Improving the social acceptability of microgrids amongst the population

Technical version of WP2 T2.1 (ethnographical study)

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Abstract

The smart grid will have to occupy a prominent place in people's lives in the years to come, as the renewable energy mix desired by all governments implies a change of role from consumer to prosumer (contraction of the consumer to producer) of electricity. The adoption of micro smart grid technology, which links solar panels, batteries, and inverters to smart meters and power regulation algorithms, by a community (e.g., a residential sector), cannot be done automatically. This is what we studied in Switzerland, based on a qualitative survey (12 semi-structured interviews and 4 focus groups) to understand the psychological and social barriers, which prevent people from integrating such a technology. The results show that blocking forces are more important than helping forces and therefore that governments need to tackle the problem of social acceptance of smart grids before focusing on mainly technological aspects in their long-term energy and environmental policies.

Keywords: Microgrid, social acceptability, context-awareness, self-adaptability, marketplace

1. Context

The micro-smart grid deployed in residential areas to ensure electrical autonomy based on the installation of solar panels on the roofs of buildings thus corresponds to one of the major strategies of the European Community. Indeed, the transition to a renewable energy mix requires strong citizen involvement to promote the stability of electricity networks. Until today, we are in an industrial logic of utilities that thanks to (oil, gas) centralized production such as coal, oil, gas, hydro, and nuclear power plants of great capacity to provide electricity in a relatively easy way to a large number of consumers.

In the case of micro smart grids, the consumer becomes a prosumer which is the contraction of producer and consumer. Consequently, it becomes necessary to develop scientific research to understand the obstacles and barriers that could affect the acceptance of these new digital smart grid technologies. Indeed, without the commitment of the user, a full-fledged actor of the smart grid community, the chances are minimal that such a project will succeed.

The whole aspect of regulation is done by intelligent algorithms. That's why we talk about smart grids. Rules of use and artificial intelligence will be programmed. The user will have his share of decision-making, in particular, thanks to devices that are called smart meters.

Therefore, smart meters will be needed to support electrical systems and microgrids as part of the energy transition. To predict and plan the output of local consumption and microgrids, they will need to collect data on other households in the community, in addition to monitoring the power cycles of appliances. These new smart meters, which we call Grid Edge Devices (GEDs), will require cooperative management. This includes virtually all the physical elements that are part of the micro smart grid such as solar panels, infrastructure equipment linking smart meters, inverters, energy batteries, appliances, and control systems.

In order to create context-aware and self-adaptive "energy" applications, such as tariff negotiation, energy transactions, and grid stability, DGs are supported by state-of-the-art AI algorithms and cooperative distributed models. In essence, there is a need for all stakeholders (system integrators, independent software vendors, peripheral equipment vendors, and demand side owners ...) to work together to develop a digital framework for a smart grid and renewable energy that works in a sustainable way.

In relation to the demand side owner and his social acceptance of the smart grid, it is necessary to be able to study in a prospective way the user experience (UX) of this "future prosumer", using qualitative methods (survey, immersion) to generate research hypotheses and then quantitative to validate these research hypotheses.

An ethnographic survey is justified by the following point. In the context of smart grid and renewable energy applications, the behavior of the application itself depends on its context: country, regulation, social environment, climate, etc. Only in-depth interviews complete the research. Only in-depth interviews completed by immersions allow this context restitution and ensure that it is well taken into account in the implementation of the smart grid.

On the side of social sustainability, a study on the acceptance of the program will make it possible to accompany a communication campaign aiming at giving the end-users the means to consciously engage in the transition towards renewable energies.

This dimension of social acceptance is crucial for the development of a coherent and coordinated micro-smart grid in Europe. Indeed, the traditional B2C (business-to-consumer) economic model will be completely challenged in the coming years and replaced by C2C (consumer-to-consumer) economic models, since these consumers will also be producers. These new and very numerous players in the electrical networks are now called prosumers. This is where social acceptance comes in. It must enable these prosumers to comply with the rules of microgrid management and promote strong joint cooperation, without which this type of project is doomed to failure. The purely technical aspect of the project is therefore a necessary but not sufficient condition. Social acceptance is a sufficient condition.

In the energy sector, consumer-oriented digital platforms are gaining momentum. It is crucial to consider the social factors that influence the acceptance of these systems by stakeholders. In the scientific literature, it is generally accepted that for a technology to be successfully implemented, its performance is evaluated according to the well-known Technology Acceptance Model (TAM). The development and dissemination of micro smart grids imply such a radical social change that we have to go beyond the TAM: we have to identify all the social barriers that could compromise the implementation of our innovative energy platform. We need to consider all dimensions of social acceptability: community, socio-political, and market.

Social acceptability by design must therefore be fully integrated into any project for the implementation of micro smart grids. Thus, as mentioned above, social acceptability is more than the acceptance of technology, it is about redefining the rules of exchange between actors whose social and economic role becomes more complex than in a traditional situation. Indeed, these actors become prosumers. This objective is achieved here through a sociological survey. On this basis of social acceptance, the design elements can be taken into account and will allow integration of an analysis of the physical and technical attributes of the electrical network from the beginning of the smart grid project.

This version of the technical paper is structured as follows. In Section 2, we provide a brief review of the literature related to the notion of social acceptance of smart microgrids. In Section 3, we present the qualitative investigation used to adapt the TAM (Technology Acceptance Model) to smart microgrid configurations. In Section 4, we present a synthesis of the fieldwork transcripts. In Section 5, we discuss these results and show what the next step of this research will be, in particular how the results will contribute to better regulation of current smart microgrids in Switzerland and Sweden.

2. Literature review

There is a great deal of academic work on the operation and implementation of smart microgrids. Fewer, however, deal with social acceptance. Most of these papers claim that the social acceptance of a smart grid is crucial to its success.

In the context of large-scale renewable energy technology projects, acceptance has been seen as a rather passive consent of the public. In contrast, household microgeneration of renewable energy requires active acceptance by homeowners. This microgrid situation, therefore, needs to be interpreted from a human factor's perspective, focusing on individual behavior and social learning and identifying underlying requirements and user needs (Sauters and Watson, 2007).

Indeed, a smart grid is not like the installation of an electrical appliance; it requires the acceptance of an entire community and more than that. A smart grid thus provides a service to a community. The service is defined in service science as an intangible production of which the customer is also a co-producer (Xue et al., 2005). More recently, Oertzen et al. (2018) showed that service co-creation is a dialogical process that involves a high level of partner participation and manifests in specific forms of co-creation.

