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Smart Grid in the Arctic City

Historical, Technological, and Social Aspects of Evolution

ABSTRACT This article presents the evolution of a smart grid in an artic city, and we analyze its development using the Smart Grid Reference Architecture (SGAM) and from historical, technological, and social points of view in an Arctic context. We illustrate the emergence of smart grid application and its relation to energy consumption habits and sustainability. The study includes observations from empirical research conducted using a mixed methods approach. This included two months of organizational ethnographies consisting of interviews with specialists at an electricity utility, shadowing the workers, participant observation in the control center, and a questionnaire survey among local residents. Three stages of transformation in the electricity network were observed: 1) the conversion from analog to digital in network operations, with residents as passive receivers of electricity; 2) introducing digital communications and a digital local area network that allowed residents to report consumption; 3) the electrical network as an evolving smart grid with a digital platform enabling two-ways communication among network actors. People became more active when smart grid applications were introduced in the electricity network and middle-aged men can now better manage their energy consumption, even though their motivation is financial, rather than environmental. At the same time, unplugging from the smart grid becomes increasingly difficult.

KEYWORDS Arctic residents, digital platform, digital technologies, energy policy, infrastructure, smart grid, smart applications

Introduction

Electricity grids form the biggest structure ever made by man (Thompson 2016; Elovaara & Haarla 2011a; Elovaara & Haarla 2011b) and are subject to economic and political interests (Bakke 2017). Human societies and the built environment need this mostly hidden infrastructure to function. In this interdisciplinary article, we study the electrical network in the Arctic City of Rovaniemi in Finland. We analyze the development stages of smart grids and map the actors' relations in the Smart Grid Reference Architecture (SGAM) in an Arctic context. The "Arctic context" means a low average temperature with high extremes; summers are light and warm, up to +30°C, while winters are dark and harsh, with temperatures often dropping below −30°C. The amount of precipitation is high; over a winter, the depth of accumulated snow is between 60–80 cm. The harsh climate results in high heating needs for the dwellings, up to 30% of final energy consumption (Treasury of Finland 2022). The population density is relatively low, 18/km^2, going as low as less than 2/km^2 in Lapland, which means that infrastructure building is challenging and expensive. Many Finnish cities have district heating networks; however, these are mostly limited to the more densely populated urban centers. Overall, in Finland, heating uses 27% of the primary energy demand and about half of the dwellings are detached or semi-detached houses, with on electrical heating in over one third of them (Motiva 2024). SGAM is the European reference architecture to achieve European policy goals. It was developed under the Smart Grid Coordination Group, supported by the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunication Standards Institute (ETSI) with the original goal of uncovering gaps in the smart grid standardization (CEN-CENELEC-ETSI 2014). It describes the European Smart Grid standard with interoperability layers, domains and zones, but it has not been conceptualized into the Artic context. In our study, the Arctic is the practical environment of smart grid applications used by the energy and water utility studied and by the residents of Rovaniemi. The SGAM architecture provides a contextual definition of smart grid in our paper, where the energy provider and application are embedded. We illustrate the changing relations in the Arctic city and how the emergence of a smart grid application relates to energy consumption habits and sustainability.

The "information revolution" was once supposed to create a city of bits in the cyberspace without considering the material infrastructure that supports it (Mitchell 1995), viewing the built environment and information as separate (Hayles 1999). However, digital technologies were also used to solve urban challenges, which transformed traditional infrastructures into what Tomitsch and Haeusler (2015) label as infostructures. Sociologists like Castells (2009) also pointed out how the shift in the ownership of information and the power that is exercised through the access and control over it changes social relations (O'Dwyer & Doyle 2012). The changing role of digital infrastructures require redefining and reconfiguring the social relations of people, their community, government, and the urban environment (Ho 2016; Rose 2020).

In Europe, digitalization of electricity networks has taken place in phases, when new digital layers have been added into the mechanical infrastructure in an effort to harmonize the climate objectives and sustainable growth. The vision is that the smart grid will deliver low-carbon electricity more efficiently and reliably, while enabling consumers to manage and reduce their energy use and minimize costs to the benefit of all (Palm, Ellegård nd Hellgren 2018). The smart grid is an obvious cornerstone for an integrated system. In the current state of urban technologies, smart grids provide the digital platforms for new services to customers. Ernst (2016) summarizes that smart grid technology now allows controllable logistical distribution in space and time. The basis of the responses is now, as Ernst reminds us, the "immediate knowledge of the network itself." Much of the work that has been going into electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid, where smartness means ICT technologies (Tuballa & Abundo 2016). This technological change has allowed new ways to price electricity and provided new tools for maintenance (Zhou & Brown 2017). In addition, in many countries, ICT tools are used to inform residents and guide them how to monitor and control their electricity consumption (Leiva, Palacios & Aguado 2017).

