ensured. Regulations acting on this layer are more likely to trigger public debates than pure technical or economical decisions (restrict the sharing of information on the users, create local or more regional instances...). In the field of energy, measures have rather been taken on the two first levels (e.g. feed-in tariffs as to increase the share of renewable technologies in the mix and liberalisation of the market), but little has been done to change directly the institutional structure of energy management.

4.1.2 Two opposed scenarios

Below we try to make explicit two competing views of the energy system, based on the literature, the micro-Delphi and the informal interactions dur-

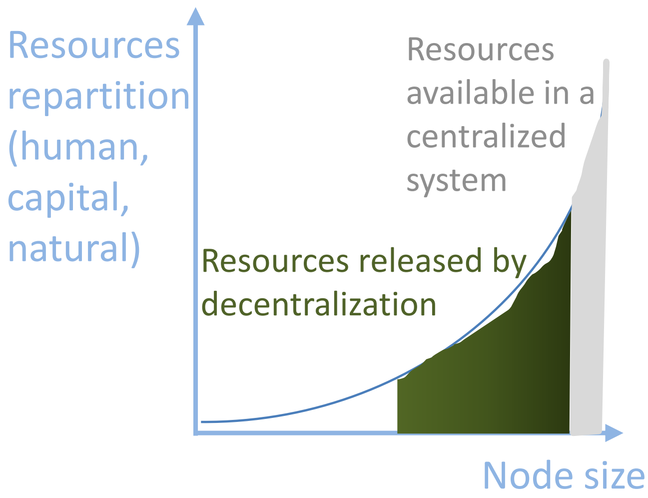


Figure 20: *Possible repartition of the resources in a network according to the size of the nodes. Wealth, typically, has such a distribution, wealthier individuals concentrating most of the wealth. By enabling and encouraging the use of the resources from smaller nodes (for instance implementing a microgrid collaboratively), the total amount of available resources increases. This gain is to be balanced with possible drawbacks, for instance efficiency losses*

ing the project. We use the 3 dimensions of centralisation to decouple the different aspects of these scenarios, and represent them on Fig. 21. They do not represent the position of any stakeholder in particular, but they allow to underline possible advantages and disadvantages of system (de)centralisation and to anticipate possible points of conflict. Indeed, the discussion on the decentralisation of the energy system was considered very interesting by most of the people who contributed to this project, and it appears that they often have a defined vision of the future that they sometimes defended quite vigorously. This may lead to political deadlocks if not handled carefully.

Note that in any case, a 100% renewable system is assumed, as this seems to be the only sustainable option on the long term[23]. This choice is likely itself to raise a controversy. We acknowledge that intermediate states, where non-renewable sources are used, will be required, but they can not be sustained on the long term because of the physical limitation of resource reserves.

The "Centralised Smartness scenario" In the "Centralised smartness scenario", the energy system is managed centrally over large scales. On the

[23]Progress in the field of nuclear energy could change the situation though, if new generation fission reactors allow to extend the duration of fissile reserves to several thousands of years or if nuclear fusion is mastered. However, the higher actual or perceived risk and cost uncertainty associated with these technologies make it likely that, if an option is available, they will be abandoned for political reasons, as was already the case in some countries after the Fukushima accident.

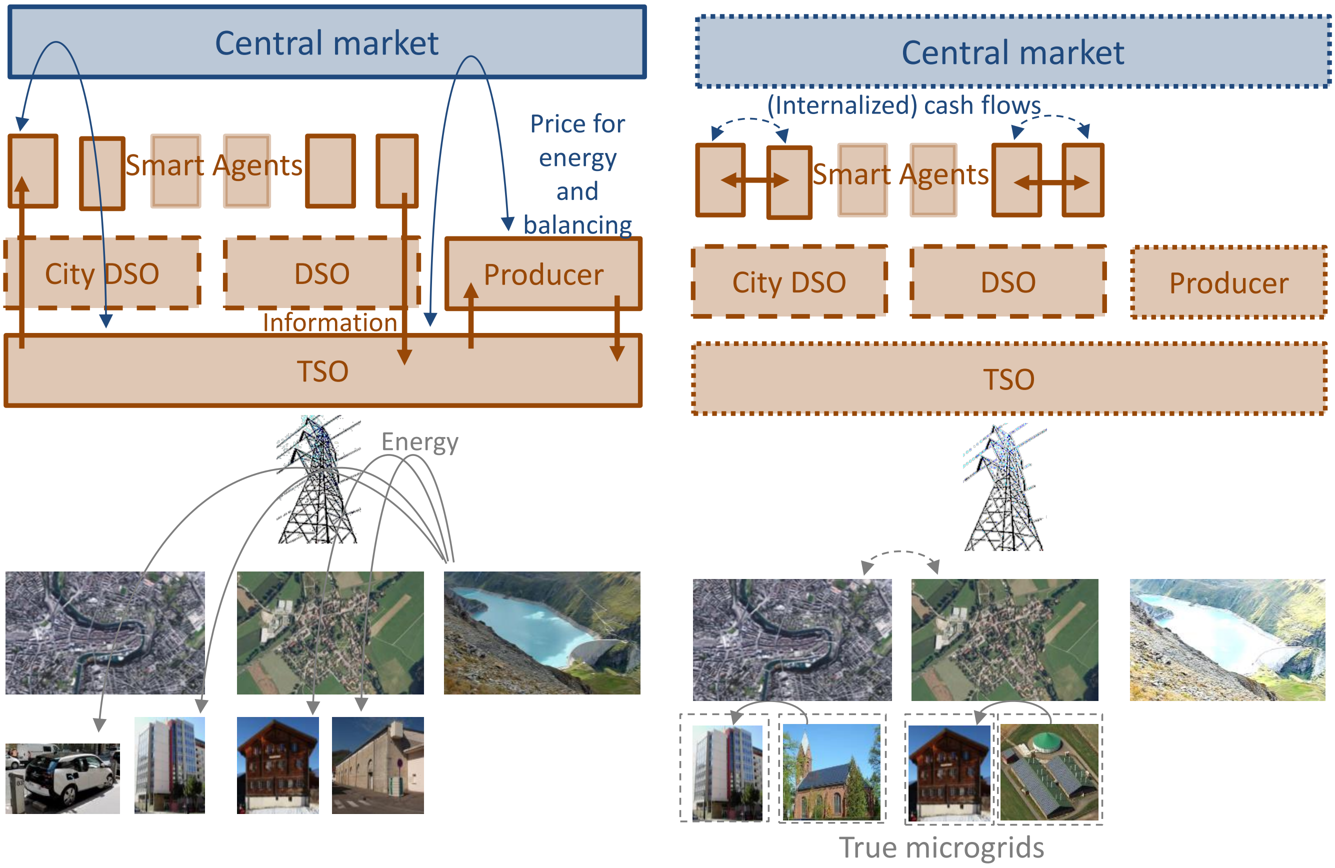


Figure 21: *Two extreme scenarios for the future energy system. On the left, the "Centralised smartness scenario", where all available resources are coordinated by a national operator playing on a central market. DSOs keep their current role and mainly ensure the maintenance of the wires as to ensure enough capacity. On the right, the "Local autarky scenario", where small energy consumers create standalone nodes as to avoid any network costs. In this scenario, the business case of DSOs (wires maintenance, energy sale) and later of TSOs (grid balancing, electricity transport sale) become unprofitable.*

technical layer, production facilities are mainly centralised, be it wind turbine fields or large solar power plants, together with dams (incl. pumped storage) and large gas power plants (biogas or gas from other chemical processes) to ensure balancing. They supply large aggregates of (pure) loads, namely cities, which also requires a strong transmission network. On the economical layer, due to economies of scale and smaller transaction costs, most facilities are owned by a handful of entities, either private or public, playing on a global market. On the organisational layer, smart technologies are deployed all across the network and share information with a central control instance to balance globally the load with the production. This corresponds to the path taken by some European countries, for instance France that is planning the deployment, by a central electricity distributor, of smart meters in 90%

of the households by 2021[24], in parallel with the realisation of large off-shore wind farm projects.

The positive aspects of this scenario are that it can in principle be attained with little change in the current situation. The variability of renewable energies should be globally smoothed (studies have shown that wind blows continuously somewhere across Europe, and the addition of solar and wind production can be fairly constant during the year [34]). The current market design already allows and encourages the exchange of large amounts of renewable energies. The governance structure of the system, namely the involvement of end users, could stay almost unchanged, making it socially easier to implement. Also, a global optimum in terms of efficiency and of emission in the transition phase is expected to be achieved by the control algorithms.

On the other hand, the computational complexity of managing such a centralised, large and strongly interconnected grid is very large, all the more as the interactions between the electricity grid and other elements (market, communication delays) are to be taken into account [12]. Moreover, the centralisation of energy production, market platforms and control servers makes higher the impact of a possible dysfunction, due for instance to a human error, an extreme weather event or a terrorist attack. The centralised market also could result in inefficient investments, for instance the construction of large renewable plants where the resources are the most present, without taking into account the distance to the loads, resulting in additional infrastructure costs or curtailment (as is the case with North Germany's, resp. North China's wind). Linked with the centralisation on the institutional layer and associated uniformisation of data handling, the system would loose flexibility. Also on the organisational layer, not involving the consumers (i.e. not sharing the information and control with them) is double edged, as it exposes the system to a rebound effect: being subsidised to increase their efficiency, but having no knowledge about how this efficiency is improved, customers might increase their final energy consumption while believing to contribute to lower primary energy imports. Smart grids would need smart users to be effective. Lastly, strong opposition can arise against infrastructure projects, in particular if they are imposed top-down.

Other disadvantages can arise from the path to such a scenario. For instance the reliance on gas (or other fossil fuels) power plants has implication on the supply security, if the resources are not domestic (as is the case in Europe). Also, the construction (and maintenance) of a strong transmission infrastructure can prove very costly, and its conception and implementation takes a long time and is vulnerable to a change in the context (as was the case with stranded assets in Germany). Lastly, the lack of incentives to an actual change of habits could result in a system where always more capacity is needed to supply a growing demand, which may pose problems on other fields than energy supply (e.g. land use).

[24] This announcement has caused some polemic due to possible impacts of the smart meter frequencies on human health and the fairness of the access to the data by the clients, which may cause changes in the law by 2020.

The "Local autarky scenario" In the "Local autarky scenario", energy, money and information flows over large distances are banished. Energy is managed at local scale by local utilities, using available resources and small storage units (electric vehicles or dedicated batteries). When enabled, the markets are local, or between neighbouring cells. Note that the size of the production facilities is not necessarily small: a city may be powered by a couple of large power plants (gas, dams) if not enough distributed renewable resources can be harvested.

In this scenario, more renewable resources could be harvested as local potentials are exploited to the maximum (arguably better than if a central authority makes the decisions for hundreds of sites). On the economical layer, the enabling of local markets may allow to capture more of the value produced locally and boost the development of local enterprises (which increases tax revenues). On the institutional side, the multiplication of instances opens workplaces. It allows for a greater resiliency of the overall system as a failure or need to change the operation of a single cell would imply relatively low costs. The limitation of resources makes energy savings a priority, requiring the users to change their habits or at least to share part of the effort by improving the efficiency of their assets. This makes them become aware of the stakes of the energy transition, and they would be more likely to support technologies that have little environmental impact as such an impact would occur close to them.

On the other hand, this need for involvement may face opposition, as users would prefer to keep their habits and to externalise the inconveniences of the facilities (e.g. smell caused by the production of biogas, appearance of PV panel on the roofs of a historical neighbourhood...). Moreover, the overall efficiency of the system may be lower, both from the energy and the economic[25] points of view. The multiplication of small facilities on the technical layer may also means the use of more raw materials, together with the risk that they are spilled in the environments (e.g. generalising the use of chemical batteries for the storage may not be a viable solution and increases the risk of mishandling of toxic waste). The mismatch between available resources and load concentration may also make the model not viable in some contexts.

The path to this scenario implies a reduction in electricity exchanges at large scale, threatening business models of the distribution and transmission system operators, who may therefore oppose to its development. Moreover, the shift of the responsibilities to the local level may result in decisions been taken by less qualified personal, which can result in non viable cells. Any local energy supply reliability deterioration would be socially unacceptable.

4.1.3 Balanced proposal

The two scenarios above are voluntarily a bit extreme, but they frame the possible options while giving an overview of existing conflicts. A more realis-

[25] Although it could be argued that as long as the money is spent locally, larger expenses only stimulate the economy.

tic option also has to take into account the current system as a starting point, and should enable as much as possible both the benefits of decentralisation (benefits of microgrids, as listed previously) and those of centralisation. The three scenarios are sumarised on Tab. 1. In the following recommendations we will target such a median scenario, which takes the form of an hybrid, hierarchic system, on the three layers, as shown on Fig. 22.

Scenario	Centralised smartness	Local autarchy	Balanced
Setup	Centralised facilities, Global (continent) market, Central operator	Match of local sources with local loads, Local/peer-to-peer markets, Local operators	Coexistence of both scales: priority given to local solutions, but higher level coordination of microgrid nodes
Advantages	Smoothing of renewable energies variability, Global optimisation	Local potentials fully exploited, Local capture of value, Resiliency, Involvement from users	Flexible (incubator), Transpose global stakes to local level, Increased acceptability
Disadvantages	Vulnerability to node failure, Operational complexity, Risk of inefficient decisions, Risk of opposition or rebound effect	Disruptive for user's habits, Inefficient facility redundancy	Design complexity, (Currently) lack of standards
Perspectives	Small changes: no reduction of dependency in foreign ressources, continuation of current trends of increased consumption, Context-reliant infrastructure (fragile profitability)	Radical change: Strong opposition from users and incumbents, need for more qualified personal	Incremental changes: No need for a global, top-down designed solution

Table 1: *Description of 3 possible scenarios for energy systems.*

3 trees The technical layer would be a multi-microgrid, where production and loads are matched locally as much a possible, the grid being used as a fall-back solution in case of failure and as an auxiliary supply when needed. The local optimisation should be completed with a global optimisation (based on aggregated data). Existing large facilities or necessarily large facilities, namely large dams, can be handled in two ways. Either they are managed by the global management system as one more node aside the microgrids or they can be piloted piecewise by several microgrids, each piece being integrated in a virtual microgrid and handled together with the microgrid, as a single node, by the overlaying grid. In the later case the management of the load on the transmission infrastructure may require *ad hoc* solutions, to handle the "virtual" energy flow (which *a priori* cannot be predicted by the TSO if the microgrids only provide information about their aggregated output).