Micro-smart grid management relies on a cluster of so-called prosumers, who are a contraction of producers and consumers, but who contribute to a given and defined power control system. This allows energy to be stored and exchanged between producers and consumers at a local level, with the complexity that the cluster or household is in turn both supplier and consumer (prosumer). For example, Wolsink (2012) shows that implementation is largely determined by issues of general social acceptance and argues that the success of a smart microgrid requires 'upstream social construction'. This requires a lot of self-governance and flexible overall regulation that microgrids must enable.

However, according to Wolsink (2014), the decentralized socio-technical networks that underpin the electricity consumption of groups of consumers/end users need to be more autonomous in terms of self-regulation. They show that this notion of social construction and the upstream need to manage a social interaction between a group of prosumers through the 'smart meters' present in each household (with a prosumer role), as it is the visualization element that will enable this management within the residential community.

Milchram et al. (2018), through a systematic review of the literature, explore the impact of moral values on the acceptance of smart grid technologies. The results show that moral values, which are often related to moral concerns such as privacy, justice, or trust, can be both drivers and barriers to smart grid acceptance.

According to Bigerna et al. (2016), smart grid projects have a significant impact on electricity consumers by changing consumer behavior, culture, and processes. Through a systematic analysis of the literature review based on 148 scientific articles, a taxonomy of socio-economic characteristics is proposed in terms of private (direct) costs, which are directly related to monetary costs paid by consumers, and social (indirect) costs, which consist of consumer perception, privacy, cybersecurity, and regulation. It is shown that social costs can hinder the deployment of smart grid technologies, even if these technologies appear to be useful based on private costs, while the scientific literature, unfortunately, focuses mainly on the latter.

The introduction of new smart grid technologies is necessarily a social and cultural transformation, involving adaptation to a new context co-created by the interaction between stakeholders and the people involved (Alvial-Palavicino et al., 2011). This study shows the importance of learning processes among stakeholders, especially the development of reflexivity among developers. Thus, the acceptance and adaptation to the implementation of a smart grid depend on the characteristics of each community.

Gill-Wiehl et al. (2022) find that community participation is almost universally cited as critical to the sustainability of the microgrid system. Community participation is most prevalent in the operation and maintenance phase, which these authors argue leads to positive social sustainability.

Rathnayaka et al. (2012) emphasize that the sustainability of the smart grid energy-sharing process is highly dependent on consumer participation, making consumer participation and management schemes crucial in energy-sharing approaches.

There is also the notion of demand-side management associated with the smart grid, which is also crucial (Klaassen et al., 2013). A social investment such as that required to be part of a residential smart grid community only makes sense if it is linked to demand-side management, where the prosumer also becomes a demand-side management actor.

Let's not forget that the smart grid is not only a way to achieve autonomy, but also to achieve sustainable development. Solar is a very volatile component of the energy mix and these smart microgrids are the real experimental element that will lead to a renewable energy mix in the future (Rajesh et al., 2017). The coal/oil plant was actually quite simple from a production and management perspective. In line with many visions of the smart grid, consumers will play a greater role in their overall energy consumption, such as distributed renewable energy resources, electrical energy storage, demand response, and electric vehicles. Thus, the notion of social acceptance will be crucial for the future and at the level of civil society as a whole.

Finally, in terms of community governance, Bari et al. (2014) emphasize that issues related to communication and management must be resolved before the full benefits of the smart grid can be realized. In addition, smart grid design must consider how to maximize the use of grid resources and available power, ensure reliability and security, and provide self-healing capabilities. This again highlights the importance of our research in building social acceptance into the design from the outset. This is what we intend to do by integrating these social acceptance requirements into the scenarios that feed our digital twins approach (Serugendo et al., 2022).

3. Methodology

When it comes to the acceptance of technological tools, much of the scientific research focuses on the TAM model (Technology Acceptance Model). This model argues that an individual's use of a new technology depends on two qualities, ease of use and the perceived usefulness of the new device. In our context, it is about more than the acceptance of technology. It is about redefining the rules of exchange between actors whose social and economic role is much more complex than in a classical situation. Therefore, we need to evaluate not only technological acceptance but also social acceptance, to remove the social barriers and give people a maximum chance to embrace this type of technology.

Numerous studies try to understand the acceptance of new technologies. Among them, many use the original Technology Acceptance Model (TAM), or its extension, the unified theory of acceptance and use of technology (UTAUT). The TAM (Venkatesh et al., 2003) was originally developed to assess the user acceptance of information technology. To answer our specific questions of social acceptance of technology, we propose to use the UTAUT (unified theory of acceptance and use of technology, Venkatesh et al., 2012) as a conceptual framework, which is a more advanced version of the TAM that is better suited to the context of self-regulated smart grids.

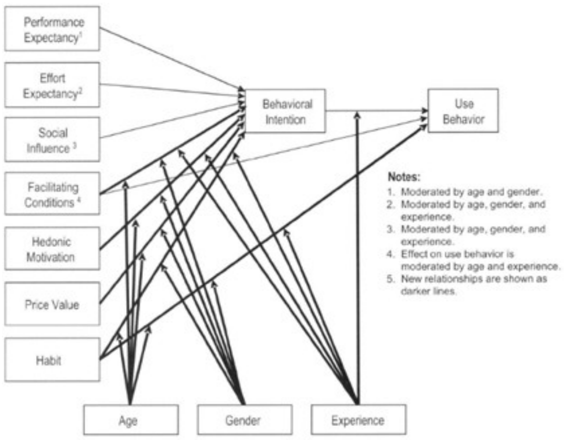

Figure 1 : UTAUT (Venkatesh et al., 2012)

The ethnographic survey is a sociological approach based on semi-direct interviews with project participants. The transcripts of the interviews are then analyzed using the QDA Miner text analysis software. The aim is to identify the main social characteristics that enable the social acceptance of residential micro-smart grids. The chosen research strategy is based on the principles of ethnography (Fragnière et al., 2019). Here, the aim is to describe and explain the social context of the respondents as they describe it. This is an appropriate strategy for the management field when seeking information about a particular context in order to better understand and interpret it from the perspective of those involved.

Applications of the TAM model and its extensions are mostly based on quantitative surveys. The interest of the TAM model is thus that it represents a proven model benefiting from numerous extensions, which are all validated in terms of statistical inferences by numerous scientific studies. The Technology Acceptance Model (TAM) goal is to evaluate the acceptance and use of new technologies based on customer behaviors and attitudes. Consequently, TAM models in the scientific literature often rely on dimensions or constructs, as seen in the previous section, that is generic and "decontextualized." Indeed, approaches to assessing the perceived value of salient attributes emanating from a smart grid user experience tend to rely on the technique of conjoint analysis, where each attribute of the “user journey” is evaluated independently to arrive at an overall score. Recent methodological approaches, on the other hand, tend to evaluate the customer experience holistically and thus take its specific context fully into account and as such in a holistic manner.