In Finland, digital platforms have emerged with applications to evaluate and inform electricity prices and energy consumption profiles; however, this development is not homogeneous within the European Union (EU). One of the main objectives of smart grid implementation in the EU is integration of renewable energy and harmonization of the European power market. In the United States, the benefits of smart grid technologies have been said to be operational safety, security and efficiency and in Japan, to help manage the risks of earthquakes while cutting greenhouse emissions (Zhang, Chen & Gao 2017). Although there are differences in objectives, what is emphasized is the "integration" of new technologies and socioeconomical aspects, as smart grid technology changes human behavior (van der Werff, Perlaviciute & Steg 2016; Bigerna, Bollino & Micheli 2016).

In this paper, we present the evolution of a Smart Grid Architecture in the Arctic city of Rovaniemi in Finland. Next, we further exemplify why this specific city is relevant for study. Rovaniemi is one of the largest cities in Europe by area and has a cold climate. As a result, it has only been possible to build a district heating network in the city center, and the electricity network is relatively expensive to maintain due to the long distances involved. The city center constitutes a mere 0.1% of the Rovaniemi municipality area, but is home to 26% of the population. Over 73% of the municipality is classified as sparsely populated area. More than half of the population of Rovaniemi lives in detached or semi-detached houses (City of Rovaniemi 2014). In Rovaniemi, the liberalization of the electricity market requires consumers to play a new role. We show that smart grid development, information and communication technology (ICT) enhanced energy systems, which are inherently multidimensional. The interaction of humans with technology, or rather the physical manipulation of technology, indeed happens on the plane of reality; however, there are other realities and interaction planes on top of that. For example, the communication layer which is about radio systems and network protocols, the information layer where humans as well are reduced to series of 1s and 0s, and, in the business layer, the human user, or more precisely the marketable information about the human, becomes the product. On these parallel layers, humans are seen either as nodes, data points, or business opportunities. We can also argue that most humans are not aware of these layers, and unable to make informed consent.

Ever since the "Clean Energy for All Europeans package" was presented in 2016 (European Commission 2016a), consumers have been placed at the center of the energy transition in the EU. While energy efficiency and decarbonization are the main goals of this transition, they go hand in hand with providing a "fair deal" for consumers (European Commission 2016b). Consumers are envisioned as active and central players on the energy market of the future. With the new regulations in force, consumers across the EU have a better choice of supply, access to reliable energy price comparison tools and the possibility to produce and sell self-generated electricity. These changes are intended to open up more opportunities for civil society to become more involved in the energy system and respond to price signals. To this end, one of the key roles of smart grids is empowering users to become more actively involved in the energy system and making informed decisions (van Mierlo 2019). With a better understanding of their own consumption habits and clear information about prices, using certified price comparison tools, consumers can judiciously change their energy consumption and/or expenditures. This is aided by smart metering, with functionalities given in the EU Electricity Directive (European Parliament and Council 2019). Access to reliable information in real-time is one of the cornerstones of smart grids, and it will enable a shift in energy consumership from passive, but somewhat predictable, recipients to active, and less predictable participants, in the energy market (Schweiger et al. 2020). As a result, the value of information increases; data on consumer preferences will be of higher value, requiring stronger rules on consumer data protection (Martinez et al. 2020).

This will also raise questions regarding the sustainability of smart grids (Calò, Louis & Pongrácz 2014), which so far has been analyzed mainly considering what smart grids can do, e.g., contribute to sustainable energy (Hu et al. 2014), or help sustainable energy consumption (Schappert & von Hauff 2020). However, the overall sustainability of smart grids has not yet received sufficient attention.

The goal of this article is to study smart grids infrastructure in Rovaniemi, an Arctic smart city in northern Finland and the evolution of the grid from historical, technological and social points of view. The research questions of the study are:

- *How did the smart grid infrastructure evolve in Rovaniemi Finland, from historical, technological, and social points of view?*
- *What was the role of the smart grid app in changing the energy consumption habits of residents in Rovaniemi?*
- *What are the sustainability impacts of the smart grid at its current level of evolution?*
- *How did the Arctic conditions shape smart grid development in Rovaniemi?*

Smart Grid Architecture

In the EU, the Smart Grids Task Force (SGTF) was set up by the European Commission (EC) at the end of 2009, to help harmonizing European standards, support the development of a pan-European energy system, support energy markets and protect customer rights. The task force is focusing, among other things, on standards for smart grids and providing regulatory recommendation on data protection, privacy and cyber security, as well as recommendations on smart grid infrastructure development. The EU SGTF defined Smart Grids as

> electricity networks that can efficiently integrate the behavior and actions of all users connected to it—generators, consumers and those that do both—in order to ensure an economically efficient, sustainable power system with low

> losses and high quality and security of supply and safety. (Smart Grids Task Force 2011: 31)