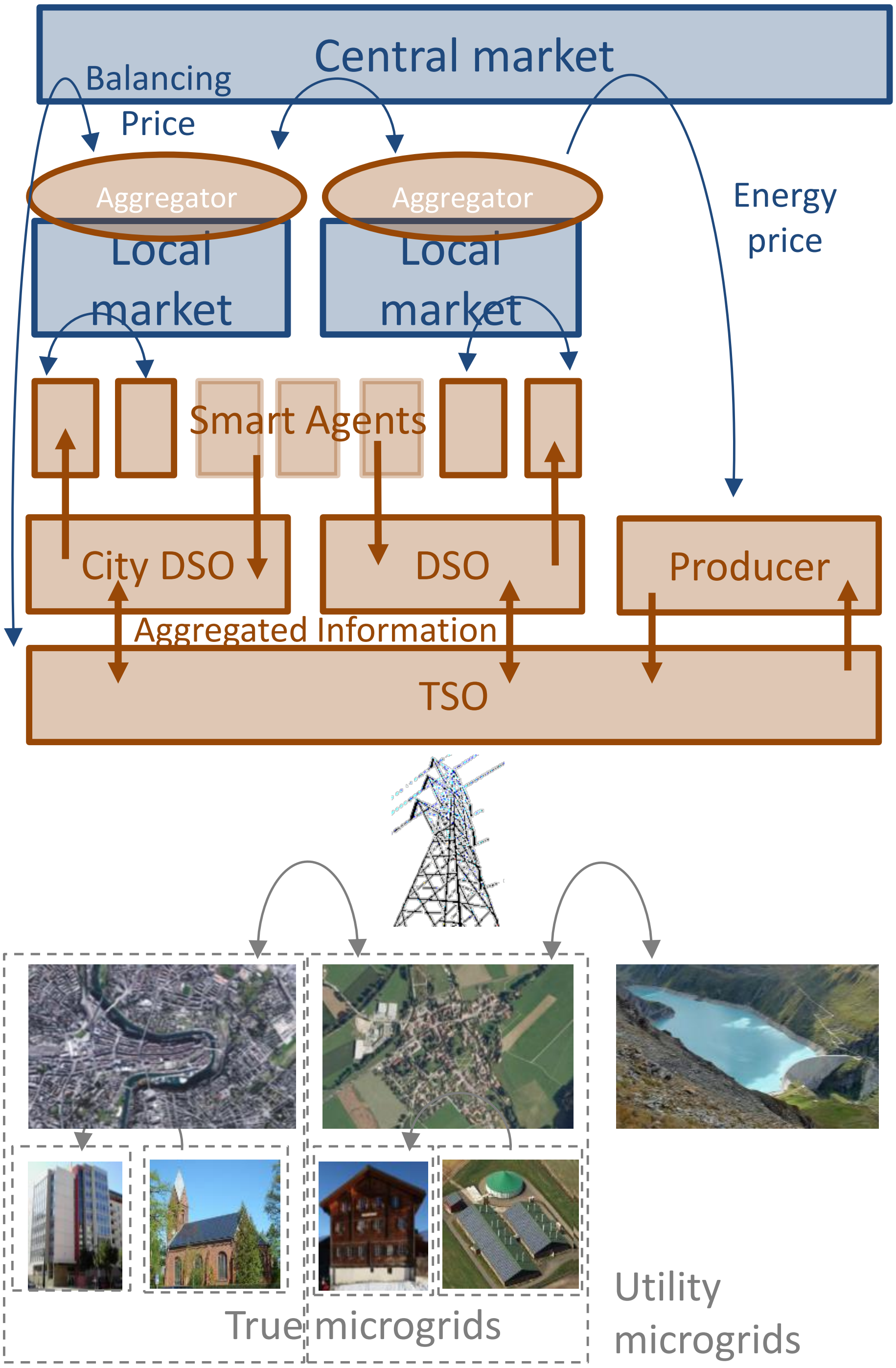


Figure 22: *Hybrid scenario for the future energy system. It is a hierarchic system, where end users (or cooperatives) create small, non self-sufficient microgrids, which are aggregated within larger utility milli-grids, which can be autonomous or still rely on remote centralised facilities. The total capacity required for the remaining large facilities and for the transmission grid is expected to decrease. On the top the economic layer is represented, in the middle the organisational layer and at the bottom the technical layer. Photos from google maps and wikimedia commons.*

The same two possibilities exist for the ownership structure (single owner or shared ownership).

A similar layout is envisaged on the economical layer: the microgrid operator enables a local market, where energy and balancing capacity are traded. One trader in this market would be in charge of also trading in an overlaying market as to take advantage of the external situation and to enable the sale of ancillary services by the microgrid (aggregator). For the local markets to stay decoupled, locational signals would have to be applied, reflecting the cost of connexion infrastructure and transmission losses.

Finally, on the institutional layer again a similar layout is envisaged, where local utilities (most probably publicly owned) would design the microgrids taking into account the local resources and local social choices and policies. These local utilities would be framed and helped by regional or national instances as to ensure enough communication and the exploitation of unevenly distributed resources. Lastly, standards would be issued by international instances as to ensure interoperability between the microgrids.

Flexibility and adequacy Such a structure is flexible, whereby the exact weight and size of the different nodes can be discussed and adjusted. However, in principle it enables the benefits of microgrids, while also ensuring that a global optimum may be reached. Note that the short-run objectives to be reached by a microgrid are aligned with the current long-run objectives for the energy system: use of renewable sources is required to increase autonomy while emissions must be reduced, or will trigger strong opposition as they would be emitted locally; imports are reduced, thanks to the implementation of local control and balancing; and the competencies to maintain and operate the microgrid are required, thus retained, locally.

This structure also enables and requires some participation from the citizens, although this intervention may be variable from place to place. In principle, the fact that the DSOs will own the assets used for energy supply would put them under pressure of choosing socially accepted solutions, more than if they only purchase the electricity from those assets. Citizens are usually more sensitive to local risks, an tend to align with their values if considering local issues, as was studied by [8][26].

The separation of the microgrids from each other also means that the overall system is flexible and can host multiple technology mixes and control technologies, thus being an incubator for research: within the microgrids, the systems tested can be very diverse, provided that the interface with the grid in standardised. Lastly, such a system can in principle be reached starting from the current situation with relatively small, incremental changes. Below we make some more precise suggestions on the format that the microgrids can take, and later on how to trigger their deployment.

[26] J. Axsen presented his work at the IEA during the project.

4.2 Three templates for Switzerland

In section 2.2.1, we presented the value propositions of microgrids, and 2.2.3 presented 3 possible business cases. Later on, section 3.2.3 summarised the position and motivations of the Swiss stakeholders, completing a presentation of the Swiss context done in 2.3. Building upon those results, we can propose some likely business cases for the Swiss context, by matching the motivations of the stakeholders with microgrid value propositions and deducing what roles these stakeholders might be willing to endorse.

They focus on three typical setups: an private entity, a village or a city, and are summarised on Tab. 2. Other possible business cases thought of, less specific to the case of Switzerland, are listed in the appendix (Tab. 7). These templates make explicit, as for the scenarios, the target of the policies suggested later, thus their importance.

Template	Self-consuming users	Autonomous villages	Served cities
Project initiator	end user (citizen, enterprise)	Local authority (municipality)	DSO
Setup	Building(s) scale, PV, CHP, (hydropower), User-driven business case	Village scale, Hydropower, CHP (methanisation), PV, Local market business case	City/region scale, Hydropower (poss. remote), DSM, PV, Energy services company business case
Drivers (Fig. 18)	Users: Minimise energy expenses, (Minimise risk), Manufacturers: Maximise profit	Support locality, Reduce externalities (comply with regulation)	Ensure grid reliability & maintenance, Maintain revenues, (City: improve image)
Activated MG values (Fig. 12)	Grid use reduction, Increased self-supply, Power reliability, Turnkey product	Grid use reduction, Increased self-supply, Local activity, Externalities reduction	Flexible maintenance of the grid, Information, Customer decoupling (energy services), Externalities reduction
Barriers	Feed-In tariff, Low grid electricity price	Lack of interest/inertia, Local opposition	Legal & Regulatory rigidity
Facilitators (*observed*)	*Decreasing FIT, Incr. El. prices, Larger offer range*	*Ambitious environmental targets*, Push for Swiss autarchy	*Low user involvement*, Regulation change, Competition/Threat on DSO revenues
Leads to scenario	Local autarchy scenario	Balanced scenario	Centralised smartness scenario

Table 2: *Description of 3 possible templates for Swiss microgrids.*

Note that, as discussed in 2.2.2, the "microgrids" envisaged here may be only partly self-sufficient, at least in the short term, making a trade-off between cost and delivered service possible. However, to deserve the name microgrids, they should proceed from an approach integrating all loads and sources in the considered perimeter, and taking into account the impact or the interaction with the overlaying grid. This makes the discussion realistic, as otherwise a fully grid-tied microgrid is very unlikely to be an attractive option given the current quality and reliability of the Swiss power system.

4.2.1 Users increasing self-consumption

This setup uses the user-driven business case (Fig. 14). The resulting microgrid would be a true microgrid, possibly powered by combined heat and power gas turbines (as suggested already in 2002 by [36]), solar panels and, in some cases given the high potential in Switzerland, by small hydropower. The user may endorse or subcontract the design of the system and its installation/maintenance, but the operation should be computer-aided and ensured by the user (choice of set values, schedule...), and he would own the assets (a service-based microgrid, corresponding more to a franchise microgrid, would also be possible, but does not correspond to the current trend in commercial offers).

Possible drivers It would proceed from the motivation, both for energy intensive enterprises and citizens, of minimising energy expenses. This makes the reduced grid use and increased self-consumption values of microgrids relevant (however, in the current regulatory context the actual sale of ancillary services can not be foreseen). Currently, these values are disabled for medium producers by the feed-in tariffs in place, which make it more profitable to use the grid as (virtual) free storage, but those are being reduced. Moreover, the price of grid electricity is expected to increase consistently on the long term for a variety of factors, according to the swiss federal office of energy [41] (the forecast is of 2011, and seems to be realising as the price increase was 5% for households from 2014 to 2015 [14]), which increases the incentive for this setup, as shown on Fig. 23. On this figure, note that we show the levelised cost of electricity from PV panels[27]. The marginal cost of producing this electricity once the panels are installed is almost null, meaning that the additional investment in the microgrid is even more meaningful (the cost of the PV installation is a sunk cost).

Furthermore, this setup is favorable for energy manufacturers, who would develop new products and to offer turn-key solutions, as was proposed by some respondents. They would have the possibility of offering system operation and maintenance services, locking in customers. As a consequence of this involvement, the costs of batteries and of microgrid solutions are expected to decrease, making this template more and more attractive.

A less probable but nevertheless relevant driver is to secure electricity supply. As mentioned by the TSO, the Swiss electricity grid is not immune to possible failures. As the swiss economy is based on service-related enterprises, relying on computer infrastructure, such failures would have particularly high costs. For now this risk is handled through *ad hoc* protection circuits, but as microgrids are further studied they may become more profitable options, as besides electricity supply protection they provide other added values which would allow to amortise directly the infrastructure.

[27] The cost due to the amortisation of the investment.

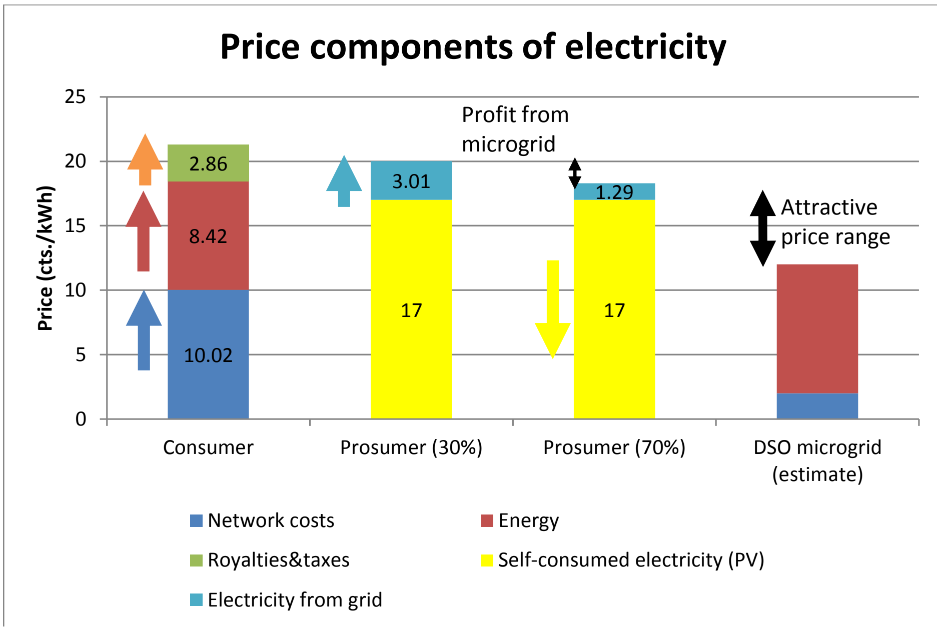


Figure 23: *Electricity price components for Swiss consumers. This diagram shows the interest, for consumers, to maximise their self-consumption through the purchase of a microgrid product. The profit obtained depends on the prices of grid electricity, which are increasing, and prices of photovoltaic, which are decreasing. Other technologies than solar are not yet considered (e.g. microturbines) but could further change the figures. This gains must be balanced with the cost of deploying the microgrid, also decreasing. They are, for now, disabled by feed-in tariffs. As DSOs can arguably deploy a more efficient microgrid, they would be able to offer price savings more attractive than the deployment of a microgrid. Data for consumers and prosumers from [41] and [54] – note that these are average values, relatively high regional discrepancies exist in Switzerland. "Electricity from grid" computed from average price:* $P_{grid} = [(1-\eta)P_{consumer} + \eta P_{PV}] - P_{PV}$*. The data for DSOs was not found, indicated heights are purely illustrative.*

Discussion This setup is likely to spread in the medium to long term if the current trends remain unchanged (enabled self-consumption, phase out of feed-in tariffs, increasing network costs, decreasing prices for an increasing range of offers and passive public utilities). However, in the short term, as pointed out by most respondents, the interest of citizens and society in general for energy supply (and energy services) is not high enough for this model to attract attention.