We have so far conducted 12 semi-structured interviews, of which the interview guides can be found in table 1, with different profiles of Swiss smart grid stakeholders. We have also conducted a series of

3 focus groups (involving microgrid experts with an economist, an engineer as well as a lawyer). This last part of the fieldwork aims to ensure that the social attributes derived from this research will be consistent with the more technical and logistical attributes of smart grids. All the interview transcripts, using QDA Miner, have been coded, analyzed, and synthesized. This will enable us to identify additional variables and generate research hypotheses that will be confronted with a thorough literature review. Based on these hypotheses, the items of the TAM questionnaires, always taken from the scientific literature, will be adapted to our specific context to better integrate the specific case of micro-smart grids.

Specifically, we have the following profiles in our respondents (people who have solar panels on their own homes, have solar panels on a building they own, have wanted solar panels but had to give up installing them, live in an eco-district, work at a fuel cell company, companies that sell and install solar panels). For those interviewees who had no idea what a micro-smart grid was, we incorporated a hypothetical scenario vignette into our semi-structured interview. The infographic showed the various elements a microgrid can interact with, such as the weather forecast, the market, or the national network, as well as the various types of energies used.

Profile	*Questions*
Has solar panels on house / building	Tell me about the process which led you to choose to install solar panels on your house/building.
	What factors particularly convinced you to take this decision?
	What obstacles did you encounter in this process?
	How could the process have been improved?
	What has changed in your daily life since you installed the panels?
	What do you like about this new routine?
	What bothers you about this new routine?
	How could these disturbances be solved?
Had to renounce installing solar panels	Tell me about the process that led you to want to install solar panels on your house.
	Tell me why you decided not to install solar panels on your house.
	What factors led you to give up, and why?
	What advantages have you found in such installations?
	What would motivate you to change your mind?
	What experiences have you had with similar installations?
Lives in an eco-district	Tell me about the process that led you to choose to move to an eco-district.
	What factors particularly convinced you to take this decision?
	What obstacles did you encounter in this process?
	How could the process have been improved?
	What has changed in your daily life since living in an eco-district?
	What rules (explicit or tacit) are present in your community?
	What do you like about this community?
	What bothers you about this community?
	How could these disturbances be resolved?
Works at a fuel company	Please explain to me, in your own words, what a microgrid is.
	According to you, what are its advantages?
	According to you, what are its disadvantages?
	How could the system be improved?
	What barriers do you think people encounter when wanting to join a microgrid?
	In your opinion, what could facilitate microgrids' acceptance among the

	population?
Hypothetical scenarios	What does this image evoke for you?
	How would you explain this image and its different elements?
	Now that I've explained what a microgrid is, if I told you it was 2035 and you lived in a microgrid community, how would you imagine your life?
	What would be the rules of a community like that?
	What needs would you have living in a microgrid?
	What would make you feel confident in a microgrid community?

Table 1: Interview guides of the hypothetical scenarios and semi-directed interviews

We also added a literature search on how people adapt to frequent power outages in other countries (appendix C).

In addition, we added fieldwork on mountain huts, which allows us to study cases of energy autarky in Switzerland (appendix A).

This research approach is therefore essentially based on the notion of constructivism. Its main objective is to understand why and how crisis management must completely revisited in the tourism sector. We therefore believe that this inductive approach is the most appropriate for our research. It is indeed well suited to understanding the perception that one has of the environment studied. The data collected through semi-structured interviews will be analyzed on a content analysis basis (with the help of the QDA Miner software) according to the codes or categories of codes retained for the analysis of the transcripts. Based on the synthesis of the results, we will develop research hypotheses that will be compared with the scientific literature.

4. Synthesis of results

	A	B	E	F
1	Category	Code	Statement	Meaning
2	Technical	Autonomy	Il a entendu parler d'un endroit en Espagne où les habitants sont indépendants en eau, et gèrent eux-mêmes le système. Pour cela, ils ont établi des contrats avec des quotas d'eau par personne, et se sont mis d'accord sur un quota accordé à chaque catégorie d'habitant, étant donné qu'un bébé ne consomme pas la même chose qu'un adulte par exemple. Il pense que ce système pourrait tout à fait être appliqué à l'électricité dans un microgrid.	A community which is self-sufficient needs to be well organized, as there cannot be any external help
3	Technical	Price	Avant cet évènement, il avait déjà envisagé d'en mettre, mais il attendait la commercialisation des tuiles solaires, ainsi que leur baisse de prix, car il les trouve plus esthétique que les panneaux, et préférait donc attendre	A high price is a barrier to buying solar panels
4	Technical	Price	Il espère que les choses vont avancer. Il mentionne à nouveau son problème de grande superficie, et que d'autres projets ont finalement pris le dessus sur celui-ci au niveau du financement, mais que ce projet reste dans un tiroir et qu'il est prêt à le ressortir quand les conditions seront meilleures.	A high price is a barrier to buying solar panels
5	Technical	Price	Il imagine qu'un obstacle pourrait être le prix, mais dans son cas il pouvait se le permettre.	A high price is a barrier to buying solar panels
6	Technical	Price	Le coût est très élevé pour poser un câble pour pouvoir réinjecter son électricité chez son distributeur, Romande Énergie.	A high price is a barrier to buying solar panels
7	Technical	Price	Le seul obstacle majeur pour lui est le prix, il n'a pas eu de problèmes techniques par exemple.	A high price is a barrier to buying solar panels
8	Organisation	Living in a community	Elle imagine qu'il faudrait beaucoup plus de sens des responsabilités, et qu'il faudrait faire plus d'économie d'électricité.	A microgrid community needs to be careful not to waste electricity, and find ways to spare it
9	Technical	Autonomy	Il voit aussi les prévisions, et le fait d'être connecté ou non à ce qu'il suppose être des systèmes industriels.	Autonomy is linked to microgrids
			Pour l'instant ils n'ont pas de batterie, mais cela pourrait évoluer, il pensait peut-	

Coding

Figure 1: An extract of a coding table after using the QDA Miner software.

The main elements appreciated by our respondents are: the cohesion of the group, the knowledge of each of the neighbors: regular meetings, mutual aid, diversity, absence of car noise, calm atmosphere, awareness of environmental issues.

The main elements disliked by our respondents are: appropriation of common spaces by certain people, lack of privacy, risk of living in autarky.

When applying the hypothetical scenarios, other elements are collected such as: rules imagined for a community living on a microgrid: no waste of electricity, lazy attitudes not tolerated, coordination of schedules, favoring walking and biking, reducing the use of electric cars, electricity quotas, good division of tasks, especially regarding the maintenance of infrastructure, shared responsibility, well-defined goals (SMART) and means of monitoring their success, measurement of the community's environmental impacts (e.g., plastic waste). Interestingly, these respondents have a much more holistic view of themselves than those who are already familiar with smart microgrids.