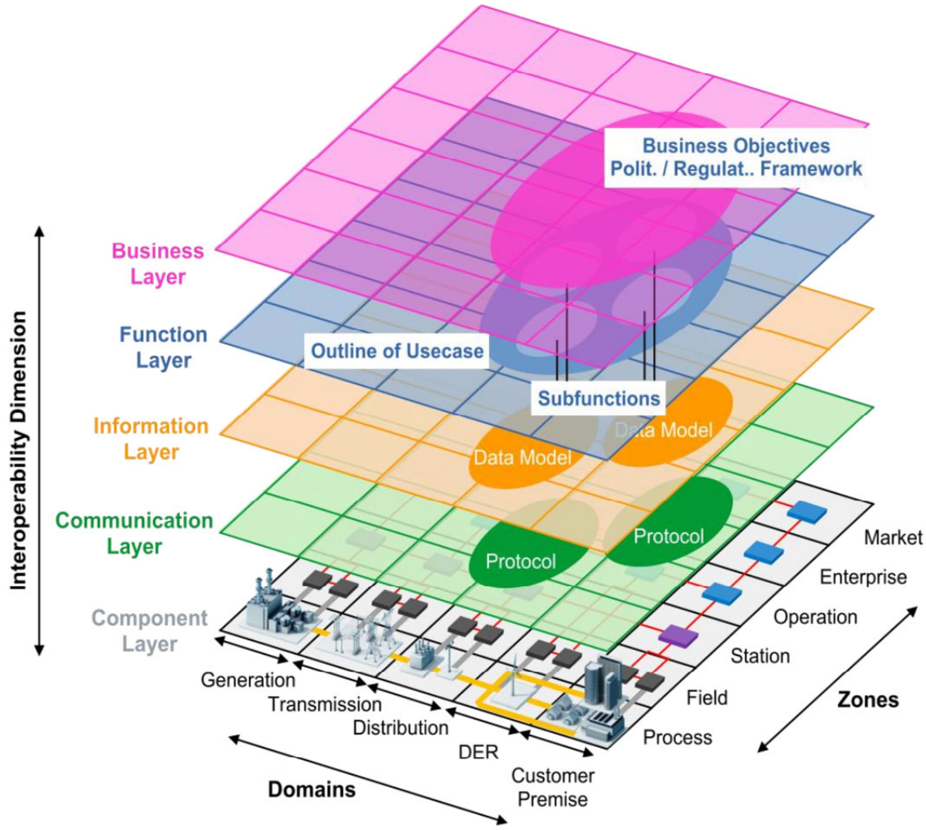
Eurelectric has recognized ten key steps toward smart grid development in three stages (Eurelectric 2011):

> Facilitation on EU and national levels—through (1) regulation, (2) standardization, (3) testing and (4) demonstration models;
> Deployment in Member States—from (5) rolling out smart meters and informed customers, through (6) monitoring and control of distributed generation, to (7) aggregating distributed energy sources and (8) integrating local and central balancing;
> Commercialization in the Member States—(9) integrating large-scale e-mobility, heating, cooling and storage, to (10) moving to a real customer participation in the power market.

The facilitation stage on EU level has been accomplished thanks to the work of the SGTF. The deployment stage is slightly delayed, although smart meter roll-out has been accomplished in Finland, but local balancing of generation is not yet fully achieved. The final stage, moving to real customer participation, is still an ongoing process. One step toward this is communication instruments aimed at consumer empowerment. The main objective is to build citizens' expertise utilizing smart grid platforms services to engage the citizens of European Union member countries to monitor their energy consumption and change their behavioral models.

Smart Grid Architecture

The smart grid development is built upon the smart grid architecture model (SGAM). Built under the EU mandate M/490 for the development of a framework for a European smart grid deployment by the CEN-CENELEC-ETSI Smart Grid Coordination Group, the SGAM is a three-dimensional framework used to model the interactions among the different entities within a smart energy grid system (CEN-CENELEC-ETSI 2014: 15). It consists of five layers (Fig. 1) representing business objectives and processes, functions, information exchange and models, communication protocols and components. Each layer covers the smart grid plane, which is spanned by electrical domains and information management zones. The most vital layers for smart grids are the information layer, which transfers information objects and data models, and the communication layer, which is responsible for protocols and mechanisms for the information exchange. The SGAM framework now introduces interoperability aspects and how they are taken into account via a domain, zone and layer-based approach in the EU. This model is intended to represent in which zones of information management interactions between domains take place. It allows presentation of the current state of implementations in the electrical grid and, furthermore, to depict the evolution towards future smart grid scenarios by supporting the principles of universality, localization, consistency, flexibility and interoperability. In general, power system management distinguishes between electrical process and information management viewpoints. These viewpoints can be partitioned into the physical domains



of the electrical energy conversion chain and the hierarchical zones (or levels) for the management of the electrical process.

Fig. 1. The SGAM framework (CEN-CENELEC-ETSI 2014: 15).