This gives some time to current publicly owned incumbents to anticipate the impact of the spread of such a model. Indeed, the reduction in grid use and electricity purchases that it implies would shrink their current revenue streams (both for large electricity producers and for distributors). This would threaten the overall system, and if not handled timely could result in a shift towards the "local autarky scenario", where private companies would provide most of the energy solutions.

4.2.2 Villages going autonomous

This template would rather be based on the Local Energy Market business case (Fig. 15), with the initiative being taken by the municipality who would mandate its distributor for the local balancing of the grid, which in turn would require this distributor to enable a local market as to be able to use locally available capacity (or install this capacity himself, but this goes against the current trend towards unbundling). This setup would require a relatively high support and participation from the citizens, as the capacity available and number of nodes are typically low. In Switzerland, such a village would likely be powered by hydropower, although solar electricity could be a component. A methanisation unit could provide biogas using agricultural waste. If the inhabitants are enough involved, they may accept the installation of wind turbines, although this has proven difficult in Switzerland. The power could come from a large facility (dam), of which only a fraction would be used (shared ownership).

Possible drivers The main driver for this setup could be the push for autarky, which has been observed in communities in the Alps [1, 65], and the value attributed to locality, pointed out by some respondents. The initiative could also be encouraged from the exterior if the benefits for the national system stability and independence are put forward, as one academic mentioned, answering our micro-Delphi.

The increase of renewable energy capacity, energy savings and emissions reduction (if heating and other carbon-intensive services are integrated into the microgrid) could also be a relevant value, helping local authorities to respect federal objectives. These values could also be relevant for some citizens.

However, the monetary value for the implementor (the local authority) would not be straightforward to capture (it would be mainly captured by the DSO, and benefits to the local authorities would have to be redistributed to end users as incentives). Other benefits could arise from indirect effects according to the context (local activity, visibility on the media...), but for a village this would not be very relevant.

Discussion This setup relies on an initiative from the local authorities, driven by non-economic motivations, which, as our study pointed out, is unlikely in the short term due to the inertia of the society. Moreover, an additional barrier may be a possible polarisation of the debate around the means needed to ensure the self-supply, as feared by one academic. Indeed, it has been shown that while they usually adhere to the energy independence vision, stakeholders become reticent when it comes to accept landscape changes, air pollution or other consequences of this vision [65].

However, this model could be encouraged by higher level governing instances or other organisations, for instance with communication campaigns (including indirectly, e.g. campaigns on the energy security for Switzerland), availability of technical expertise, energy objectives or even explicit regulations. As local communities would most probably refer to the regional utilities for the implementation, those would be pushed towards a more proactive role, and in turn push for an adaptation of national instances, resulting in the overall system tending towards the balanced scenario (as long as local authorities protect their own prerogatives).

4.2.3 Services for the cities

This setup would be initiated by a city's DSO, and its ultimate form could be the Energy Services Company business case (Fig. 16), whereby the DSO would provide energy services to the city population, instead of energy supply (it might even own the devices, such as convectors, fridges or PV panels, in the same ways telecoms might own the modems they provide). The supply of energy could become more difficult than for a village, due to a larger density of population. Remote resources (e.g. dams) would probably have to be used, resulting in a virtual microgrid. On the other hand, this very density makes it easier to install district heating infrastructures and deploy other efficiency measures. On large cities, the splitting in a multi-microgrid system may make the grid easier to handle.

Possible drivers The driver for this setup on the short term would be for DSOs to reduce their network costs. In a fast expanding urban environment, deploying a microgrid with local renewable sources and balancing capacity (e.g. DSM) would avoid adding or scaling up transformers and allow smaller dimensioning for new wires, as pointed out by the policy-maker. Providing services instead of energy supply allows DSOs to manage directly the devices, thus increasing controllable capacity. This value is currently almost disabled by existing regulation which imposes the dimensioning of the facilities, as pointed out by some respondents, but a coordinated action could allow for a softening of these standards.

As for the village, the city would benefit from the increase in renewable energy penetration and compliance with the corresponding federal objectives. As suggested by some respondents, the resulting "green image" could also bring indirect benefits, such as tourism or installation of enterprises wanting to benefit from this image, but this would only be true for the first early adopters.

In the longer term, however, the main driver may become the diversification of the energy services offer and securing the associated revenue streams, enabled by the information and decoupling of customers values of microgrids. Indeed, as shown in 3.3.3, public utilities may soon face fierce competition from new entrants, who would for instance enable the "self-consuming users" setup described above. This competition would threaten the curent business model of DSOs, relying on electricity sale. Thus they might have to enable new products (as envisaged by one DSO respondent), which would be based on energy services, as electricity by itself is non-differentiable.

Discussion The main barriers to this setup are regulatory and administrative. Internally, DSOs lack the legal flexibility to change their economic model (price heat together with electricity, for instance). Externally, the size of the aggregated load requires to obtain the approval from the regulator for some measures, and the ancillary services that a microgrid could provide (e.g. voltage or reactive power, rather than frequency regulation) are not yet enabled.

However, such a setup is unlikely to face large opposition from inhabitants, who do not have to be strongly involved except if they do want to, and would not, in majority, incur possible negative externalities. As DSOs have some weight on political decisions, they could obtain changes in the regulation without too much opposition. Ultimately, the generalisation of such a setup, where villages and smaller nodes would be aggregated with the cities and decisional power centralised on the larger DSOs could result in a system closer to the "centralised smartness" scenario.

4.3 Recommendations – Proactivity for all

Sections 3.1.3 and 3.2.3 have pointed out the inertia and the medium-term sight of the public stakeholders in the field of power distribution, while underlining the problems that their standstill position may pose in the currently changing system: cheaper technologies, increasing number of prosumers, liberalisation of the market... The last two sections, 4.1.3 and 4.2, have in turn proposed some possible future scenarios, both at system and system component scale, to orient this changes to. The "hybrid system" scenario, based on the current system with the progressive entrance of microgrids, would reduce the constraints on the grid while increasing the share of local, renewable energy resources in the consumption. It addresses the problem of institutional inertia as it can be reached through relatively small and often local measures, of which consequences are easier to predict and restrained spatially than decisions taken at national level. This reduces the risks associated with the transition and increasing the flexibility of the resulting system.

We now try to give some concrete recommendation on how to reach this system. These recommendations are targeted to public or publicly owned incumbents, as identified in 3.2.3. Indeed, their possible opposition is the first barrier identified to a microgrid deployment, and has to be overcome. Moreover, the micro-Delphi has shown that the influence of these stakeholders is still strong in the Swiss power sector, and as they currently provide a reliable and trusted service this is wished to continue.

We make the separation between the national, regional, and communal or city level. In Switzerland, each should mainly address one layer of the energy system as presented in 4.1.1, at its scale and time horizon.

4.3.1 Legislators and regulators provide the framework

National instances are expected to have a clear long term orientation as to provide a stable framework for the policies and decisions of other stakeholders. As the full liberalisation of the market is scheduled for 2018, and their interference into the organisational structure of local utilities is not welcome (in Switzerland), their role will be greater on the technical layer. This is already the case, as the Federal office for energy provides guidelines for the conception of the future energy mix of Switzerland, which are pursued through feed-in tariffs and subventions. The long lead times of technical infrastructure also corresponds to the time-frames of national planning.

It can be noted that the national instances would have the possibility of imposing the path towards any scenario on all levels. It could set a standard for local markets while imposing the organisational structure of the DSOs. Moreover, restraining the number of third parties that can have access to data on the personal consumption of users would prevent entrants from doing load aggregation. Similarly, limiting the number of loads that can be managed by single server or enterprise (for security reasons) would also set the size of the control cells. However, this is likely to raise a large opposition, particularly in Switzerland where regional autonomy is defended. We would rather recommend less radical actions:

Provide a national roadmap for the deployment of microgrids Aside the roadmap for smart grids [20], the planning of the transmission grid [63] and the Swiss Energy Law targets in terms of renewable energies [7], a long-term plan should be done as to address the design complexity barrier of the balanced scenario.

The roadmap should target the exploitation of existing potentials at local scale, as to match as much as possible the production with consumption. A precise mapping of all renewable resources (e.g. hydro-power, biomass, solar, wind, ev. geothermal), loads and existing grids would be the first step. This data would allow to determine regions that can materially become “cells” of a future microgrid-based system, that is where the identified potential for renewable energies and associated aggregated variability matches the expected load and possibly available balancing resources (combined heat and power, storage and load side management). It could then be applied for instance by using locational signals. As Switzerland has an history of such planning tools and a number of competence centres, the creation of the roadmap is feasible within a relatively short time.

Enable new solutions for the balancing of the grid, with new standards As pointed out by our respondents, such solutions (e.g. creation of a locally balanced microgrid instead of increasing the dimensioning of the transformer) are currently unlikely to be accepted by the regulator, disabling part of the savings and other added values brought by microgrids.

Already envisaged by our respondents as realistic measures are: the legal possibility for the DSOs of reducing the dimensioning of their facilities, according to balancing solutions implemented; the creation of new ancillary products, possibly beyond frequency regulation (e.g. reactive power regulation) and the possibility, for small nodes, to sell them; the creation of a grid communication standard as to enable real-time operation of the national grid using the local capacities (already a recommendation of the federal energy office [20]). Enabling real-time or time-of-use pricing is another solution used in other regions of the world which incentive the installation of balancing capacity, but might face more opposition.

Coordinating the launch and maintenance of those standards at national level is particularly urgent to avoid that every enterprise develops its own system (as is already happening for house automation), reducing interoperability. On the long term, international standards will also have to be adapted (namely at European level), but due to the modular and flexible structure proposed by the balanced scenario they can be implemented later, as action is taken by foreign countries.

Revise feed-in tariffs and other subsidies The current feed-in tariffs for solar and small hydro-power have triggered a large demand resulting in a long waiting list for projects [45]. These subsidies disable the grid cost reduction value of microgrids for end users. Moreover, the projects are subsidised independently from their impact on the grid, which on the medium term may result in higher costs for DSOs and TSOs. In fact, the current regulation implies that utilities have to incur all the costs required for accommodating new injection sources on the grid [44].

A revision of the system is therefore needed, besides the phasing out of pure feed-in tariffs that is already foreseen. The new subsidies scheme should encourage system-friendly solutions, beyond renewable sources (design reducing the variability, demand side management implementation to smooth output...), as is recommended by the IEA [28]. In particular, they should include locational signals (prices reflecting the actual cost of the infrastructure that was required to "transport a given kWh") as to reduce the impact on the network loads and subsequent costs. The aforementioned roadmap could be taken as a basis for the definition of these subsidies, but some preliminary measures could require less deep analysis and be easier to implement, for instance higher subsidies for renewable sources in urban areas (high load concentration).

Prepare solutions for existing assets If an increasing number of decentralised production and balancing facilities are deployed, the transmission grid and centralised assets (in Switzerland, namely dams) may become less and less profitable on the long-term. In the case of dams, the glacier retreat is also a factor that may impact profitability already on the medium-term [22]. Penalising local storage, as is envisaged in Spain [50] and as suggested by the policy-maker, would be a protective solution but would severely hinder the deployment of microgrids.

Instead, measures should be taken to ensure the profitability of these assets during the rest of their lifetime, and the planning of further developments should take into account possible changes in the profitability context. For Switzerland, an important contribution to this profitability could be the international trade, providing electricity transport across the country and balancing capacity to foreign countries. This would be facilitated by an opening to the European market, already envisaged. Internally, the costs and associated risks could be shared by enabling ownership or rental of part of the assets by the utilities using them, who in Switzerland often already have some experience in the coordinated management of such assets.

Research, education and empowerment Those are important points for most of the respondents. Not only the research on new solutions (hardware and software) should be encouraged, but their field testing and later application should be facilitated. Solutions should be open and safe, as to improve the cyber-security of the smart grid systems. The creation of a platform which would allow the conception of a microgrid and bring together its stakeholders was evoked by one respondent. Such a platform could be made available by Suisseenergie as are already energy calculators for buildings, and would present not only the gains for the users but also for the overall system (according to the same respondent, putting forward the gains in terms of independence at swiss scale could be effective). This would empower regional utilities and local stakeholders, but ultimately they have to take action, as we explain next.

4.3.2 Innovative revenue streams for DSOs

DSOs are more flexible than national instances, namely the TSO, as their decisions have a more localised, thus smaller in terms of costs, impact on the overall energy system. Their structure is rather determined by the collectivities owning them, so that their main impact will be on the economical layer, by enabling local markets and creating new products. Their goal could be to provide microgrids as the ones described in 4.2.2 and 4.2.3. Those should allow to collect profits both from end users and external stakeholders, which are income sources for the collectivities owning them.

In some countries, DSOs are already struggling to find new business models. Indeed, the DSOs are already usually legally in charge of buying energy from prosumers. In the current system, a generalisation of the prosumer behaviour would therefore reduce drastically their profits. In Switzerland, the need for new revenue sources starts to be felt, with some companies launching innovative pricing policies. We propose the following measures:

Enable local markets for electricity supply and balancing By proposing prices for generated electricity lower than retail prices, but higher than wholesale prices, DSOs could retain some profit, as explained in 2.2.3, based on [60]. They could increase this profit if they achieve savings on the infrastructure by balancing electricity locally. This requires to create also a market for balancing capacity. In general, pricing should encourage system-friendly behaviour rather than maximum output, as is currently the case, since DSOs have to buy electricity at retail price. At least one Swiss utility is already implementing such an intermediary price, proposing a solution deemed promissory by the policy-maker. In a further step, DSOs could operate an exchange platform where users would trade directly these products, but as users are very unlikely to be willing to participate in such a platform in real time, intelligent agents would first have to be enabled, which would take decisions according to instructions set by the user (willingness-to-pay) – research on this field is still ongoing, and the regulation would have to be adapted.