We also observe that the trust elements are required by all respondents. This is the case for the technical salient attributes: energy efficient buildings, assurance that infrastructure is working properly and regular monitoring, emergency contacts, a solution to store energy (so that they have reserves for the winter), and information sessions for newcomers. This is also the case for the mental salient attributes that require trust: team spirit, seeing that everyone is involved and making an effort, contingency plans before starting the project, ensuring that other community members are aware of the value of energy, being able to identify with the values of the project.

Table 2 summarizes the elements which are appreciated or disliked in eco-districts, the hypothetical rules for a microgrid community, and the trust elements identified.

TOPIC	*Opinion*	*Type*
ELEMENTS FOUND IN ECO-DISTRICTS	Group cohesion, knowing each of the neighbors	Appreciated
	Regular encounters, mutual aid	Appreciated
	Diversity	Appreciated
	No noises from cars, calm atmosphere	Appreciated
	Raised awareness about environmental topics	Appreciated
	Appropriation of common spaces by some people	Disliked
	Lack of privacy	Disliked
	Risk of living in autarky	Disliked
HYPOTHETICAL RULES	No wasting electricity, lazy attitudes not tolerated	
	Schedules coordination	
	Favor walking and biking, reducing use of electric cars	
	Electricity quotas	
	Good division of labor, especially regarding infrastructure maintenance	
	Shared responsibility	
	Well-defined objectives and ways to monitor success	
	Measuring environmental impacts of the community	
TRUST ELEMENTS	Buildings with low energy consumption	Technical
	Assurance that infrastructures are working correctly and regular monitoring	Technical
	Contact persons for emergencies	Technical
	Solution for stocking energy, to have reserves for winter	Technical
	Information sessions for newcomers	Technical
	Team spirit	Mental
	Seeing that everybody gets involved and makes effort	Mental
	Backup plans before starting the project	Mental
	Assurance that other members of the community are aware of the value of energy	Mental
	Being able to identify with the values of the project	Mental

Table 2: Summary of elements identified in interviews and hypothetical scenarios

From all these elements, we can already draw social insights indicating the risks of blocking forces to the social acceptance of microgrids and also the opportunities of helping forces. We present them here visually (see Figure 2) in a force analysis diagram.

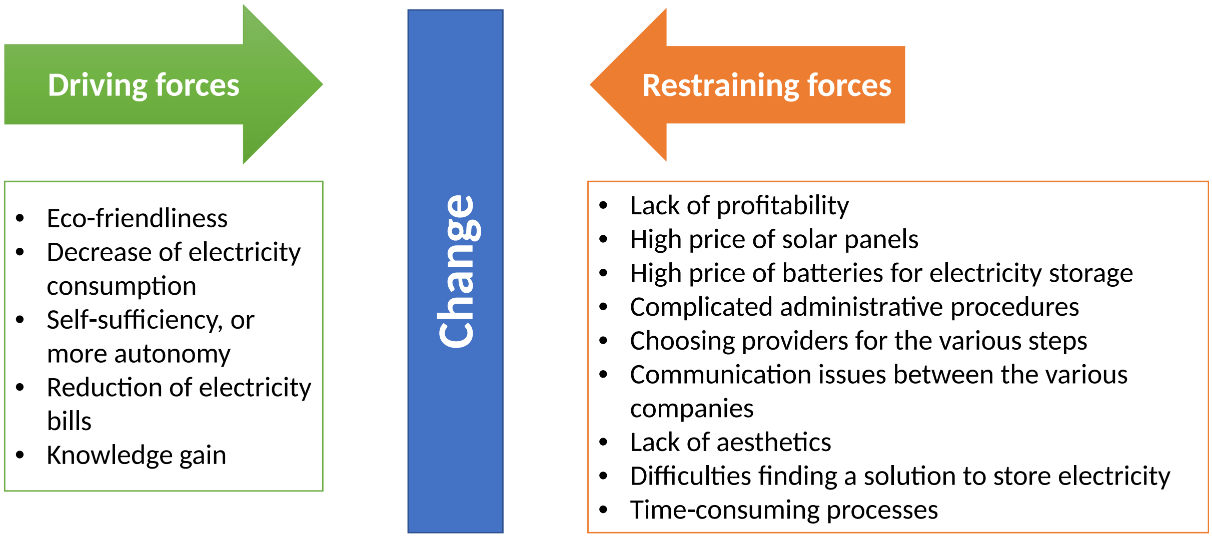

Figure 2: A compilation of the main results incorporated in a force analysis diagram

In the synthesis, we first summarized the recurring elements shared by most of the respondents. In the rest of this section, we present the atypical elements, i.e. those that concern only a few respondents. As such, among the respondents, several opinions were shared on different issues.

Firstly, with regard to **price**, six interviewees considered electricity to be closely linked to the economy. Four of them consider the profitability of installations to be a key issue, while three respondents think that the increase in electricity prices is an incentive to investigate having their own energy source, such as solar panels. Four respondents felt that installing solar panels was expensive and that external financial support was needed, and three felt that the high price was a barrier to buying solar panels.

Two respondents feel that **environmental friendliness** is not enough of an incentive to install solar panels, while four feel that environmental friendliness is a good motivation to take action in this direction. Two respondents believe that electricity and microgrids are related to the environment, while two believe that learning more about these issues has increased their awareness of environmental issues. In addition, two respondents believe that people have different views and values about better energy sources. In addition, two respondents felt that members of a community must have similar values and be committed to these values.

In terms of **responsibilities**, four respondents felt that in a community each member must take their responsibilities seriously. Two of them also think that the sense of responsibility is increased in a community where everyone is interdependent.

Regarding **group cohesion**, four respondents think that it is pleasant to have good group cohesion in a neighborhood. In addition, two of them think that it is very necessary for a community. Two respondents think that people need to be actively involved in order to build group cohesion and two others think that the influence on members of a group is stronger when there is group cohesion.

On the topic of **monitoring and emergency plans**, four people felt that regular monitoring and maintenance of infrastructure was necessary for people to feel safe. Two felt that access to information about their own consumption was important for other members of the microgrid. In addition, two respondents believe that risk and crisis management need to be put in place so that members can feel safe.

Living in a community means better relations between neighbors, according to two respondents. In addition, four respondents felt that community members need to make collective decisions rather than individual ones. Two respondents felt that for a community to function well, members need to see others actively involved, while two respondents felt that members of a community who are not motivated to get involved should not penalize the progress of others.