While the SGAM framework allows for the visualization and mapping of the—mostly information-based—interactions among different actors within a smart energy system, it is nonetheless cities' history, geography, climate, economy and population that influence their energy transformation (Talandier 2018). Often, the research on smart grids focuses on how to implement new technologies and on the potential changes in the energy utilities business and operating environment (Parviainen et al. 2017). The literature mentions the social acceptability of smart grid technology from the perspective of residents (Elabban & Abu-Rug 2016; Masera et al. 2018). It is often assumed that residents, as consumers, will make active rational choices regarding their electricity consumption with the help of ICT (Stengers 2013; Goulden et al. 2014). This narrative presupposes that the energy information is visible (Bertoldi, Ricci & de Almeida 2001), which can encourage the consumers to either decrease or delay their energy consumption (Delmas, Fischlein & Asensio 2013). However, the introduction of smart grid technology now allows to profile residents to modify their behavior (Elabban & Abu-Rug 2016), which might cause resistance and ethical problems (Vallés et al. 2016). In addition, some studies argue that smart grid technology and its digital platform can support a more democratic energy system (Skopik 2013) by increasing the autonomy of the local residents (Wolsink 2012). In addition, smart grids have enabled the spread of digital platforms into built environments and people's homes. These digital platforms can be seen as sociotechnical systems, as they comprise both the technical processes, elements and associated organizational processes integrating our homes devices. Therefore, it is important to study how digital platforms affect everyday life (Reuver, Sørensen & Basole 2017) and contribute to sustainability.

Smart Grid Sustainability

Sustainability is often viewed as the triple bottom line, where environmental protection, economic growth and social progress happen concurrently. In terms of smart grids, the three dimensions of sustainability are illustrated in Fig. 2.

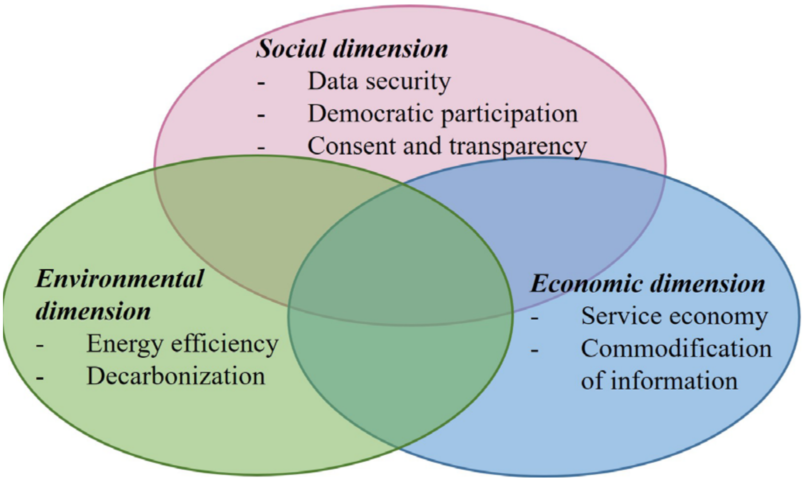


Fig. 2. Smart grid sustainability, key issues.

In the *social dimension*, privacy and security issues are often addressed with "end-of-pipe" solutions such as data protection, encryption, etc., while the efficient and effective system operation often relies on virtually unrestricted possibilities of access and control. A number of solutions concerning these issues have been presented, and they generally rely on the concentrated accumulation of data (Calò, Louis & Pongrácz 2014). Another critical element of social sustainability is the expectation of democratic participation that conceptualizes energy transition from a lens of democratic engagement (Szulecki & Overland 2020). Questions, however, arise in terms of digital intelligence, and whether citizens are truly able to provide informed consent. The European Union sees smart grids as a structure allowing the democratic participation of end-users and fostering a two-ways communication between users and utilities (European Commission 2011; Giordano & Bossart 2012). The "two-ways communication" embodies the more active role of the consumer. In the traditional system, the user was a passive recipient of energy, and the electricity provider monitored the customer's consumption as a one-way information flow. The smart grid system allows for the interaction between customer and producer; the consumer can receive information from the provider that may prompt them to change their consumption habit, as a response to, for example, peak demand or high electricity prices (Abrahamsen, Ai

& Cheffena 2021). The role of the end user is crucial in bringing new technologies into everyday use and thus gaining the maximum benefit of future smart energy networks. Therefore, producing knowledge about the end user's preferences related to smart energy networks will be highly valued. Smart homes and smart buildings are examples of systems equipped with a multitude of embedded digital devices as well as connected sensors (Albino, Berardi & Dangelico 2015). However, development of these smart grid infrastructures is usually studied in a different context than the dispersed Arctic context. In the dispersed Arctic context, energy consumption is high because of the cold climate. In addition, building the electricity transmission infrastructure is expensive because of the long distances and the dispersed population.