Shift towards service-oriented products Today mainly the electricity or other energy agents (including network connexion) are priced. Some Swiss utilities are also providing heat, but pricing this together with electricity poses regulatory problems, as mentioned by one DSO in our micro-Delphi. Other Swiss DSOs also start providing internet access. This could generalise to other services, such as cooling, lighting, ventilation, energy management (including information on the consumption) etc., whereby the DSO would price the service, that they would provide at lower cost than initially paid by the consumer thanks to savings in terms of infrastructure, primary energy use etc. Such a model has been studied for the context of the UK [24]. It would first require to enable smart management of the grid, which is already being implemented by some DSOs, and may face regulatory barriers linked with the mandate of the DSOs, which requires local authorities to revise their policy, as explained below.

Enter national energy and ancillary service markets Once enabled the local balancing and management of the grid, DSOs will be able to play on the national markets, as foreseen by the TSO during our micro-Delphi. Even if the total amount of energy supplied is not expected to be very large (if the match between resources and loads is done), the control latitude and flexibility of the system may be sufficient to provide ancillary services to the overlaying grid. Those would either help to balance the rest of the national electricity grid or could in turn be aggregated to provide balancing on the international level. Some ancillary services can and are already being traded by at least one aggregator in Switzerland, while others require previous action from the national regulator as to be enabled, as suggested in the previous section.

Accommodate competition by seeking synergies On the two previous points, DSOs may face a significant competition from other stakeholders. Indeed, energy manufacturers, both Swiss and international, are more and more offering advanced energy solutions and energy services, while non utility companies are starting to play in the Swiss ancillary services market. However, DSOs have an advantage given their strong link with local authorities. Indeed, one DSO mentioned the use of public roofs for the implementation of solar PV panels as one way of lowering the barriers to the deployment of these solutions linked with contractual complexity. More generally, public buildings could be early adopters of the DSO offers (as was done for district heating in at least one Swiss city), as to facilitate the testing of the technologies. By seeking such organisational synergies DSOs could become faster than competitors, while also proving the credibility of their offer and building upon the trust they already earned. Such synergies require the involvement of collectivities, which we study in the last part.

4.3.3 Collectivities show the path

In a decentralising energy system as described in 4.1.3, the collectivities play a key role, be it communes or cities. Groups of users or even enterprises can also be impactful but may lack the motivation or information for such an involvement. Both collectivities and private stakeholders can be much more dynamic than larger instances, therefore measures can be taken for the shorter term. They usually do not have technical expertise and are not entitled to change the economic layout, but they can change the organisational layer of the system, as to reach the models presented in 4.2 (according to their nature).

In Switzerland, they already play a significant role, as many communes decided to take in charge their energy supply by creating a dedicated DSO or taking a share into an existing enterprise. Apart from energy, they sometimes also operate a transportation network or even communication grid through dedicated enterprises, together with other public services. The joint management of all these services could enable interesting synergies.

A special note for collectivities: more than for other stakeholders, it may be useful for them to take these measures explicitly in the frame of the deployment of a microgrid. Indeed, a microgrid may be presented in a way to make it attractive (putting forward the renewable sourcing, the reduced reliance on external ressources or other factors according to local specificities), raising awareness, interest and even a feeling of membership from the users, which in turn is an enabler for the microgrid according to some respondents as presented in 3.3.3. Also, by transposing external stakes to the local level (energy production, grid balancing), a microgrid deployment may help citizens to understand those: as one DSO mentioned, a microgrid "sounds simpler to manage". Moreover, as the deployment of a microgrid can imply changes on other infrastructures (electric transportation, building isolation...), it is more likely to attract attention than a debate on the electricity distribution (this being double-edged).

Enable the discussion between all concerned stakeholders This can take several forms. Providing information to the users on the projects and their implications is the first priority. This involvement of the users is often promoted for projects in developing countries [3, 19], as to ensure the education and involvement of the users, but not very common for Swiss projects as users are deemed not interested and reticent to participate, as pointed out by most respondents. The implementation should also be done fully transparently, for instance being regularly audited. Users should be able to give a feed-back on the process, and ideally discuss in person about it ("pizza helps", according to one respondent). Not only would this increase the understanding, acceptability of and involvement in the project by the users, but it would also allow to find and exploit some potentials that would be difficult to identify and use systematically otherwise (typically private household applications).

Find and document a consensual solution As pointed out by our respondents, Swiss citizens are quite pragmatic and able to reach a consensus provided that the benefits of the solution are clearly shown. Possible concerns (comfort, confidentiality, technologies used, health risks...) must be addressed as early as possible. In case of disagreement, a compromise should be seek to avoid a polarisation of the debate, which could be fatal to the project. As presented in 3.3.3, the discussion and consensus may have to address the definition of the public service itself (provide energy services rather than electricity), and thus would require the involvement not only of local stakeholders but also higher level governing instances as to ensure the compliance of chosen solutions with regulations.

Stimulate synergies The mandated enterprise (typically the local DSO) should be brought in close contact with other administrative divisions who could have a significant impact on the local energy system (building management, transportation...), as suggested in the previous section. The communication between those must be facilitated, for instance through an interdisciplinary committee. The final target should be a system were not only electricity distribution, but also other energy flows (fuel, gas...) and other energy services (heat, lighting) are integrated and jointly optimised. Indeed, electricity represents only a fourth of the final consumption, and is responsible for a very little share of the emissions, so that effective measures should target all the components of the energy balance.

Share information about successful cases One of the main barriers to the deployment of microgrids is nowadays the lack of standardised solution. Sharing the experiences done in different places is primordial, as to reach a better understanding of the diversity of contexts and possible solutions. This is also the role of national instances and NGOs, but the publication by the implementors of clear evaluations of their own systems is necessary.

Conclusion

On the relevance of microgrids as a basis for the future energy system, our conclusion would be that they are both a threat and an opportunity. On one side, the (partial) autonomy from the grid and the product differentiation that they enable makes possible a direct competition between entrants, private energy manufacturing and energy service companies, and incumbent public utilities. This threatens the current revenues streams of utilities and, possibly, the economic viability of existing infrastructure. On the other side, the enhanced grid management that they allow could become a source of savings for incumbent utilities, making their offer more competitive and at the same time increasing the renewable energies share in the energy mix. In both cases, the profitability of the underlying business model has still to be proven by large scale deployment of products and is controversial among swiss stakeholders but all interviewed stakeholders agree it probably already exists for specific cases. Found estimates point towards an actual profitability, at least for modest levels of self-supply, and identified trends indicate a possible increase of this profitability. However, in Switzerland, it is hindered by some regulations, which are expected to change in the short term. This calls for more action from the public bodies to maintain the current public service level.

Microgrid values, trends and barriers An overview of the literature and of existing projects around the world has shown that the technology is attracting increasing attention and being deployed, both in the laboratories and on the ground. As a result, its costs are decreasing, and as microgrids have several value propositions, which can be bundled to give a variety of business cases, it is likely that the expansion will continue worldwide. We did an exhaustive recension and analysis of these values. At system scale, what microgrids could bring is increased reliability, flexibility and customisability (customer decoupling and information, allowing for enhanced control). For these be properly harvested, the microgrids should be deployed in a coordinated way with existing centralised assets in what we called the “hybrid scenario”, otherwise a purely microgrid-based system might prove inefficient due to redundancy of assets and non harvesting of some renewable energies.

However, in Switzerland, the micro-Delphi has allowed us to identify several barriers to a large scale microgrid deployment. Some are linked with the current regulatory environment, which disables several value propositions of microgrids both for utilities and for end users. Other barriers are linked with the position of incumbents, who, given the current high reliability of the Swiss electricity grid and the lack of interest from end users for energy issues, see no relevant values in the deployment of microgrids.

Anyway, the initiated phasing out of subsidies (namely feed-in tarifs) and liberalisation of the market (scheduled for 2018) might make microgrids an attractive option for end users (enterprises or citizens) in the medium term. At the same time, manufacturing companies are developing new microgrid products, targeting all market segments, from large energy intensive remote industries to grid-connected citizens. Other companies propose directly energy services, easier to differentiate than energy supply, although this model is not yet widely spread. These new offers might or might not be adopted in Switzerland, according to the evolution of the context. For now the relatively low expenses associated with energy incurred by Swiss consumers and the lack of clear benchmark product and proven benefits is preventing microgrids from being considered as an option.

The dilemma for utilities Should this situation change, Swiss DSOs would likely face both internal and external profitability problems. Internally, the increased self-consumption or electricity injection from end users decreases the existing revenue streams, based on electricity sale. Externally, fierce competition from new entrants can be expected, as explained in the previous paragraph. Actually, current trends found during the literature review and the micro-Delphi point towards such a change. First, electricity prices are expected to increase in the long run by the Swiss federal office of energy, for a variety of reasons. Second, active research and deployment on the ground in several countries leads us to expect the emergence of benchmarks. Thirdly, some non-utility Swiss companies are already proposing new products in the field of energy, which do not explicitly imply the installation of a microgrid but give more control to the user and allow to harvest the flexibility of their loads to sell ancillary services to the grid. Moreover, current regulations on self-consumption have been found to be rather permissive, enabling microgrids, from the pure regulatory point of view, which could in principle result in microgrids spreading anarchically.

For now, the interviewed utilities and policy maker express a rather "wait-and-see" position, and do not envisage large changes in the energy system nor in their own model for the next 5 to 10 years. This is justified by the reliability of the Swiss energy system and the fact that Swiss utilities are trusted, therefore customers are expected to turn to them if they require new products. Moreover, if utilities would take the lead in the development of microgrids, they would incur costs which would have to be passed on to the end users, which is difficult to justify in the currently satisfactory context.

Necessary action We suggest that this *status quo* should be broken by the public bodies, while they are in a good place to secure their position. Otherwise, the market share of private companies might start to increase, with possible impacts on the system reliability and on prices, as feared by some respondents. This for now is prevented by the fact that the electricity supply of a household necessarily relies heavily on the grid, which belongs to the utilities, but microgrids precisely allow to reduce this reliance.

The currently stable customer base and the possible synergies between utilities and other public instances (building management, transportation,...) provides fertile ground to test and deploy innovative solutions and harvest the network cost savings enabled by microgrids, which can then be fed back to the clients as to increase the competitiveness of the public offer.

Recomendations Finally, we provide some recommendations on how to conduct this transition. These rely on documented scenarios. For the overall system, an "hybrid system" is recommended, where priority is given to local ressources within microgrids and where a regional and national management also allows the harvest of centralised remote ressources, namely hydro-power. For the system components (microgrids), three templates are proposed according to the context, for end users, small communities and larger cities. All along the work, several tools are proposed to help conceiving and evaluating the microgrids and the overall system, namely the formal separation of the "3 dimensions of centralisation", technical, economical and organisational, allowing to decouple the technical complexity, often a deterrent, from other aspects of microgrids.

To reach these targets, measures are needed at all levels of governance. At national level, some existing regulations have been pointed out, which prevent microgrids from being profitable, thus these should be adapted. This requires a national planning of the future system, taking into account the entire structure, besides existing targets on the energy mix and grid development. At regional level, utilities should start to implement new solutions, using smart grid technologies as to enable the local balancing of their microgrid (at city scale), while providing enhanced energy services to their clients. This focus on energy services rather on energy supply has been studied in other countries and is one promissory field for efficiency increase and product differentiation, but furthermore an actual debate on the redefinition of the current electricity supply based public service must take place. At local level, municipalities should try to stimulate this transition by fostering the communication and discussion between the stakeholders, namely provide incentives for end users to involve. For this, microgrids might be an interesting concept in enabling a discussion of aspects beyond electricity distribution, with a focus on leveraging local ressources and achieving, a system that is sustainable at a scale as small (thus tangible) as possible. In that sense, they enable a grassroots energy transition.

Future work Research has also a prominent role to play in this transition. Extending our analysis to other contexts and providing tools for the actual deployment of microgrids could be the next steps:

- **Studying other energy systems**: Barriers and opportunities for microgrids depend heavily on the regulatory, natural, market and other environments. This work focused on the case of Switzerland, while only giving an insight in more global trends. However, the understanding of those other contexts will allow not only to issue recommendations to the corresponding authorities, but also to complete the general understanding and description of a microgrid-based system. The current report gives indications on where to do those analysis (meta-analysis showing deployment in US and India), proposes a tool for the analysis of stakeholder positions (intelligibility diagram) and applies a procedure to collect information that can be rolled-out elsewhere (micro-delphi questionnaire).

- **Learning from case studies**: For now, there is no example of a microgrid implementation in Switzerland. However, they are spreading in other parts of the world, including in developed countries. Finding cases which fit our "3 templates for Switzerland" (4.2) may show in a more concrete way possible designs and existing challenges. Our work is a first step in this analysis as it provides a framework for the description of the microgrid itself (3 dimensions of decentralisation) and of microgrid business cases (business case palette).

- **The microgrid conception tool**: As the case studies allow to complete the data that we accumulated, our database would provide a basis for a microgrid conception tool, which should be made publicly available, as are other calculators, to help collectivities deploy their own microgrid. Based on this database, our work provides some tools for the technical conception of the microgrid, in terms of technologies and energy flows (microgrid flowchart), determine and quantify possible costs and benefits of the system (microgrid value tree – to be expanded into a computational tools), and possible organisational structures to share those (business case palette).

- **Design a roadmap for microgrid deployment**: As mentioned in the recommendations, a roadmap for microgrid deployment is required to orient the action of local actors in how to reach a global optimum. This process implies a gathering of data on natural resources, loads and existing infrastructure (generation and grid) all across the country. An optimal microgrid map can then be determined, dividing the territory in cells where resources can balance the load, to provide a long-term goal. The path to this new system is then drawn by identifying existing centralised assets, assigning them to future cells and planning their renewal or dismantling according to the expected realised electricity production potential within microgrids. An important dimension of this research will be to determine what are the relevant levels where information has to be aggregated before being passed to the upper level and what incentives can be designed to approach a global optimum.