In terms of **knowledge and information**, four respondents felt that being involved in the process of installing solar panels had taught them a lot about the issue, even though the process was not successful. Several opinions on these topics were shared by two respondents, not the same two people each time; information on how to get involved in the process of installing solar panels can be hard to find; knowing that everything is under control is important to feel safe; communication is crucial in communities, as it is better to give too much information than too little; it can be difficult to know the amount of electricity you are using; and word of mouth has a strong influence on one's opinion of solar panels.

In terms of **consumption habits**, four participants think that having solar panels or being part of a microgrid means being more conscious of one's consumption. On the contrary, three felt that people do not seem to be very careful with the amount of energy they use and that they have wasteful habits. Two respondents felt that habits could easily be changed if the necessary infrastructure was in place.

Administrative procedures and laws are unclear and complex, according to three respondents. However, three others said that they had no problems with these procedures and that the process went smoothly. Two people felt that the procedures for installing solar panels in small areas were drastically different from those for large areas. In addition, two respondents felt that the administrative procedures should be simplified, standardized and centralized, and two others felt that support from politicians and distribution network operators was needed to improve these procedures.

Three respondents believe that there may **be trial and error and grey areas in the implementation of resource management**. Three of them think that resource management should be applied not only on a small scale but also on a larger scale.

Three others believe that **a combination of technologies, for example, a mix of photovoltaic and thermal panels, is a good solution for better management**. Two respondents felt that the proportion of available roof space to be covered by solar panels should be well thought out. In addition, two respondents felt that resource management should be organized and planned by the community rather than improvised. Two respondents felt that the role of distribution network operators in resource management was unclear.

Regarding **consumption rules**, two participants think that electricity quotas could be a solution to manage the electricity consumption of microgrid users. Another opinion, shared by two respondents, is that buildings should have low consumption to avoid wasting electricity. Two respondents believe that there should be a change in consumption habits so that conservation behaviour becomes the norm.

With regard to **autonomy**, two respondents felt that total self-sufficiency entailed certain risks, such as not being able to leave one's home. On the contrary, for two other respondents, the idea of being self-sufficient is pleasant and motivating.

Finally, two interviewees estimated that **electricity storage** is a problem, as batteries are expensive.

We propose now verbatims and reflections related to some of the elements presented above. This will help us creating questions items that are presented in the next section.

Quotas and consumption rules

Pre-defined quotas are a social requirement that emerges from the synthesis. "I don't have the right to consume more than xx amount of electricity per day". It is typically an element of fairness.

“I suppose there could be electricity quotas distributed among households according to the number of people living in the household.” - 24-year-old man living in Vaud

Buildings need to be low-consumption to avoid wasting electricity.

“On a logistical and material level, everything should be adapted, for example inside the buildings, so that everything is done in such a way that we consume as little as possible.” - 22-year-old woman living in Vaud

There is a need to change consumption habits so that frugality becomes the norm.

“We should be more careful with our electricity consumption, for example by not turning on the lights when it's sunny so that we don't consume for nothing”. - 22-year-old woman living in Vaud

Living in a community

For a community to work well, members need to see that others are actively involved, while personal data protection requires that smart meters provide comparative information on personal usage vs. community usage Link to literature review (stickers comparing electricity usage with neighbors in California).

“At the community level, I would need to see that everyone is doing their bit and that there is no one who is lazy and doesn't want to make an effort.” - 22-year-old woman living in Vaud

“If there are people who do not want to make an effort, they should not block or penalize others.” - 59-year-old man living in Spain

Autonomy

A community that is self-sufficient must be well organized because there can be no help from outside.

As a comment, we could interpret that a real social problem is a relationship with the main national network.

A solution could be to have an “orchestrator” in each microgrid. In the literature review, we can see those in remote locations (for instance in India), microgrids survival. In our developed countries, where objectives are more related to economics, sustainability, or national policy than survival, people’s motivation won’t be sufficient to properly manage a microgrid.

“I heard about a place in Spain where the inhabitants are water independent and manage the system themselves. To do this, they have established contracts with water quotas per person, and agreed on a quota for each category of inhabitant, given that a baby does not consume the same amount as an adult, for example. I believe that this system could be applied to electricity in a microgrid." – 59-year-old living in Spain.

Mobility

Batteries of electric cars could also be used as a battery for the whole house.

Mobility aspects are also more and more integrated into the concept of microgrids since there can be an interface with EVs (Electrical Vehicles). This is a trend observed in the scientific literature.

"At the moment we don't have a battery, but that could change, I was thinking of getting an electric car so that I could use the car as a battery." – 65-year-old living in Fribourg

5. **Proposed questionnaire items based on the ethnographic study for TAM extensions as well as conjoint analysis fieldwork**

Table 3 shows some opinions of the respondents on various topics. Frequency expresses the number of respondents who share that opinion.

TOPIC	*Opinion*	*Frequency*
ADMINISTRATIVE PROCEDURES	Administrative procedures and laws are unclear and complex	3
	In some cases, there are no issues with administrative procedures, and the process runs smoothly	3
	Procedures to install solar panels on small surfaces and large ones are drastically different	2
	Administrative procedures should be simplified, standardized, and centralized	2
	Support from politics and distribution network operators is needed to improve administrative procedures	2
AUTONOMY	Being entirely in autarky has risks, for instance never leaving the place of residence	2
	The idea of being self-sufficient in electricity is pleasing and motivating	2
CONSUMPTION HABITS	Having solar panels or being part of a microgrid implies being more conscious of one's consumption	4
	People do not seem to be very cautious with the amount of energy they use, and they have wasteful habits	3
	Some habits can change quite easily if the infrastructure needed to make the shift is available	2
ELECTRICTY STORAGE	Electricity storage is an issue for individuals, as batteries are expensive	2
EMERGENCY PLAN / MONITORING	There needs to be regular monitoring and maintenance so that members can feel safe	4
	Having access to information regarding one's consumption is relevant to the persons concerned	2
	Risk and crisis management must be put in place so that members can feel safe	2
GROUP COHESION	It is pleasant if there is good group cohesion in a neighborhood	4
	Influence on one another is stronger in a group where there is group cohesion	2
	Group cohesion is deeply needed in a community	2
	People need to actively participate so that group cohesion can be	2