From an *environmental* point of view, the main objective is a quantitative reduction of energy use, referred to as energy efficiency, and a qualitative improvement of replacing fossil energy sources with renewables, thus achieving decarbonization. The new European Climate Law sets a legally binding target of net zero greenhouse gas (GHG) emissions by 2050. Decarbonization and digitalization are supposed to work together in a transition towards a more sustainable energy system, in which households play a bigger role in managing electricity demand (Smale, Spaargaren & van Vliet 2019). Smart grids can match fluctuating electricity generation and demand while ensuring an economically efficient power system with low losses and high quality and safety (ERGEG 2010). From an *economic* perspective, the key challenge of smart systems for utilities is to make profit concurrently with the energy efficiency objective. This leads to a transformation where the main objective is no longer to maximize the MWhs sold, but rather to better distribute the available MW capacity and maximize the utilization of (variable and non-dispatchable) renewables. This points toward non-material services and the commodification of information, which becomes a valuable asset that can generate income. Consequently, the *social* dimension of smart grid development is often related, on one hand, to user response and interaction with a smarter power network, and, on the other hand, to concerns related to privacy and security with respect to a technology which is potentially very intrusive.

Overall, smart grid sustainability is at the intersection of contributing to climate change mitigation, providing the means of an energy market revolution that is primarily based on the value of information, and empowering consumers to make informed decisions.

Methodology

The objective of this study was to investigate the evolution of the smart grid infrastructure in Rovaniemi from historical, technological, and social points of view, and evaluate its impact on the daily lives of residents. This also gave an insight into the current sustainability impact of said smart grid. The research was conducted by a multidisciplinary research group, comprising researchers with different disciplinary backgrounds.

Empirical research was conducted by studying the electric network of Rovaniemi, Lapland. The city covers an area of approximately 8,016 km² (three times the size of Luxembourg) and has an average annual temperature of 0.9 °C. This means that building and maintaining infrastructure is expensive and energy consumption is high, especially during the sub-zero winter months. Buildings also need to be energy efficient. From the perspective of the residents, when the key digital technologies were microprocessors and relays, they were passive users of electricity. Only after the introduction of digital local area networks (LAN), did residents become active participants of the energy system by choosing the electricity provider they wanted and reporting electricity consumption. This is consistent with the EU expectation of energy democracy, which is also a significant element of smart grid social sustainability. Finally, when computerized data network arrived, residents were able to select electricity providers, and information technology monitored energy consumption automatically.

A publicly owned private entity called NEVE Ltd. is the distribution system operation (DSO). As DSO, NEVE maintains the electricity grid and provides digital services to its customers. We conducted empirical research in the NEVE Ltd. in 2018 and 2019. Our research was restricted by a non-disclosure agreement (NDA), which affected our research position. The NDA was drafted by lawyers to protect intellectual properties, business secrets and cybersecurity. Therefore, we did not have free access to the archive of the electricity company. Furthermore, it was time-consuming to find the right contact persons and the leading experts. To get funding and gain access in the first place, the electricity company wanted some form of control of the research process. Essentially, we could observe, interview, and conduct small surveys of residents. This allowed us to utilize a mixed-methods approach.

Table 1. Mixed-methods approach and triangulation.

	Historical aspects	**Technological aspects**	**Social aspects**
Interviews (for more details, see Table 2)	Interviews with experienced experts	Interviews with managers and experts	–
Observation	Field observation of infrastructure	Observation of the development of ASSARI software	Observation of testing of ASSARI application
Quantitative questionnaire	–	–	Questionnaire to customers
Additional materials	Document analysis of technical documents	Document analysis of technical documents	Analysis of organizational documents like policies, reports, and internal communication materials

Our case study included 1) two months' observation, 2) deep interviews, and 3) statistical analysis of a quantitative questionnaire (N=131) with open questions. Our goal was to our study the NEVE's smart grid infrastructure from technological, historical and social points of view. To fulfil this goal, a two-month participant observation was conducted in NEVE Ltd. Observations were done by the principal investigator and one post-graduate researchers. Detailed notes were taken to be able to obtain a holistic picture of the arctic smart grid infrastructure from technological, historical, and social points of view. The observations were conducted overtly and by permission, and an NDA was signed before entering the premises for reasons of cybersecurity and to protect the sensitive information and vital infrastructure of the electricity provider NEVE Ltd. The case study was part of a research project financed by Business Finland.

Our observations focused on NEVE's interoperability layers: business, functions, information, communication and components. In addition, we observed NEVE's main smart grid domains: generation, transmission, distribution, distributed energy resources and especially customer premises. We could also follow the different operational zones in NEVE Ltd., which included the electricity production process, several substations in the field, operational efficiency, enterprise and market change in the context of the smart grid. We observed the daily work of senior experts and operating officers responsible for electrical substations and electrical network in NEVE's main building.

Our interviews focused on new digital business services and provided data for analysis of the introduction of smart grid technology to the Arctic residents. The interviews aimed at investigating smart grid technologies from the point of view of the daily lives of the residents. In this, a vital role is played by ASSARI, a web-based smart grid application introduced by the electrical grid operator to replace and supplement paper documents and manual labor. We were also actively taking part in the user interface and usability design of ASSARI. ASSARI's user interface and usability test was created together with the ICT and customer experts at NEVE. Thus, we were able to a form a deep understanding of the functionality of the ASSARI smart grid application.