- **Extend the reflexion on the future of the energy system**: We have introduced the "3 dimensions of decentralisation" as a support for our policy recommendations. They could also be useful for the conception of microgrids. Beyond this, they open the way to a quantitative analysis of the decentralisation of energy systems. Possibly, systems with different degrees of decentralisation on the technical, economical or organisational layer will appear to form clusters. Advantages and disadvantages of moving one way or the other, drivers of this (de)centralisation, and impacting policies, could be explored.

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A Database content

Below are given the contents of the database described in 1.2.2 as of the end of the project. These elements can be used to create a microgrid conception tool.

B Micro-Delphi interview protocol

On page 108, the protocol used for the Micro-Delphi is presented.

C Micro-Delphy intermediate summary

In the last pages, a summary of the answers is presented.

Features	Value Proposition	Description	Remunerated	Alternative	Criterion	Parameters	=Drawbacks
Priority to and optimal use of local (renewable) resources	Primary energy savings	Increase efficiency (by reducing transmission, CHP), thus increase margin	Network operator (losses), Energy supplier (energy coupling)	Stepwise infrastructure improvements	Profit increase	Potential efficiency increase, loss reduction, bargaining power of buyers	Not decreasing energy prices while costs reduce may not be well accepted
	Reduction of externalities	Reduction of the effect of externalities (e.g. Health problems)	? Depends on internalisation scheme. Tipically authorities	Normal saving measures, less automated, less connected, less measured	Cost of avoided externalities minus the profit from the internalisation of those	Potential efficiency increase, loss reduction, bargaining power of buyers	Difficult to quantify
	Footprint reduction / Sustainable development	Reduction of ressources use, of footprint, namely through assets sharing and operational improvements	?	Normal saving measures, less automated, less connected, less measured	Future cost of ressources scarcity	Reserves, degree of dependence over technologies	Difficult to quantify, predict
	Grid use reduction	Reduce electricity imports through local production (ev. storage), thus also avoid connection costs if any, and enable upgrade deferral	End users, Energy supplier	None	Cost of electricity import	Imported electricity, amount of RE capacity, cost of connection (usage hours w/ congestion, needed redispatch), cost of electricity	Benefits sharing difficult to implement. May make the distribution/transmission grid a stranded asset - thus faces opposition from incumbents
	Energy exports	Sell power back to the grid	Energy supplier, end user	Conventional power plant or DG unit, VPP	Price of exported electricity	Policy support (FiT), wholesale market price	Too much decentralised generation with no control destabilises the grid. In the extreme case of a MG scenario, there is nobody to buy the energy.
	Energy price stability	Reduce exposure to price fluctuations, international/national pressure	High-level end user, Authorities	Long-term contracts	Expected cost of fluctuations in price of inputs	Avoided material/energy flows, expected prices	Full autarky is technically difficult and constraining
Implementation of smart control	Final energy savings	Reduction in energy consumption	End user	Normal saving measures, less automated, less connected, less measured	Monetary value of saved energy	Price of grid electricity/other inputs, savings potential, production capacity	Reduction as only objective function does not allow for grid stabilization. Self-consumption requires legal framework
	Improved asset use	Reduce the payback time of investments (typically batteries, but also avoids curtailment of extra renewable power), thus the risk	DG owner	Large scale connexion	Savings, incl. risk premium	Interest rate, infrastructure reliability, energy market expectations, number of hours with demand match capacity	Local optimization of asset use may not be optimal globally.
	Increased renewable capacity	Grid stability (release constraints) through balancing of (unpredictable) renewable capacity (MW) share	TSO	Increase interconexion, build additional capacity (plants, FACTS, centralised storage) (OR forbid connexion)	NPV of new infrastructure	Variability to be compensated (share/size/type of renewable), smoothing capacity of the microgrid, often future values to be estimated	Technically difficult, requires standards.
	Peak shaving	Reduce worst case dimensionning of the wires and transformers, increase their lifetime	TSO	Increase wires and transformers capacity or replace them more often	NPV of new infrastructure	Peak height and width constraints the necessary storage/demand side management capacity	Technically difficult, requires standards.
	Provision of ancillary services	Sale of ancillary services (as VPP): Frequency regulation, voltage regulation, blackstart, fast response, Demand shift, Operational reserve, load following...	Aggregator	Build a power plant	Profit from ancillary services sale against profit from power plant	Pricing of ancillary services on the market, available capacity/user flexibility, outside option capactiy	Requires standards, low prices
Implementation of monitoring	Information on system	Improve grid infrastructure optimisation and maintenance through constant monitoring, avoid non-technical losses (theft)	Utility, implementor	Large scale smart grid	Saved control costs	Monitoring capacity, processing capacity, intervention price	Risk of information overload, reliability of measurements

	Information on users	(For implementor) Information gathering, (for end user) entertainment	Service provider	Smaller scale implementation (smart-buildings!=microgrid)	Price of information, participation of the users	Willingness to pay of users, value of energy consumption information	Systematic Information gathering may face public opposition.
	Education/Involvement of users	Raised awareness on energy issues, enable/stimulate collaboration and action on those, e.g. through gamification (""video game"", ""social network""?)	? Tipically Authorities	No sensibilization, or advertising campaigns	Cost of avoided campaigns and other positive externalities	Price of campaigns, considered extenalities	Depends on political choices, difficult to quantify
Push for local implication/control	Increase Renewables acceptability and coordinate penetration	Improve acceptability of delocalised production facilities while co-ordinating their implementation for optimal potential use (incl. EV, heat...)	DG owner, Energy Supplier	Keep implementing in distant places	NPV of shorter term profit against lower proft increase for the outside option	Obtained implementation acceleration, obtained profit from implementation	Pose problems at utility level for variability compensation
	Local economic activity stimulation	Workplaces linked with the microgrid operation/maintenance	? Tipically Authorities	Normal development, with delocalised workplaces	Cost of subventions and development programs to attract equivalent amount of economic activity.	Degree of local operation, complexity of operation, trade-off local/contracted services (installation, operation)	Quitte technical work, centered on energy management
	Increase tax revenues	Increase tax revenues from local energy sale, services provision and activity	Authorities	Smart grid with high shares of DG	Tax income	Tax rate, existing regulation, proportion of local DG/services	New tax levies can be misperceived
	Synergies stimulation	Get stakeholders together thus stimulating innovation, at a larger scale showcase a larger number of technologies	? Tipically Authorities	RnD programs	Avoided RnD incentives	Degree of RnD stimulation, cost of RnD	Difficult to quantify
	Risk hedging	Reduce investment risk through the small scale and the careful consideration of actual needs	Investor	Large investments in carefully audited projects	Risk mitigation	Total number of microgrids financed, stability of the system (population, wealth...)	Local users may not be willing to invest at all by themselves. Large investors require credibility that a small organisation may not have.
	Collaborative, flexible renovation/ maintenance/ operation of the grid	Reduce costs by gathering more stakeholders around grid renovation or operation (interruptible connection)	Utility	Normal grid replacement, implementation of a large scale solution	Renovation cost reduction	Financing scheme, price of infrastructure, use of infrastructure	Complex management, requires standards
Reduced grid dependence	High quality power supply	Supply quality(reference) / reliability	High-level end users	Contingency generators	Expected cost of failures	Expected Duration/Impact of the failures, degree of internalisation	Push for high reliability technology - expensive rather than accessible
	Increase system reliability, resiliency and security	Avoid costs linked with failures (blackouts)	Utility	Normal stabilisation measures	Expected cost of failures		Islanding capacity of microgrids can be a disturbance for the broader system if not coordinated.
	Decouple customers and enable new products	Increase added value extraction from consumers through differenciation	Energy supplier, Distributor, Utility	Single energy quality standard (BAU)	Increase in added value capture	Demand curve for energy, new services enabled	Risk of creating a 2-tied society, technically not trivial
	Marketable product	Extract value from customers wanting to buy a turnkey solution for specific or created energy needs	Installer	Provide unbundled products (PV panels, batteries, software...)	Willingness to pay for turnkey product	Complexity of the product, flexibity, deployability	Regulatory issues with energy distribution above certain capacities.
	Electrification of rural zones	Energy supply	Energy supplier	Grid connexion	NPV Grid connexion and Grid electricity price	Technology State of the Art, Energy mix	Expensive for typically underdevellopped zones, which will minimize immmediate costs

Table 3: *Microgrid value propositions*

Name	Description
Project initiator	Starts the project
Project funder	Finances the project
Estate owner	Provides the land for the infrastructure
Manufacturer	Provides the hardware and software
Installer	Installs the infrastructures
Consumables supplier	Provides fuel, spare parts, etc.
DG owner	Owns (buys) the generation capacity
Energy producer	Uses the generation capacity (ev. lending)
Energy supplier	Buys and sells energy to and from the final users (and buys on the wholesale market if needed)
Third party service provider	Uses the available ressources (information) to provide products beyond energy supply to users (e.g. home automation)
Aggregator	Uses the available ressources (information) to provide products beyond energy production to grid (e.g. ancillary services)
Network owner	Owns (buys) the distribution infrastructure
Network operator	Provides energy services by using (buying/renting) available ressources
DSO	Provides energy at PCC with the distribution grid (if applicable)
TSO	Provides energy at PCC with the transmission grid and/or buys ancillary services (for now single actor in every country)
End user - Consumer	Consumes the energy or services provided by the above
Regulator/Mediator	Coordinates the entry of the other stakeholders, lowers transaction costs and enforces contracts.
Local authority	Issues rules and levies taxes/fees on the profits (eventually redistributing them). Can be a local government, the consortium board...
Legal regional authority	Provides a general framewok
Rest of the society	Influences the microgrid development in several ways but has no direct action

Table 4: *Microgrid roles*

Stakeholder	Motivations	Biases	Comment
Local Policy makers	Ensure energy access, Comply with environmental targets, Support local economy	Electoral calendars (short sight), Small means	Financed by citizens -taxes (often end users)
National/regional policy makers	Achieve environmental targets, Ensure strategic energy security, Provide legal framework, Analyse context changes	Trade-off with growth, diplomatic issues, large inertia	Financed by citizens -taxes (often end users)
Regulator	Find efficient market design, Create technology and safety standards, Prevent abuses	Large, unflexible associations, may reject unconventional solutions.	Appointed by governments. Transparency and readability are important stakes
NGOs	Lobby for environmental targets	Not always experts, sometimes an extreme position is needed for readability, but may lead to wrong solutions/unefficient lobbying	May represent a given group of the society
Citizens	Use energy services, Minimize energy costs, Maximize comfort, Reduce environmental impact, Protect private sphere	No expertise, no sensibilisation	May be pushed by Authorities.
User cooperatives	Use energy services, Minimize energy costs, Reduce environmental impact, Coordinate members	Not representative of the other citizens	Often state participation. Subject to be disolved in case of lack of motivation.
(Industry) unions	Create business-friendly environment, Improve marketting image	May be profit oriented, often conservative	Represent their members. May be fairly influent
Energy intensive/reliant entities	Use premium energy services	Push for high quality, rather than accessibility	Usually financed by Authorities, thus citizens
Banks, investment funds	Maximize profit, Minimize risk, Show green image	Possibly no expertise, biased by other stakeholders	May be pushed by Authorities
Entrants, private energy companies	Maximize profits, Innovate	Obligation of quick results, short term thinking	Depend on existence of liberalised electricity market
TSO/Large scale utility	Ensure reliability of transmission grid, Sustain profitability, Contribute to standards	Large infrastructure, not flexible, interest in high investment rates and high transmission flows	Natural monopoly, thus usually regulated/financed by Authorities
DSO/Local utility	Ensure energy access, Sustain profitability, Ensure reliability of distribution grid	Link with local authorities (political choices)	Sometimes financed/ controlled by Local authorities
Energy providers	Ensure energy access, Sustain profitability	Link with utilities, large inertia	Often owned or owning other utilities
Universities	Innovate	Field compartimentation, risk of misuse of technologies	Ultimately financed by citizens
Energy manufacturing companies	Maximize profits, Innovate	Focus on profit, Technological bias (sell what you have)	Always remunerated/executive
Smart-world companies, Startups	Maximize profits, Create new products (service/information)	Focus on profit, Gadget-oriented objects (marketable) rather than energy efficient	Complementors of the microgrid operators, implementors...
European Countries	Enable free-trade		
Oil/gas exporting countries	Export energy agents		

Table 5: *Microgrid stakeholders*

Type	Barrier	Description	Factors	Solutions
Technical	Technical feasability	Microgrid design is still an active research field. Depending on the available ressources, some features may not be under reach (e.g. islanding capability, voltage control, protection...). This can tipically be solved with additional infrastructure, thus strongly relates with the economic viability issue.	Available ressources, Regulatory standards (connexion, safety...), technology state of the art	RnD required to develop affordable, reliable solutions; Holistic conception from the beginning.
	New technologies	Multiplicity of new technologies, sometimes with no benchmark: no pricing (actual estimation costs in terms of working hours) nor guarantees on the fiability.	Envisaged Complexity	Public consulting, subventions to engage the evalutation
	No global optimum	The optimisation (technical or economical) of the microgrid operation allows to reach a local optimum that may not be compatible with the system-wide optimum (e.g. electricity storage instead of transmission to a distant point of consumption with better efficiency)	Optimisation algorythm, inputs from the system, internal and external market design	RnD required to develop suitable communication standards, incentives must be provided to reach the global optimum
	Complex design and operation	The conception of the microgrid must be holistic, there are few engineers capable of such for now. Same for the operation, that differs from the one of a conventional grid, and requires information about the overlying grid.	Size of the system, availability of ressources, existent infrastructure	Public consulting, Training of ingeneers
Economical	Economic viability	May not be viable economically given the price of energy and the acknowleged revenue sources (e.g. self-consumption, locational, efficiency value) and existing markets - relates with Regulatory compliance.	Price of primary energy, price of technology, installed infrastructure, degree of internalisation profitable services	Internalisation of externalities for current system, technology subventioning, legal enabling of revenues
	Financial cost and risk	A microgid requires a long term capital investment that is costly and may become non profitable if some factor of the environment changes (new policy, technology, electricity price)	Cost of the system, country stability, cost of capital	Subventioned loans, risk sharing agreements
	Business model development	Value extraction and sharing is not straightforward. New operational metrics, tariff structures and billing procudures may be required, posing also a regulatory issue.	Implemented features, customer type, existing system	Research on possible business models, enabling (regulation) new revenue sources/services
Legal and regulatory	Standards compliance	Grid connexion requires the compliance with complex standards not always compreensive to entrants (e.g. anti-islanding and LVRT requirements), that may limit the features of the microgrid.	Existing standards, expected degree of authonomy	Less restrictive standards, standards vulgarisation, reduce capabilities of the microgrid
	Regulatory compliance	As a natural monopoly, electricity distribution has been (and has to be) heavily regulated. Compliance with such regulations can be a burden (e.g. utility franchise) and decrease attractiveness.	Existing regulation	Less restrictive or new regulation, vulgarisation
	Ressources/terrain ownership	Distributed energy ressources can be installed anywhere, including on places that the implementor does not own	Ownership system in given context	Negociation with owners, expropriation, purchase of surface
	Loads/habitations ownership	In places where appartments/assets are rented rather than owned, neither the tenants nor the owners will have an incentive to work on the infrastructure	Rental system, contracts design	Contracted requisitions on energy renovation, subventions to reduce return time