	built	
KNOWLEDGE / INFORMATION	Getting involved in the process of installing solar panels teaches a lot about the topic, even if the process does not succeed	4
	Information on how to get involved in the process of installing solar panels can be hard to find	2
	Knowledge that everything is under control is important to feel safe	2
	Communication is crucial in communities; it is better to give too much information than too little	2
	It can be difficult to be aware of the amount of electricity one uses	2
	Word of mouth has a strong influence on one's opinion of solar panels	2
LIVING IN A COMMUNITY	Community members need to make common decisions, rather than individual ones	4
	Living in a community implies better relationships between neighbors	2
	For a community to function well, members need to see that others are actively getting involved	2
	Members of a community who are unmotivated to get involved must not penalize others' progress	2
PRICE	The topic of electricity is closely linked to the economy	6
	Profitability of installations is a key issue for people considering the installation of solar panels	4
	Solar panel installation is expensive and financial support is needed for individuals	4
	A high price is a barrier to buying solar panels	3
	The increase of electricity prices is an incentive for people to investigate having their own energy source	3
QUOTAS / CONSUMPTION RULES	Electricity quotas could be a solution to manage microgrid users' electricity consumption	2
	There needs to be a shift in consumption habits, so that sparing behaviors become the norm	2
	Buildings must be low consuming so that there is no electricity waste	2
RESOURCE MANAGEMENT	In the process of implementing resource management, there may be trial and error, as well as grey areas	3
	Resource management should not only be done on a small scale, but also a larger one	3
	Combining technologies, for instance mixing photovoltaic and thermal panels, is a good solution to have a better management of resources	3
	The proportion of available roof area to be covered by solar panels must be well thought out	2
	The management of resources must be organized and planned by the community, rather than improvised	2
	The role of distribution network operators in regard to resource management seems unclear	2
RESPONSIBILITY	In a community, each person needs to take its responsibilities seriously	4
	The sense of responsibility is increasing in a community where everyone is dependent on each other	2

VALUES / ECO-FRIENDLINESS	Being more eco-friendly is a good motivation and gives people an incentive to take action in this direction	4
	Eco-friendliness is not enough of an incentive to install solar panels	2
	Learning more about the topics of electricity and microgrids raises awareness of the environmental issue	2
	People living in a community need to have similar values, and to be committed to these values	2
	People have different views and values regarding which energy sources are better	2
	The topics of electricity and microgrids are linked to the environmental issue	2

Table 3: Opinions of respondents on various topics

6. Next steps and methodological elements with digital twins

Next steps and methodological elements with digital twins

In the next step of this research presented here, we will evaluate how the attributes of social acceptability are combined with more technical attributes related to the physical laws of a power grid. We will thus assess how the attributes of social acceptability are combined with more technical attributes related to the physics of a power grid. In a classical relationship between multiple generators and often a single electric utility supplying electricity to many consumers, the logistical and managerial elements of the grid are provided by a single actor. Here we are dealing with a much more complex case, where numerous consumers also become producers (i.e., prosumers). Therefore, all the technical constraints associated with the grid must be considered, as well as the social acceptability characteristics that make them cooperate, otherwise, the project has no chance.

So the findings of this paper will enable us to develop an adapted TAM questionnaire with new question items as the ones presented in Section 5.

To finalize the field study phase of this research, we will be using Conjoint Analysis (CJ). CJ is a market research tool used to determine which attributes are important in a product or service by examining the tradeoffs consumers are willing to make. In the social or psychological sciences, conjoint analysis is often used to determine consumer preferences and estimate consumer utility for various services. By conducting a survey and then applying the theory of conjoint analysis, a utility function can be calculated. In this study, "part-worth" (i.e., utility functions) will be estimated for each respondent and for the entire sample using the non-metric conjoint analysis procedures adapted to qualitative scales. Finally, this utility function will be integrated into a discrete choice experiment (DCE), the solution of which provides the optimal service design as well as optimal pricing. According to constrained optimization theory, the shadow price, also known as dual value, represents the change in the objective function of the optimal solution due to a small change in the constant of a given constraint (see for example Fragnière et al.,2017). Consequently, the utility functions generated by conjoint analysis will be incorporated into a discrete choice experiment model to optimize the weights of the selected social attributes that form the basis for the Digital Twins algorithms.

A digital twin is a virtual representation of a physical object or system, such as a micro smart grid. Digital twins are used to simulating the behavior of real systems and optimize their performance. For micro smart grids, digital twins can be used to model and analyze the power system, including power distribution, the behavior of individual components (e.g., prosumers and stakeholders), and their interaction with the grid and other power sources. This can optimize the operation of the microgrid, including load balancing, demand response, and integration of renewable energy sources.

The goal is that on the basis of this field study, we can create adequate scenarios that will feed our digital twins approach so that finally the real implementation of our micro smart grid in a residential community becomes sustainable. This should be a model in Switzerland and Sweden to promote the energy transition as in these two countries the expectations in this field are high for the next decade.

Social acceptance scenarios to be used through Digital twins as quasi-experiment for engineering validation

Basically, the main research proposition we are looking for will be related to the behaviors of all people involved in a crisis (service providers, users, and clients as well as all stakeholders). So we intend to test them through quasi-experiment. In a simple quasi-experiment with a control group and an experimental group. An experiment is, according to William Ralph Inge, “a test under controlled conditions that is made to demonstrate a known truth, examine the validity of a hypothesis, or determine the efficacy of something previously untried” (quoted in Shadish et al., 2002). In a quasi-experiment, however, participants are not randomly assigned to a case (Shadish et al., 2002), after which the results of the two groups are compared (Campbell & Stanley, 2015). Knemeyer and Naylor (2011) have identified the necessary conditions for quasi-experiments to establish the causality of two tested variables (2011); first, with all else equal, only the independent variable should be changed, and second, the independent variable has to affect the participants, and the dependent variable has to intervene. In particular, we will rely on a quasi-experiment protocol such as the ones employed in human ethology. Indeed, human ethology employs two main methods: naturalistic observation and experiment (Eibl-Eiblsfeldt, 1989). In fact, the ethological experiment falls into the category of quasi-experiment. It means that we are not able to “control” all the variables present in the experiment as is the case with pure laboratory experiments. So our goal is not to generalize findings but rather to discover new behavioral patterns. In this research, the quasi-experiment will be conducted directly in the digital twins, which is quite original in terms of methodology. There is also no standardized approach. We can, however, describe it as a process containing these four main steps:

1. Hypothesis formulation. We start by formulating a hypothesis related to a given human behavior (within the context of a microgrid community). This hypothesis is the answer to the stated research question.

2. Hypothesis “operationalization”. We then “operationalize” the hypothesis through a simulation of the ecosystem under study to obtain a prediction of it.

3. Data collection and analysis. We collect and analyze the data of the experiment (e.g. different deviations from the expected behavior of a person in a micro-grid environment).

4. Conclusion. We compare the statistical results to the prediction and also to other findings in the literature to assess the validity of the hypothesis.