We conducted deep interviews with specialists in smart grid operators in the management, smart grid and digitalization units (Table 2). Interviewees were selected based on their expertise. We particularly interviewed people with digital services research, development and innovation (RDI) expertise and experts with long work experience, to form a holistic picture of the system's architecture and its implications. The digitalization experts were interviewed regarding customer architecture and benefits of smart grid application from the customer's point of view. The digitalization unit experts were women (2) and the technological experts in the management unit and smart grid unit were men (5). The experts were interviewed, with open questions, to clarify the electrical infrastructure and its operational and technological functionalities in the Arctic. Interviews lasted 1.5 hours per participant. The interviews were transcribed and a content analysis was conducted. We conducted data analysis using themes that focused on phases of digitalization. This data content was analyzed using sorting to summarize the main subcategories of social, technological and historical elements of the digitalization process.

We used a mixed-method approach, where different questions are addressed using different data and methodologies (Neuendorf 2017; Patton 2015), which allowed us to get access to historical, technological and social elements, and also to acknowledge potential discrepancies and using them to enrich our understanding and identify areas for further investigation. The historical aspects rely mainly on interview and observation data and the consumer perceptions rely on quantitative data from the questionnaire. Observation data helped to add the Arctic context in SGAM architecture and provided details of the digitalization. The observation was carried out at NEVE's headquarters (HQ) in Rovaniemi. We made observations in the control center in the HQ which was located in the unit that controls the electricity networks of the city of Rovaniemi (Information Management and Digital Solutions unit). During the observations, notes were taken on the historical, social and technical development of the digitalization.

Table 2. Conducted deep interviews.

Organizational level	Interviews	Interviewees (N=7)
Management unit	Technological manager and digitalization manager	2
Smart grid unit	Technical and technological experts of smart grids	3
Digitalization unit	Digitalization development experts	2

Further, data of the residents' experiences of the smart grid application were gathered using a web-based questionnaire (N=131) that focused on how residents perceived the smart grid as a digital platform in their daily lives. Participants were selected by random sampling from NEVE's customer database and contacted by email. The questionnaire was developed together with an expert team consisting of resident interface, service design, statistical mathematical and system architecture experts (see Appendix 1). A small pilot study (N=12) was conducted before the questionnaire was submitted to residents and minor stylizations were made to the questionnaire. The data were cleaned and imported into the IBM SPPS Statistics Version 24 program for calculations and analyses. The first frequencies of variables and descriptive statistics, such as minimum, maximum, mean and standard deviation, were calculated from the data. Also, Chi-Square test and Person correlations Sig (2-tailed) were calculated between variables.

We followed the rules of the Finnish National Board on Research Integrity TENK, appointed by the Ministry of Education and Culture, which promotes the responsible conduct of research, prevents research misconduct, promotes discussion and spreads information on research integrity in Finland. We also followed the General Data Protection Regulation (EU) (GDPR), which is a regulation in EU law on data protection and privacy in the European Union (EU) and the European Economic Area (EEA).

The Historical Aspect. Changes in the Electrical Network Relations

Next, we will present three changes in network relations in the electrical network and their relations with the residents in the Arctic. We could identify three phases of electrical networks 1) the conversion from analog to digital calculations, introduction of microprocessors and relays, with residents as passive receivers of electricity. 2) The introduction of digital communication technology, whereby a digital local area network allows the residents to report consumption 3) electrical network as a digital platform with the smart grid part of the habitat.

Conversion from Analog to Digital

As background information, on 21 October, 1901, the Imperial Senate ordered that the municipality of Rovaniemi should create new land use and building decrees for its densely populated areas, which formed the legal basis for the building of an electric grid.[1] In 1944, near the end of the Second World War, the electricity infrastructure of the city was demolished. Rebuilding of the electricity grid took place after the war and living standards began to rise. In 1950, electricity volume increased fivefold. New high-voltage transmission power lines were constructed to carry power from the new hydroelectric power plants of Lapland to the demand centers in other parts of the country. After the war, regional networks administered by the regional network operators were all connected to the national transmission grid and distributed electricity regionally, usually on 110 kV lines. The municipality shared the responsibility for the maintenance of the basic infrastructure and constructed other infrastructure for built environments, for example the district heating network. The district heating network is only available in the urban areas. In most Finnish cities, the electricity companies also provide hot water for the district heating systems, which is produced in power plants in the cities that produce both electricity and heat. This means that DSOs maintain a natural monopoly by controlling the physical infrastructure delivering heat and power to their customers. Citizens were mostly passive residents of these services and the public utility employed a large number of personnel to enable bureaucratic processing of information.