	Interoperability	As no common communication standard exists the multiplication of particular cases may make the system integration of microgrids uneconomic		
Contracting and implementation	Incumbents opposition	Microgrids reduce the role of large scale distributors/TSOs or generating companies and reduces the loads on, thus the profit from lines. Ultimately such profit decrease would be repercuted on connected users.	Energy market structure (public/private), degree of independence possible with only local ressources.	Public control on incumbents, long term planning for a reduction in infrastructure and associated costs.
	Multiplicity of Stakeholders	The factors above make it important to coordinate several stakeholders (some of wich are not involved full time), which is difficult, due to time contraints and possible personal conflicts	Scope of the project, mentality	Public mediation, increase rentability through subventions, research on business models
	Debate polarisation	The discussions around Migrogrids involve ideology questions that might create a strong polarisation shadowing other considerations and preventing consensus (e.g. green vs. pragmatic, capitalist vs. communist, nuclear vs. anti-nuclear)	Proposed design, society structure	Full transparency, moderation by a respected third-party
	Concerns on long-term agreement	The factors above require a long term agreement between parties, that is a contracting burden	Considered timeframe, legal framework, rental system	Framed contracting, enforcement measures
Socio-ecological	Local pollution/ressources use	Microgrids shifts the consumption (combustion) of ressources at local level, which may have impacts on the health or confort of populations.	Chosen technologies, population density, geographical situation (windy)	Technological work arounds (filters), holistic planning
	Data/Control permissions definition	Who has access to the control algorythms, controls parameters, measurements, etc.? Note that if the operation of actuators is ensured by the billing company, conflicts of interest may arise. Coupling between a technical and a social issue, together with a security problem. However, the issue also appears with Smart-grids in general.	Aimed degree of controlability / measurability, mentality, legal framework	Layered control structure, data agregation in real time (no storage of small level data), criptography
	Electricity distribution as a foundation of our society	Energy supply is nowadays considered as a standard product and consumers have little motivation to push for improvement. Moreover, any disruption of this security due to implementation of smart-grids would raise fierce opposition.	Citizen engagement, education	Education, sensitisation through campaigns
	Local acceptability	Distributed energy infrastructures sometimes face opposition on confort (landscape, noise) considerations	Used technologies, impact on surroundings	Education, sensitisation through campaigns, subvention RnD reducing inconveniencies
	Legal responsibility	Smart infrastructure allows to take decisions on how to manage the grid that may raise new legal responsibility issues, e.g. in case of partial load shedding (if it results in physical injuries) and responsibility attribution problems	Degree of redundance of the grid, diversity of stakeholders	Generic approach to possible incidents, insurance contracting, single managing entity contracting all damages
	2-Tied society	Microgrids allow an heterogeneity of energy services that may face opposition on social considerations	Existing wealth inequalities, degree of engagement of public authorities, competency of local authorities	Minimal service imposed by law (like water quality norms). Subventioning of local collectivities.

Table 6: *Microgrid Barriers to deployment*

Category	Context	Geographical situation	Drivers	Specificities	Stakeholders	Value	Incentives	Barriers	Examples
Isolationist Microgrids	Poor countries, high electricity theft	Developping Countries, e.g. India	Avoid non-technical losses, such as theft	Focus on metering	Local authorities, suppliers	Information on system	Actionable tools for the compelling of offenders	Costly for the context	India
	Unconnected facilities	Mountains, construction sites (provisory), developping countries	Increase quality of life through access to electricity, Avoid connection costs	Storage or flexible ressources required (often diesel generators)	Locals, National govermnments, NGOs...	Grid dependency reduction	Development program	Often demand curtailment is needed	Haiti, India
	Scarcely connected zones, with large ressources. Strong community sense. Increasing prices.	Islands close to the continent, small villages, Japan	Reduce the dependency on foreign ressources/prices and vulnerability	Small use of the grid (near islanding)	Local authorities, prosumer consortium	Imports reduction, local activity stimulation	Financial support for MG implementation makes this profitable	DSOs may oppose to the model, and might forbid the access to the grid, still marginally needed	Samso
Public Microgrids	Countries with a strong environmental awareness, dynamic cities	European countries	Make a showcase of the microgrid for the promotion of the city	Focus on renewable generation capacity, implication of inhabitants	City hall	Indirect added value	National subventions	Impact on the global system might be forgotten. Political communication may not result in actions	IssyGrid, NiceGrid, GreenLys
	Strong environmental regulation	European countries	Decrease region/city emissions (including emissions from imports) as to comply with binding targets/regulations	Focus on renewable generation capacity, trade-off with the connection to centralised ressources	City Hall/ regional government	Emissions reduction	Binding regulations, enforcement tools	Can be costly for the authorities	
	Ageing/unreliable transmission grid, vulnerability to natural catastrophies, critical facilities with special needs	USA, Portugal rural, hospitals, universities, military	Ensure a continuous/high quality supply of energy	Seamless islanding capability, with load shedding sometimes required.	Locals, local authorities	Grid renovation	Grants, reasearch projects	Installing backup generation may be cheaper	New York
VPP Microgrids	Large unpredictable production capacity, destabilised grid	Danemark, Germany	Decrease the fluctuations due to DRE by consuming the electricity locally or storing it	Storage capacity or demand side management.	TSOs, (DSOs?), locals	Renewable capacity smoothing	Tariffication of the consumption stability or real time price	Pricing of the services provided is not easy in a liberalised context. Solution may not be approved by the regulator	Cell controller project, Swisscom blackboxes
	Grid with few centralised regulation capacity	Countries phasing out of nuclear	Use the microgrid to provide ancillary services to the overall grid.	Large control capacity and responsive interface with the MV grid	TSOs, locals	Ancillary services sale	Increase/subvention price of ancillary services	Pricing of the services provided is not easy in a liberalised context. Solution may not be approved by the regulator	Future development
	Zones with increasing load and/or sets of loads with large consumption variability	CFF network, electric transport network	Reduce the worst case consumption to avoid the need for redimensioning the supply point (transformer, power plant)	Storage capacity	DSOs, specific large companies such as CFF or t-l	Peak shaving	Increase regulatory overhead for capacity increase	Solution may not be aqpproved by the regulator. Relies on IT to ensure the security of the system in the worst case scenario.	CFF Eco-drive
Private Microgrids	Evolving technologies, technical uncertainty	University sites, Enterprise Headquarters	Develop and study microgrid solutions	Carefull planning, multiple technologies involved, state of the art	Researchers, engineers	-	Research grants	-	EPFL, Los Alamos, FEUP, Siemens HQ...
	Existing projects with strong implication from installers/project managers or need for projects		Sell a turnkey product as to ensure new incomes (e.g. after the installation of a couple of PV pannels provide also the batteries and intelligence)	Standardised modules, attractive interface	Manufacturers/installers	Decoupled customers	Deductible from taxes, enable local markets	Privately managed infrastructure. Wealthy people may be able to get a better service.	NiceGrid? Siemens, ABB

	Residencial zones	Mainly cities	Collect information from the users to provide innovating services and/or advertising purposes	Exhaustive metering, user interface	Start-ups, IT giants, local authorities (for educational purposes)	Information on users	Liberalise the market and the regulation	Creation of needs that might be away from energy savings	

Table 7: *Microgrid possible business cases*

Type	Objective	Policy	Description	Constrained Stkh.	Targetted Stkh.	Impact	Drawbacks	Examples
Information and education	Inform	Information campaign	Traditional marketing of a given lifestyle, technology...	Government agencies	Final users or other target group	Increase demand (for a service)	Unquantifiable outputs	OFEN's Energico
		Mandatory product labelling	Impose the labelling of given characteristics on a product, typically origin or generated externalities	Providers	Final users	Competition on non economic value	Sourcing of foreign products, possible discrimination	Energy label
		Product certification/ awards	Provide an audit that certifies a given quality of a product	Government agencies	Final users, Providers (if some advantages linked with the label)	Competition on non economic value	Costly to audit and follow-up	Minergie label
	Facilitate	(Open) Computational tools/ expertise provision	Finance the creation of a platform for technical advice geared towards non professionals/decision makers	Agencies, Teaching institutions	Final users, local authorities	Decrease transaction or entry costs	Costly, little flexibility	EnergyScope
		Training programes	Enable professionals to implement given solutions more efficiently	Agencies, Teaching institutions	Providers	Increase offer	No follow-up of the use of teaching	
Research, Development and Deployment		Reviews, Case studies	Ensure the folow-up if the state of art and it's communication with relevant stakeholders	Research instutions	Any	Promote best-practices and avoid past errors	Communications is not always easy, risk of overhelming information	IEA WEO
		RnD subsidies	Grant companies/public instutions capital to develop research programs	Developpers, Research institutions	Providers	Obtain scalable, cheaper solutions	IP rights management	Appolo program
	Plan	Roadmaps and scenarios	Delineate strategies/perspectives for the deployment/development of a given technology	Manufacturers	Entrants, providers	Coordinate research efforts towards clear goals	Requires consensus and follow-up	IEA Smart-Grid roadmap, Prognose
Policy development and reform		Strategic plans	Delineate policy objectives on the long term (scenarios) and means of reaching them	Policy makers	Providers	Improve readability and consistency of policies, thus increase market confidence	Lack of flexibility, trust problems if failed	Strategie Energetique 2050
	Close the loop	Creation of supervisory bodies	Create committees in charge of the follow-up and reflexion over given policies/areas	Policy makers	-	Improve reactivity and get feedback	Non performative per se	Creation of the IEA
		Ombudsman	Appoint a mediator to make the link with the users/the enterprises	-	Any	Improve feedback on the implemented policies and highlight bottlenecks/conflicts	Can slow down the application of decisions	
Economic instruments	Incentive	Grants	Grant capital to finance a given project/activity	Targetted	Providers/ RnD, final users	Incentive given solutions	Money tracing	
		Subsidies	Grant capital to finance a company/person	-	Providers, final users	Stimulate investment; reduce prices	Corporate welfare	Oil subsidies
		Public loans	Loan a given amount at preferential interest rate	-	Providers, final users	Reduce capital costs, Incentive investment	Non profitable	
		Funding	Grant capital to a given institution	Targetted	Any	Encourage development is a given area	Money tracing, efficiency	IEA funding
		Procurement, PPP, PPA	Contract a company for the construction of a public infrastructure after a tendering process	Targetted	Providers	Competition for the tenders	Right/transparent Proposal selection	French tenders for wind farms
		Tax relief	Relief a taxpayer from taxes on a given criterium (size, sustainability...)	Taxpayers	Constrained	Incentive given solutions	Administrative complexity	Credit impot recherche
	Price	Taxes	Levy an amount of money on a given characteristic of a revenue source (added value, net income...)	Any	Constrained	Discourage given solutions	Price increase, competitiveness loss	TVA
		Feed-in tariffs	Guarantee a purchase price for energy during a given period	-	DG owners	Incentive DG	Risk of overhelming costs if not designed and adapted properly	PV feed-in tariffs in Germany

		Tradable permits	Impose quotas on emissions through the emission of tradable permits, therefore allowing a competition on efficiency	(Large) Energy Consumers	Energy consumer	Internalise externalities	Risk of falling prices	European Emmission Trading Scheme
Regulatory instruments		Market design/tariff structure	Define products and possible transactions and contracts, as well as supporting policies (guarantees, enforcement...)	Market regulators	Providers	Can make more profitable given technologies by enabling the sale of new services	Complex, needs clear readability	Decouple electricity sales from profits
	Impose	Targets	Compell companies to reach given targets (emmissions, consumption)	Any	Providers	Push demand for efficiency measures/technologies	Enforcement costs	
		Standards	Set requirements for the provision of a given service (e.g. grid access)	Initiators	Providers	Stimulate competition through interoperability and ease RnD	Lock-in risk	Grid Connexion requirements
	Implement	Obligations	Force companies to given actions	Any	Any	Obtain a desired result	Resistance	
		Audits	Force companies to assess their own performance	Any	Any	Incentive improvements	Complex implementation	
Voluntary approaches		Negotiated agreements	Agree on environmental targets with a company, with audits and enforcement means possible	Companies	Companies	Encourage collaboration and communication	Not systematic	
		Unilateral commitments	Let companies set their own targets and reach them as to improve image	-	Any	Give the example to other companies	No guarantees of enough action	
		Public voluntary schemes	Invite companies to meet specified environmental targets on a voluntary basis	-	Companies	Provide a framework for efficiency	No possible enforcement	

Table 8: *Energy policies*

Interview Protocol for the project "Microgrids: a tool for a grassroots energy transition"

Study of the positioning of stakeholders in the sector

Confidentiality note: The interview is recorded. The interviewee recognises and accepts that its statements may be used for the project "Microgrids: a tool for a grassroots energy transition" of the CEN, unless otherwise explicitly stated during the interview. The recording and transcript of the interview will not be published. The results will be anonymised; the names and organisations of the interviewees will not be disclosed.