According to Wacker (1998), theory building is grounded on the four following components: a) definitions of terms and variables; b) a domain (i.e., the exact setting in which the theory can be applied); c) a set of relationships; and d) specific predictions. We refer to Wacker because his Theory Building approach was created for the operations management research community, and it fits well with our research since we approach the self-regulation of smart grids as operation management (i.e. operating modes).

Construction of a social scenario feeding the digital twin simulating a residential micro smart grid community

A social digital twin provides a simulation, prediction, and decision-making environment to address varied and complex social issues by digitally reproducing the connections and relationships between people, things, the economy, and society.

A virtual model created to faithfully represent a physical object is called a digital twin. The object under study, such as a smart grid, is equipped with a variety of sensors that are important for its functionality.

We will work on the notion of a "social scenario" by feeding digital twins. For example, we could study social phenomena such as free behavior in the microgrid community (see Alotibi et al., 2019). Another example would be to simulate the concept of gamification to create socialization among prosumers).

Here is an example that we have already developed. We have seen those trust elements are necessary for a good social acceptance of the smart microgrid. In addition, salient technical and social attributes are always part of the trust elements:

Case 1: Low energy buildings and adaptive consumption behavior (demand side management).

This leads to a scenario where it is necessary to Optimize energy use, minimize energy consumption, peak shaving

Case 2: Ensuring that the infrastructure is functioning properly and regular monitoring.

This leads to a scenario where digital twins serve as both an actor and a monitoring tool (e.g., combined with a BIM model).

Case 3: Fairness, i.e., everyone gets the same energy, wait times, and prices.

This leads to a scenario where people are contacted in case of emergency and there is supervision and an alert system like a police force.

As a future social scenario, we explore regulatory aspects regarding the national network. In Switzerland, the national grid takes back excess energy, while in the US, for example, it is forbidden or impossible to return it to the national grid.

7. Conclusion

In this paper we report on the main elements of social acceptance of smart grids in Europe from a qualitative survey. In a second step, based on these findings, we will carry out a quantitative survey in order to measure precisely the share of these social attitudes in order to counteract or compensate for them to facilitate the dissemination of micro-smart grids. We will also use them to feed a digital twins programme in order to integrate a "social" scenario in addition to technological and technical constraints in order to best simulate the user experience in a smart grid context. Indeed, this research is part of a complete European project between Switzerland and Sweden (LASAGNE), which aims at making these autonomous electric systems socially sustainable and not only technological.

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Appendix A. Observations and interviews related to the case of mountain huts in Wallis

We had the opportunity at the end of 2022 to carry out an analysis of the use of renewable energies in mountain huts, which we presented to the managers of a company equipping mountain huts with solar panels, batteries, and inverters to ensure their energy autonomy. Here is a summary.

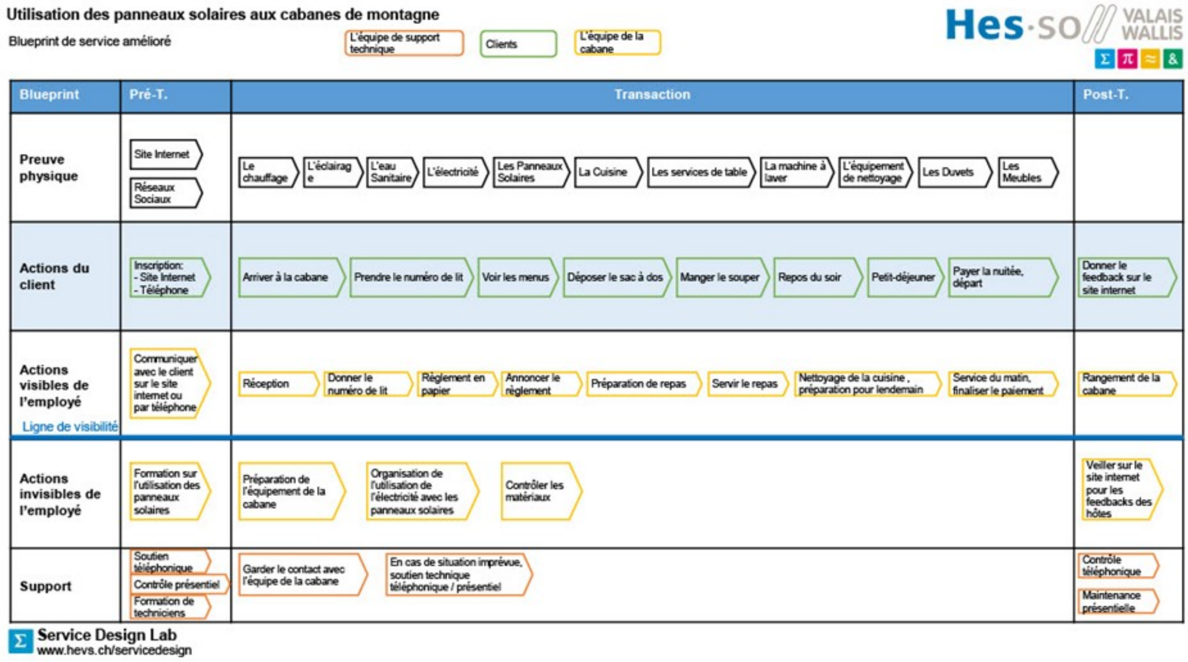
Due to the Covid pandemic, sanitary requirements have increased and electricity consumption is also increasing in the mountains. Faced with this reality, what is the possibility of using electricity produced by renewable energies (especially solar) in mountain huts? The research conducted uses Service Design tools, including observations, interviews, a customer journey and the "Services Blueprint", to provide recommendations to the company.

For mountain huts, it is important to control and save energy. At present, energy sources have to be transported by heavy means, resulting in CO2 emissions. The main objective is to design systems that are as economical and simple as possible. The Blueprint of the service "Use of solar panels in a hut", i.e. the description of the customer path extended to the interactions and processes allowing to deliver of the service has been realized (see illustration below).

The following elements need to be improved for the supplier and its technical support as well as for the clients in the cabins:

- training of specialized technicians
- regular face-to-face maintenance and technical support
- training of the hut team (mainly the janitor) in the use of the solar panels, basic maintenance, and upkeep, good operating practices (manual and question-and-answer list), as well as a procedure to follow in case of unexpected situations

Many huts need to upgrade their energy system to better serve their guests and also ensure their energy independence. Far from the grid, the supply of electricity is complex and expensive. Thus, and taking into account the above recommendations, the installation of solar panels can offer an interesting solution to the energy problems of high-altitude huts.



Appendix B. Interview guide for the focus groups in the Meyrin residence

We have since December 2022, conducted 4 sessions as part of T2.2, to build an interview guide that mixes attributes of social acceptance of the micro-grid by the participants (T2.1) with technical social attributes that are driven by the dimension of the laws of physics of smart grid. Below is the interview guide.