As the standard of living increased, the energy consumption per capita in Finland grew to be the highest in Europe. This can be explained by energy-intensive industry (metal and paper), a high standard of living, the cold climate and long distances. Digitalization began when electronic relays were introduced in the 1970s. Digital relay technology with microprocessors were commonplace in the 1980s and more efficient analog-to-digital converters were introduced. The processing power of the microprocessors in the 1980s allowed the replacement of remote terminal units and other old electromechanical equipment with digital technology. In the 1980s, modems and the telephone network were first used as a separate control network. In the 1990s, modems using the telephone network were replaced by digital technology. A fully computerized data network was finally operational in 2012. This freed up personnel from the operator duties and allowed the downsizing of the old public utility. In addition to microprocessors taking over the work of humans, residents were now asked to report their electricity use.

With the digitalization of the power system came a parallel and coordinated technological development of its monitoring, control and management via digital interfaces. When the system was digitalized, the same information could be seen in a digital interface to control, manage and monitor the electricity network. For Arctic residents, though, the digitalization meant they were now themselves responsible for monitoring their electricity consumption.

Locally centralized operations started to accumulate data and the companies began to analyze them with a view to optimizing maintenance operations and increasing efficiency. This further changed and emphasized the role of the ICT in the company (NEVE Ltd). According to the digitalization service director, during the 1990s, ICT services were purely a support unit for the main business of the electrical company.

> The Electrical substation was operating in physical form in manual technology. The same electrical substation started operating in digital form in the centralized information architecture. This enabled the launch of digital business and the installation of remote metering. (Interview with technical expert)

In 1990, the electricity grid operator introduced an automatic data management department which was given responsibility for harmonizing system mass and system architecture design. The goal was to create services to residents through one process. This has created difficulties with data management, where the most important component is viewed to be in resident relationship management.

As shown above, it takes considerable time and resources to build and develop smart grids and fully adopt new urban technologies. Research into infrastructures of modernity like the electricity grid shows that once the momentum for digitalization has reached a tipping point, the reshaping of social infrastructures follows (Hughes 1987). However, based on our literature review, the limitations of current research historical phases of development of urban technologies are not fully understood in the Arctic context.

Toward Digital Communication Technology

Research points out that infrastructural change promotes new effects across all levels of analysis and destabilizes academic boundaries (Tilson, Lyytinen & Sørensen 2010). The introduction of ICT in the smart grids first allowed the de-bureaucratization of labor-intensive work. In addition, the privatization of the public utility sparked three transformations: improvement of infrastructure (for example ground cables), the addition of the digital layer, and a business process transformation that was considered necessary to capitalize on the investments in new digital technology in smart grids. According to the interviewed experts, this has been a technological turning point in the old electrical and infrastructure companies.

> Upgrading Microscada's Rovaniemi network enabled the launch of digital business and the installation of remote metering. Microscada is a microcomputer-based, distributed and programmable supervisory control and data acquisition system. It provides integration of pipeline data, pipeline control and substation control. This basic infrastructure enabled the launch of a digital business and the establishment of a dedicated ICT unit. Initially, only a few people worked in the unit. (Interview of manager)

The key technology enabling the smart grid in the built environment were the smart meters that can be tracked remotely, with the data used to maximize the efficiency (Fettermann et al. 2020; Finnish Energy Authority 2018). In the EU, Finland has been particularly active in the roll-out of smart meters and in using hourly data in balance settlement, and smart meters have been installed in over 99% of consumption places (EU Regulation 2009/72/EC has 80% by 2020 goal). This means that digital processing of applications and information management take place via digital interfaces in built environments to control data flow, network security and information.

The local smart grid is part of the common Nordic electricity market (Nord Pool), where the electricity price is provided in real-time. The pricing depends on the electricity production method and consumption levels and relies on cross-border electricity flows between neighboring power systems (Talandier 2018). Residents can choose where to buy their electricity and can buy spot price electricity that consists of a basic charge, the energy price in the Nord Pool and the seller's margin. Until the introduction of smart grid technology, there were few incentives for residents to play an active role (Sioshansi 2011). This changed when the smart grid technology allowed data (and later power) to flow in both directions and required utility companies relying on centralized unidirectionally distributed electricity to develop new services (Rifkin 2011). This also enabled network operators to considerably reduce their core workforce. Using decentralized ICTs, the network operator has a new role: it provides the infrastructure for interactive communication. European Commission reports have pointed out the organizational and management issues related to smart grids (Giordano et al. 2013), but little is yet known about how the residents will act as active co-players in future electricity systems (Geleen, Reinders & Keyson 2013), and there are considerable gaps in the literature regarding who the users of smart technologies are and how they use these technologies in their homes (Gram-Hanssen & Darby 2019).

Current Level of Smart Grid Evolution

The web-based smart grid application ASSARI was introduced by the electrical grid operator to improve the paper-based and manual labor-intensive process of electrical meter inspection. We studied ASSARI and focused on analyzing the residents survey. ASSARI is a digital platform, and its interfaces are built in such a way that the application program requests data every time from the database. The ASSARI environment runs on Asure, in Microsoft's cloud service. However, Microsoft's cloud platform is not the statistical system, as Kolibri and Generis hold the customer data. The test and service platforms are located on separate servers. The database contains the log of the integration environment. A database is an organized collection of data, generally stored and accessed electronically via a computer system. The ASSARI system contains System Logs, Resident Information and Blob Storage, Resident Management and Resident Information. Blob storage is a feature in Microsoft Azure that lets developers store unstructured data on Microsoft's cloud platform. It has a centralized information system with two virtual servers, test and production servers and logging bases. In addition, the centralized information system has two different Dockers-frame containers. A container is a standard unit of software that bundles code together with all its dependencies, so that the application runs quickly and reliably from one computing.