Note: Each main question shall be first asked in an open manner, as to get a first impression of the perception and priorities of the interviewee and give him the opportunity of bringing in new ideas. However, the answer shall be quickly oriented using the more specific questions. Whenever relevant, the interviewee will be encouraged to make explicit the context(s) and time scale where and when his/her answers apply.

I. 00:00 Future of the energy system

Q1. - 01:00 What are the main challenges of the future electricity system?

See whether the stakeholder considers distribution as a priority, and which of local and global scale is envisaged first. This is to evaluate implicitly the utility of microgrids value propositions for the interviewee.

Efficiency

1. Energy savings;
2. Multi-energies;
3. Measurability (consumption/production/line use data);
4. Smartness

Robustness

5. Reliability (infrastructures in good shape, resilient);
6. Stability (effective management of renewable sources);
7. **Integration of decentralised resources / Phase out of centralised (e.g. nuclear);**

Liberalisation

8. **Involvement and empowerment of local stakeholders**
9. Conciliation of local and national levels;
10. Multi-stakeholders - entrance of new stakeholders;

Viability

11. Risk management;
12. **Profitability - market integration;**

Others (specify)

Q2. - 04:00 To what extent will the electricity grid be decentralised?

Governance

1. International organisations;
2. National governments;
3. Regional authorities;
4. Local authorities
5. Smaller (groups or individuals);

Technical Interconnexion – Intelligence level

6. Large (neighbour countries/EU);
7. Intermediary (Country);
8. Small (Region);
9. Micro (Neighbourhood);
10. Nano (Building);

Production

11. Centralised
12. Decentralised

Deployment

13. Large equipment suppliers (international);
14. Large generating companies
15. TSO (national);
16. DSO (local);
17. Start-ups;
18. (Local) Generation owners
19. User communities;
20. End users;

«You've suggested that the energy system is heading towards a more decentralised model. It has been proposed that microgrids may be a useful technology to implement this change.»

II. 06:00 Microgrid concept

Q3. - 07:00 What is your perception of the microgrid concept? Do you know any example?

Technologies

1. Meters (Measurability);
2. Smart loads (Controllability);
3. HV grid interfacing;
4. Energy storage;
5. Decentralised Renewable Sources (PV, wind...);
6. **Other NRE, centralised (cogeneration...);**
7. **User interface (GUI);**

Make sure that both parties are speaking about the same object. Evaluate the perception, more or less holistic, of the energy system by the stakeholder, and his/her comprehension/knowledge. If needed, the concept will be presented or explained.Possible examples may allow going beyond Navigant Research data.

Features

8. Smart control at local level;
9. Renewable integration;
10. Efficiency;
11. Primary energy reallocation;
12. **Multi-energies (electricity, heat, water);**
13. **Involvement of local stakeholders;**
14. **Islanding capability;**

«Now that we agreed on the concept, we are trying to find what the microgrid concept could bring, beyond economic value»

Others (specify)

III. 09:00 Microgrid value propositions/opportunities

Q4. - 10:00 What value propositions may microgrids bring?

Economical (savings on the bill) – For user

1. Primary energy savings
2. Final energy savings
3. **Imports reduction (through self-consumption)**
4. **Provision of ancillary services**

Technical – For grid

5. Stabilization of zones with high renewable share
6. High quality power supply
7. Renovation of the grid
8. **Increase system reliability, resiliency and security**

Socio-cultural – For all

9. Increase Renewables acceptability&penetration
10. Synergies stimulation
11. Energy autarky (control)
12. **Local economic activity stimulation**
13. **Education of users**

Environmental – For all

14. Reduction of externalities
15. Sustainable development

Others

16. Information on system
17. **Information on users**
18. Decouple customers

Prioritise, or even complete, the list of opportunities/parameters already identified. The answer may have to be confronted with the one in question I to check the coherency. Identify possible conflicts, real or perceived, on the sharing of benefits.
Q10/Q11 must be reformulated for each stakeholder (e.g. for a DSO it becomes: would the obligation of implementing a microgrid change the way you operate?)

«Right, but someone has to be able to extract this value»

IV. 15:00 Microgrid stakeholders and business models

Q5. - 16:00 Based on the value propositions you mentioned, who would be the initiator or promoter(s) of microgrid projects?

Civil Society

1. End user;
2. User communities;
3. Local government;
4. Other governments;

Specialised enterprises

5. Manufacturers /Installers;
6. **TSO;**
7. **DSO;**
8. Actors' union

New entrants

9. Research institutions;
10. **Start-ups;**
11. Telecoms;

Others (specify)

Evaluate the perception of the complexity of the energy system (in terms of stakeholders). Propose some business cases and evaluate their relevance for the interviewee. Identify possible problem, actual or perceived, of communication/contracting, or deadlocks/ignorance of other stakeholders. Evaluate the openness of the stakeholder towards others and estimate if synergies would be possible.

Q6. - 19:00 Which stakeholders do you think would be involved in the implementation of microgrids?

Civil Society

1. End user;
2. User communities;
3. Local government;
4. Other governements;

Specialised enterprises

5. Manufacturers /Installers;
6. **TSO;**
7. **DSO;**
8. Actors' union

New entrants

9. **Research institutions;**
10. Start-ups;
11. Telecoms;

Others (specify)

«We've spoken a bit about the final user, but as he is an important component of any project, we would like to focus on him for the next couple of questions.»

Q7. - 21:00 Do you think sufficient monetary value can be extracted from microgrids, which would trigger their deployment? Why/Why not?

Q8. - 23:00 Do you think that the possible non-monetary value of microgrids could be sufficient to drive their deployment, even without a business case?

V. 25:00 The role of the end user

Q9. - 26:00 To what extent would end users be involved in the deployment of microgrid projects (today and in the long run)?

1. Passive customer, without participation;
2. Active consumer via technical constraints (agreed upon power cut schedules);
3. Active consumer through sensors and actuators (smart building);
4. Heterogeneous involvement, depending on desired service/willingness to pay
5. Public consultation to accommodate the users' expectations;
6. Decisional power within a user assembly;
7. Project initiator;
8. Project undertaker – energy emancipation;

Q10. - 28:00 What aspects do you think could motivate the end users to be involved in a microgrid project?

Trust

1. Trust in the implementor;

Efficiency

2. **Monetary savings;**
3. Energy savings;

Services

4. Energy autarky – reliability&control;
5. Utilitarian aspect (building automation);
6. Comfort (control upon comfort variables);
7. **Gamification (design and widgets/gadgets);**

Well-being

8. Emissions reduction and sustainability;
9. **Social interactions (creation of a community dynamics);**

Other (specify);

Assess the influence that citizen movements (like the anti-nuclear manifestations) could have. Explore what degree of commercialism (as opposed to a genuine interest for a responsible consumption) is attributed to the final users, and compare it with the one of the interviewee himself.
This is to assess the importance of economical barriers and the impact of a possible awareness growth.

«Despite all the potential of the technology that we've been listing, it has not gathered much attention until now. We would want to understand why.»

VI. 30:00 Microgrid barriers and alternatives

Q11. - 31:00 What barriers do you see to the deployment of microgrids? What mitigation measures could lower these barriers?

Prioritise/complete the barrier list. Mentioned solutions (technical, economical, political) allow estimating the acceptability of propositions.

Economical (technical)

1. Economic viability (feasibility)
2. Cost estimation/uncertainties
3. Financial risk (political decisions)
4. **Costly design**

Regulatory/legal

5. Standards compliance
6. Regulatory compliance
7. **Resources/terrain ownership**
8. Loads/habitations ownership

Organisational

9. **Incumbents opposition**
10. **Multiplicity of Stakeholders**
11. Concerns on long-term agreement

Social

12. **Privacy: Data/Control permissions definition**
13. Electricity distribution is a foundation of our society
14. Local acceptability/Debate polarisation

Negative externalities

15. Local pollution
16. **2-tied society**

Others (specify)

«We've mentioned some measures to mitigate barriers. Now do you see ways of incentivising the microgrids deployment?»

VII. 35:00 The role of public institutions as facilitators of the microgrid deployment

Q12. - 36:00 To what extent should the governments (local, regional, national, international) intervene to contribute to a successful deployment of microgrids?

Assess the role of the regulatory context and obtain ideas on possible action levers.

Local

1. None (liberalism);
2. Low – regulator (market operation);
3. Medium – incentives;
4. Strong – subsidies, taxes, and work on the regulation
5. Very strong – public enterprises;

Regional

6. None (liberalism);
7. Low – regulator (market operation);
8. Medium – incentives;
9. Strong – subsidies, taxes, and work on the regulation
10. Very strong – public enterprises;

National

11. None (liberalism);
12. Low – regulator (market operation);
13. Medium – incentives;
14. Strong – subsidies, taxes, and work on the regulation
15. Very strong – public enterprises;

International

16. None (liberalism);
17. Low – regulator (market operation);
18. Medium – incentives;
19. Strong – subsidies, taxes, and work on the regulation
20. Very strong – public enterprises;

Q13. - 38:00 What actions, undertaken by public institutions would be most necessary/ relevant/ impactful to incentivise the deployment of microgrids?

Standards

1. Change of connexion standards;
2. Creation of a communication standard;
3. **Tariffs structure change (e.g. based on the consumption stability);**

Incentives

4. Public subsidies;
5. Tax on the energy consumption;
6. Increase of the tax on emissions;

Procurement

7. Mandate for the implementation of microgrids;
8. **Public-private partnerships;**

Communication

9. **Provision of experts or a computational tools for decision making;**
10. Marketing/Sensitization campaign;

Other (specify)

«So the government will have an important role. Now there are other factors that may come into play. What's the evolution for the coming times?»

VIII. 40:00 Microgrids future

Q14. - 41:00 Do you see, today, weak signals (concrete elements) that may favour a possible development of microgrids in coming years?

Economic factors

1. Technological improvements;
2. Ancillary services price increase;
3. **Uncertainty and potential increase of costs (energy, infrastructure);**

Technical factors

4. Technical constraints (need of a stabilisation of the grid);

Social factors

5. **Longing for autarky/security of supply from the users;**
6. Sensitization and growing awareness on environmental concerns;
7. Public demonstrations (like the mobilisation against nuclear);

Critical mass effects

8. Political choices;
9. **Positioning in favour of microgrids;**
10. Market studies showing an increased interest for the product;

Others (specify);

The answer must be confronted with the projects of the interviewee himself, if mentioned in previous questions. This is to check if there is a bias in the perception of the stakeholders that would be an inhibitor.

Q15. - 43:00 What prospect do you see for microgrids? Where and when?

1. Niche market (rural electrification) – Overtaking by smart-grids at larger scale
2. Competitive solution in given contexts (which ones?)
3. Large scale deployment;

Q16. - 45:00 Should your building be connected to a microgrid, would that change the way you (as a citizen) manage/perceive energy?

1. Yes, it would make me feel better as I think that's how energy should be managed
2. Yes, it would encourage me to change my construction/consumption habits;
3. Yes, it would force me to think/learn more transdisciplinarily to integrate local resources and making the link with other projects
4. Yes, it would force me to interact with other stakeholders;
5. No, I don't think so;

Q17. - Is there anything you would like to add that we might not have covered?

Microgrids: a tool for a grassroots energy transition
Micro-Delphi results

Respondents: 3 Academics (1 not specialised, 1 working on technical aspects, 1 working on economic aspects of microgrids); 2 DSOs (serving 2 distinct regions of CH); 1 TSO; 1 Policy-maker (PM), left-winged legislator; 1 Manufacturer, international

I. Future of the energy system

Q1. - What are the main challenges of the future electricity system?

-**Growth of renewables:** is acknowledged by all respondents, one academic specifying that it will realise even in places with low potential. DSOs and TSO see in this a cause for more complex system operations (together with smartness, as mentioned by the manufacturer) and a problem to ensure safety during maintenance periods, and one argues that DSOs can and will take any measures they might consider relevant to ensure their legal mission. However, the PM denies the problems caused by bidirectionality.
-**Emergence of standalone users:** is envisaged by all stakeholders as well, although the PM and TSO do not expect a large involvement from final users, with different implications. For utilities it will require new communication standards and again regulatory measures if needed, while for the PM they would be a threat to CH national pumped hydro resources and the manufacturer sees a need for new business models taking these stakeholders into account.
-**Market design and lack of business cases**: are mentioned by the TSO, two academics and the manufacturer, the markets being unprepared for decentralisation and smart technologies in general. For the manufacturer, regulation has to evolve to enable some of them, while new products have to be designed according to the TSO, this being a big research opportunity according to one academic.
-**Risk and uncertainty:** are explicitly mentioned by the three academics and one DSO, while the TSO mentions possible changes in the grid control paradigm. They stem from the intricateness of the system, but one important factor is political risk, due to the fact that policy makers lack insight into technical aspects. This could make the choices for all stakeholders difficult (although they do not express it in this study).
-**Storage:** is perceived as a big challenge by one DSO and the PM, although technical issues will solve by themselves according to an academic, arguing that the number of teams working on them is large.
-**Other elements:** are a possible continuation of nuclear, possibly with new decentralised technologies, suggested by one academic, the technical difficulty of implementing the European free market for the TSO and the decrease in consumption mentioned by the PM (which makes energy savings less of a challenge, an opinion shared by one DSO).

Q2. - To what extent will the electricity grid be decentralised?