Why would a community consider participating in a community microgrid?

The reasons are numerous, but one can invoke goals of electrical autonomy, local independence (also can be national, if one wishes to contribute to the independence of the country), energy efficiency and savings, reducing exposure to volatile utility costs, need or desire to increase energy resilience, improving air quality or generally reducing one's carbon footprint and greenhouse gas emissions. Some will see other objectives such as the social aspect of being able to solve their own problems as a community and personally craft and manage their own energy resources (social dimension). Finally, of course, the economic dimension will play a major role in this type of decision to live in "autarky".

What are the microgrid solutions to address user needs?

First of all, we need to consider some important aspects – will the installation supply only residential users, or residential and commercial? What about public services?

Then, with concrete examples, we are able to explain to our study participants how a microgrid works. We need to explain what a smart meter is, an inverter, a solar panel, a battery, a fuel cell, regulation equipment, and also an interconnection with the utility grid, but without getting lost in too technical and complex concepts.

Once the concept of the microgrid is well understood, we can review the different uses of these microgrids. Is it used in parallel with the utility grid, or for the main part of the self-consumption of the community? Is the consumption intended for heating, electrical appliances, EVs (electrical vehicles)? Is the micro smart grid coupled with other autonomous systems?

How to address microgrid regulation aspects and what, if any, interconnection will be maintained with the grid?

We need also to explain to our study group the management and regulatory aspects of the smart grid. Indeed, the notion of the regulation of a smart grid between production, storage, operation, and consumption requires a whole series of monitoring, analysis, diagnosis, and decision-making that are necessary for its good management. All microgrids are smart by their nature, which means that algorithms will largely automate these regulation processes. However, for the microgrid to function properly, human involvement is necessary. One can imagine, for example, that a company offers a turnkey smart grid "service" system with real-time monitoring that is done remotely with occasional on-site intervention for repairs and maintenance. At the other extreme, one can imagine that the community buys its own smart grid equipment and software, as well as solar panels, inverters, and batteries, and that it manages everything autonomously. Between these two extremes, multiple configuration possibilities exist.

Who will be affected, who will gain or lose and who will care, and the basis for their concern?

Here, the notion of prosumer is introduced. “Prosumer” is the contraction of producer and consumer. Indeed, moving from the utility grid to a microgrid would convert people from electricity consumers to the new role of prosumer. This has important implications for us as individuals, as well as for the communities affected.

Community responsibility must be taken into account. Who are the driving this decision and how are they organized? What will be the governance structure for handling matters related to the microgrid? How will pecuniary operational losses or gains be managed? What benefits, burdens and limitations would this impose on those affected?

We must consider here the micro, meso, and macro levels. Indeed, we know that in the future, in order to ensure the stability of electrical networks based on an energy mix that is increasingly based on renewable energies, microgrids managed at the local level will have an increasingly important role in terms of self-regulation, both at the meso (regional) and macro (national) levels. Eventually, an "orchestration" at these three levels will be necessary.

Many legal issues must be considered. For example, in some states, it is possible to dump surplus energy on the grid, while in others it is forbidden! The whole issue of grid interconnections and microgrids represents great uncertainty. New business models linked to this new role of the prosumer must be invented. It is no longer the classic case of B2C but rather C2B, B2B, and possibly C2C!

The notion of demand-side management must also be taken into account here. Indeed, a microgrid community must also consider how much of its own energy consumption to conserve. The establishment of a virtuous circle should be the desired end state, where a community takes measures to reduce power consumption while establishing a new source of clean power and installing the modern power-management infrastructure needed for a microgrid.

Finally, we will also introduce the notion of electricity pricing in this chapter because it is an essential element of these microgrid production and consumption controls.

As a final focus group question, we want to look ahead to post-implementation matters like servicing, maintenance, upgrades, expansion, becoming an energy provider for outside users if enough surplus is generated, etc.

Here, we examine what the user needs to consider after a microgrid is implemented and functioning. We will provide some practical advice, best practices, and a list of matters to address to ensure one makes the most of the microgrid and can address potential problems before they manifest.

For example, a plan for system maintenance and repairs needs to be established. System optimizations and upgrades must also be forecast, and a regular schedule established. The community may grow or shrink in size, consequentially affecting the electrical load. Users need to have a plan for that as well to ensure the microgrid is able to meet its objectives.

The user also needs to monitor regional or national policies and regulations to see if anything may increase the cost or complexity of managing a microgrid. Many utilities and the politicians they support view the emergence of such local entities to be a threat and have already or will attempt to change or implement laws that discourage the establishment of microgrids.

Appendix C. Literature search on how people adapt to frequent power outages in other countries.

Topic	*Country*	*Observation*
SCHEDULES	Lebanon	People have to match their working hours to the times when electricity is available
	China	Some companies receive notice of load shedding only a few hours in advance
	China	Government calls on businesses to cut consumption when there is too much demand
	Central African Republic	Pace: two hours of power every 48 hours
COMMUNICATION	Congo Republic	Companies are sometimes not informed about load shedding and it is not always justified
	USA	The telephone network and Internet are cut off, the only way to receive information is with a battery-operated radio
RELOAD	Ivory Coast	As soon as there is power, people charge all their appliances. They take advantage of the electricity as soon as it is available.
	Central African Republic	If their workplace is not affected by power cuts, some people take their electronic devices (mobile phones, computers, etc.) to work. Sometimes they even take those of their relatives who do not have the opportunity to charge them elsewhere.
	Lebanon	Some people charge their mobile phone on their car battery.
	Lebanon	Generators are in theory illegal, as they are highly polluting. However, in practice they are tolerated.
TRAVEL	USA	The proper functioning of public transport is not guaranteed during a power cut.
	Lebanon	People's budget priority is still the car, because it is essential.
	Lebanon	With supply problems, some people are sacrificing days of work queuing at petrol stations to fill up to ensure that they can get around the following days.
FOOD AND WATER	Lebanon	Food should be eaten soon after purchase, as it cannot be kept cold.
	Lebanon	There are also problems in supermarkets, due to breaks in the cold chain.
	USA	Try to open the doors of freezers and refrigerators as little and as long as possible to keep them cold.
	USA	Water can also be a problem, either because it is completely cut off or because it is contaminated and therefore not drinkable.
MEDICINES	Lebanon	The supply of drugstores is not guaranteed, making access to medicines difficult.
LIGHTING	Lebanon	Safety on the streets can be weakened without street lighting.
TEMPERATURES	Mali	Heating and cooling systems can be switched off, making the interior of buildings too hot or too cold depending on the season. This makes it difficult to concentrate. The quality of sleep may also deteriorate, which can affect the mood of employees.

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