-**An hybrid system**: is expected by all stakeholders, although the PM advocates that liberalisation of the market (mentioned as not positive by one DSO) will not work as final users are not ready to involve and that centralised capacity has to be protected and used to balance the system, as is done today, suggesting a rather standstill position for this

stakeholder.
-**The current system is deemed too successful and efficient:** to disappear, both the grid and centralised generation infrastructures. An academic argues that nuclear will remain, opposed to most other respondents' view, and the TSO envisages an abandon (political decision) of hydro facilities if economic conditions are not favourable, while other respondents consider it as perennial.
-**Microgrids:** are mentioned by one academic and one DSO as progressively being plugged to the existing grid. The other DSO, the PM and the Manufacturer mention the emergence of new nodes, namely commercial and industrial customers.
-**A necessary central authority**: is mentioned by two academics, the TSO and the PM, the later considering that national level is the most important for energy governance. The academics give it a role of market regulator (Elcom, unbundling regulation) and data protection, while the TSO sees it as a necessity for the management of international transfers.
-**DSOs:** defend their own current role as main energy governance stakeholders, with the perspective of a reduction of their number across CH, and explicitly claiming a willingness to take any measure they may consider adequate to ensure the reliability of the system. This role is acknowledged by one academic and the manufacturer, who both underline the current reluctance from DSOs to accept new technologies and solutions but foresee an evolution towards a more proactive role.
-**The role of final user**: is controversial. While one DSO argues that they will always have to rely on the DSOs to implement any decision the other DSO points out that the possibility of creating prosumer consortiums, selling energy to the grid, already exists and is used. This is a counter-example to the position of the PM, who argues that final users are not enough motivated by energy matters to incur the high transaction costs of an initiative, as they trust their provider. However, he recognises that the possibility of self-consuming may make users more aware of their consumption, and ultimately make them want to leave the grid. This is also the visions of academics and the TSO.

II. Microgrid concept

Q3. - What is your perception of the microgrid concept? Do you know any example?

-**Several definitions**: exist and are not consensual, as pointed out by one academic and the PM, while the manufacturer provides a formal definition.
-**User community or single entity service:** is required by all respondents but the Manufacturer, be it to ensure acceptability or because self-sufficiency is the first driver. Scale ranges from building to city level.
-**Islanding feature:** is not required by any of the stakeholders, except the Manufacturer, although one DSO considers it important, at least for some time, while the PM requires a grid connexion.
-**Generation and loads:** operated together and geographically close to each other are mentioned by most respondents, together with storage, measurement, control etc. infrastructure. The PM mentions virtual microgrids and storage, the latest as a condition for profitability, while the other stakeholders consider it optional.
-**User interface:** is a central point for two academics, while deemed useless and in the field of "gadgetology" by the PM as users are deemed not interested enough.
-**Integration of multiple energy types**: is a possible feature for all stakeholders if asked

except one DSO and the PM. A full rethink of the overall system is proposed by one academic while the manufacturer sees an opportunity for control and a DSO considers it as a legal and technical problem.

III. Microgrid value propositions/opportunities

Q4. - What value propositions may microgrids bring?

-Energy savings and increased autonomy: are acknowledged by all stakeholders, except the PM. One academic and the TSO underline that autarky can be a main driver for CH citizens. However, the economic benefit is not guaranteed given the competition with amortised infrastructure (TSO, DSOs), and one academic doubts of final energy savings.
-Security and reliability improvements: are mentioned by two academic, the manufacturer and the TSO, the later underlining the fact that CH is not immune to failures of the transmission grid.
-Lighter constraints on the grid and ancillary services provision: are acknowledged by all respondents, although as pointed out by one academic and the TSO they cannot be priced yet. However, according to the TSO, savings for the transmission grid (whose dimensioning already allow significant amounts of solar) are less than for DSOs (who but both see it as non competitive against the existing amortized infrastructure).
-Information and control to the user: are controversial. For one academic, the DSOs and the PM it is not valuable as users are not interested (low electricity price), or expected savings are low as pointed by one DSO. On the opposite, two academics, the TSO and the manufacturers see a range of new opportunities and products, and a change of mentalities is envisaged by the TSO and one academic, as a consequence of the prosumer paradigm, a possibility that the PM also mentions.
-Sustainability and locality: are seen as possible drivers by the three academics, one DSO and the manufacturer, while one DSO and one academic consider that local activity is unlikely to be stimulated, and another academic points out that electricity is already almost carbon free in Switzerland, thus the sustainability is not a relevant driver.

IV. Microgrid stakeholders and business models

Q5. - Based on the value propositions you mentioned, who would be the initiator or promoter(s) of microgrid projects?

Q6. - Which stakeholders do you think would be involved in the implementation of microgrids?

-Final users: are the most likely to take the lead according to two academics, the TSO and the PM, often as cooperatives, although on different grounds (access to local capital for one academic, ideals for the TSO, avoid network costs for the PM). One academic, one DSO and the manufacturer see also a possible role for users, although costs are too high, which can be overcome if plug-and-play products are made available.
-DSOs: do not see themselves as leaders, as they have legal objectives, but envisage an involvement through technical advice and implementation, with an interest in operations improvement. The other stakeholders also see a role for them, although the observation from one academic and the manufacturer is that there is a heterogeneous involvement (smaller DSOs moving faster), and another academic suggests that they will specialise and compete for

different services (storage, wires…).
-TSO: does not mention himself as possible entrant. Indeed, the PM mentions that the CH grid is strong enough and two academics see them as observers, focussed on centralised resources, but having to follow the evolution. One academic considers them as "gone" in the new microgrid-based system.
-Local governments and cities: are possible promoters for two academics and the TSO, driven by emissions reduction and satisfaction of new needs.
-New entrants: such as ESCos, are expected by all but the PM, taking advantage of possible new values, namely from information, and designing new products.
-Large entities: are seen by one DSO as possible implementers to satisfy own needs (mentioning a large REN producer wanting to smooth output) and the manufacturer.
-A third party platform: is suggested by one academic, as to manage the multiplicity of stakeholders mentioned by all academics.
-NGOs: are mentioned by one academic as certifying or incentivising authorities.

Q7. - 21:00 Do you think sufficient monetary value can be extracted from microgrids, which would trigger their deployment? Why/Why not?
Q8. - 23:00 Do you think that the possible non-monetary value of microgrids could be sufficient to drive their deployment, even without a business case?

-Case specificity: is underlined by the academics and the manufacturer, as different portfolios of added values can be bundled to create a suitable business case.
-Monetary value: is deemed sufficient by two academics (case of Valais with hydro, resp. freemium business case), one DSO (ancillary services and investment deferral) and the TSO (investment deferral). The second DSO argues that if the value was large enough stakeholders would have entered the market already and the PM argues that sufficient value is only found for very specific cases (heating and cooling or special cases of investment deferral). The manufacturer does not formulate an opinion.
-Regulatory issues: are raised by one DSO and the TSO, namely the fact that utilities are legally bound to dimension the grid for worst case, thus reducing profit from investment deferral and under-dimensioning.
-Non-monetary values: are deemed insufficient by all respondents but one academic. However, all recognise that those can be main drivers in special cases. Namely environmental concerns are invoked by one academic, the two DSOs and the manufacturer while a second academic denies its importance in CH. Security is mentioned as the main driver for militaries by the manufacturer.
-Internalisation of non-monetary values: is envisaged by one DSO and the TSO.

V. The role of the final user

Q9. - To what extent would final users be involved in the deployment of microgrid projects (today and in the long run)?

-User has the key role: for two academics and one DSO, although they would need the technical expertise of DSOs or other stakeholders.
-An heterogenous involvement: is expected within the communities.
-A larger range of involvement: is envisaged by the second DSO, from completely passive to initiator.

-**Permission from the user:** is required, but sufficient, for another academic and the TSO.
-**DSOs:** would rather take the lead, with small implication from the users according to the PM and the manufacturer (although DSOs did not show such motivation in this interview).
-**Transaction costs:** are deemed too high by the PM, hindering user's implication.

Q10. - What aspects do you think could motivate the final users to be involved in a microgrid project?

-**Monetary incentives:** are the first motivations for all respondents except for two academics, who point out that energy consumption is not rational: control features may be as attractive as money for the one, and wealthy populations may engage on purely environmental considerations according to the other. However, for one academic pure bill reductions are difficult given the technology.
-**Community feeling:** is not expected to be a driver for CH population by one DSO (on the base of one experience), the TSO and implicitly by the PM and manufacturer. However, one academic and the other DSO see the sense of compromise and pragmatism of CH population as enabling a union behind a common objective. The second academic points out that it would be possible to play on the social pressure to force consumers to align their behaviour and their expressed ideals.
-**Real time information and control:** are not expected to have a large impact for the DSOs (based on experience from products launched in the past), the TSO and the PM, as people are not aware of their consumption, and control may even become a constraint, according to the TSO. However, for the three academics the control may be appealing, provided the right interface or a turn-key solution and incentives.
-**Ecological awareness:** would motivate 10% of the population according to the TSO, but is not a driver for one academic.
-**Incentives:** should be put in place, either as punishments according to an academic or as an extension of existing support of renewables for one DSO.
-**Simplicity and communication:** have to be emphasised as pointed out by two academics, to avoid polarisation of the debate or blockages.

VI. Microgrid barriers and alternatives

Q11. - What barriers do you see to the deployment of microgrids? What mitigation measures could lower these barriers?

-**Interference with the existing system:** could be disturbing according to one academic, the TSO the PM and the manufacturer, calling for new standards. The reduction in centralised resources could accentuate this issue. Moreover, the local optimum may not be compatible with the general one, as pointed out by the PM and one DSO.
-**A reduction in the current level of supply quality:** is simply not acceptable in CH, as pointed out by the TSO and the PM. Some failures in pilot projects would severely hinder microgrid deployment.
-**Opposition from incumbents:** is expected by two academics, while the third sees them as competitors who will develop new products to avoid customers going off-grid. Such an opposition would be all the more efficient as DSOs usually are publicly owned and have a relevant weight. The two DSOs mention the financial problems that microgrids would pose to their model, which would ultimately be reflected on the tariffs applied for customers who

remain connected, and one mentions that everything would be done to ensure the legal service.
-**Transaction costs:** are seen as high by one academic, the TSO (depending on scale) and the PM (overwhelming), while the two other academics, one DSO and the manufacturer consider that there are tools to cope with that complexity, which even opens the way to new revenue sources.
-**The lack of interest of the users:** on energy issues is mentioned by all respondents but one academic and the manufacturer, due to low prices of electricity. However, this indifference could rather be an opportunity for one DSO, as it gives the freedom to the DSO to implement the technology.
-**Technical and cost issues:** are raised by one academic, one DSO and the TSO (financial risk), while the two other academics and the other DSO minimize it, as being soon resolved by research, and the risks being relatively low, as the infrastructure is local.
-**A possible polarisation of the debate:** is a threat seen by two academics, requiring full transparency.
-**A moral problem:** linked with possible inequalities is acknowledged by one academic, but minimised by the other.
-**Data issues:** are acknowledged by one DSO and one academic, minimised by the other academic while the PM sees it only as a problem if new, gadget like services start being provided.

VII. The role of public institutions as facilitators of the microgrid deployment

Q12. - To what extent should the governments (local, regional, national, international) intervene to contribute to a successful deployment of microgrids?
Q13. - What actions, undertaken by public institutions would be most necessary/ relevant/ impactful to incentivise the deployment of microgrids?

-**National governments:** have a regulatory role according to two academics (decide the market design, possible portfolios and avoid exertion of market power), provide the legal framework according to the TSO, but should have a smaller role in the perception of DSOs, who either deny them the right to impose new solutions or see only a role as incentive setters, not very relevant in CH (as CH has a trends of phasing out subsidies). The third academic considers that the responsibilities of the national level should be delegated, although federal taxes could have an impact and fossil subsidies should be stopped as they are distorting the market. For the manufacturer the most important is that the policy is clear to quieten the markets.
-**Local authorities:** Have an incentivising role, and should provide the implementing framework according to the 3 academics, one DSO and the manufacturer, although two academics point out that public subsidies are not a trend in CH and that the DSOs are protected as source of income. One DSO and the PM, on contrary, see little role for them, the PM suggesting that they have little capacity anyhow.
-**Liberalisation:** and new forms of private partnerships are deemed positive by two academics, while for the TSO and the PM the monetization of value propositions should be enabled. However, liberalisation is unwelcome for DSOs, as it threatens quality and the privates have profit as the primary objective (on the contrary ban of certain technologies and labelling is effective). The manufacturer underlines that governments are unwilling to touch

public utilities anyhow.
-**Research:** is mentioned as an important point by all respondents but the TSO and manufacturer. Storage technologies should be enabled according to one DSO, business cases for the other DSO and for one academic. For another academic, the standards are but set by the industry rather than public bodies anyhow.

VIII. Microgrids future

Q14. - Do you see, today, weak signals (concrete elements) that may favour a possible development of microgrids in coming years?

Q15. - What prospect do you see for microgrids? Where and when?

-**Innovation and new projects:** are observed by all respondents but the TSO and one DSO. Storage price decrease would be an important factor according to one DSO and the PM, although the later sees microgrids rather in developing countries. Cost decrease should result according to one academic and the other DSO, although for the later this decrease is on energy price and implies a supply security unfavourable to microgrids.
-**Controversial factors:** are environmental/climate change awareness, acknowledged by one academic, but which impact on behaviour is denied by one DSO; and possible disruptive events, deemed possible by one DSO and the TSO are considered unlikely by the PM.
-**Growth of renewables:** may be a trigger according to one DSO and the manufacturer.
-**Inertia:** of the electric system is pointed out by the 2 DSOs, who exclude large changes in the coming years. On the other hand the PM points out that the stakes are being shifted from the TSO to the DSOs, which is a new situation.
-**The emergence of electric cars:** and corresponding available storage capacity could be an enabler and even a driver of microgrids, as mentioned by one academic.
-**An hybrid system:** is expected by two academics, one DSO (on the long term) and the manufacturer (for whom it is "inevitable"), while the last academic envisages a full scale deployment, with TSOs becoming obsolete, and the second DSO, the TSO and the PM foresee a small deployment apart from specific cases: isolated areas or dedicated networks, partly due to the European market that requires a strong transmission system.

Q16. - Should your building be connected to a microgrid, would that change the way you (as a citizen) manage/perceive energy?

-**The question was misunderstood:** in most of the cases, and answered for the general citizens rather than the respondent
-**Consumer interest:** is not high apart for exceptions, as pointed out by the DSOs and the PM. For the other respondents, this could change, but would rather be an enabler for microgrids than a consequence according to the manufacturer and one academic.
-**Not enough service:** is provided by microgrids to trigger interest, according to one DSO, while one academic mentions new features that could be attractive, which would be an enabler according to the TSO.