Through ASSARI, residents can see their readings that come from automatically readable devices, and they can thus monitor their own consumption, while energy efficiency is encouraged. Targeting household-level energy consumption also requires an understanding of energy consumption in relation to individual household members' activity patterns (Palm, Ellegård & Hellgren 2018). However, these individual activity patterns cannot be followed with the ASSARI application.

As we mentioned earlier, the SGAM is utilized as a framework for interoperability analysis by merging the bi-dimensional smart grid plane (including the power system management and the energy conversion chain) with the interoperability layers dimension including functionality and technical implementation. In this context, it is useful to map the area where different actors and applications operate, allowing for a more practical understanding of their roles, interdependence, and their position with respect to the end users. As shown in Fig. 3, NEVE can be located primarily at the business and the component level. NEVE's roles on the business layer relate to its in-

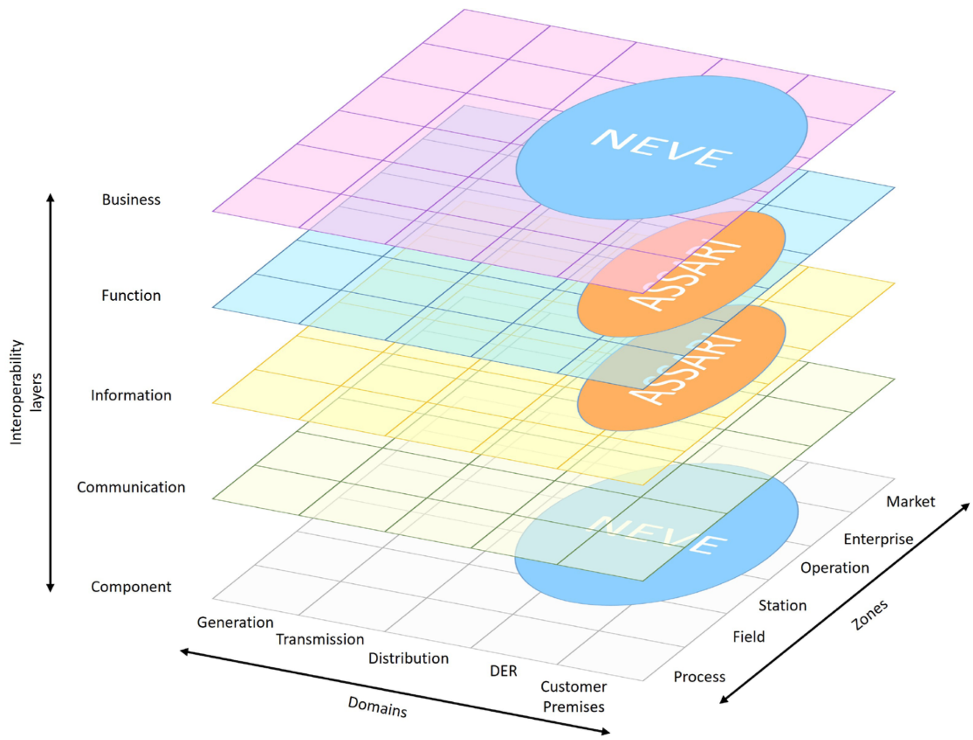


Fig. 3. NEVE and ASSARI in the SGAM architecture.

formation exchange and smart grid-based business capacity: on the domain axis it can be considered to cover the area between the consumer and the distribution system, while on the power management side, it covers the area from monitoring of the power system up to the energy trading operation. At the same time, considering its role as DSO, NEVE operations on the "Component"—the smart grid—level, can be mapped along similar reference lines. From a broader perspective, the role of such a smart grid application can play a more strategic role within the Arctic context. As mentioned earlier, Arctic settings (such as our case study) are often characterized by a remarkable heterogeneity in population density and its distribution. This, in turn, is more likely to stretch the capacity and logistic constraints of an infrastructure originally designed to support a limited population spread over a large area. The smartening of the power infrastructure is therefore strategic in adding the necessary resilience in such a potentially exposed system, creating the conditions for further efficient and effective modernization of the distribution level infrastructure. Coherently, this is further represented by the localization of the primary of NEVE and ASSARI within the SGAM architecture (Fig. 3): as the described conditions are likely to affect the infrastructure at the lower domain levels (Distribution-Customer level), the required flexibility can be developed through the smartening of the system and, therefore, through an intervention across the zone levels.

Continuing this analysis, the ASSARI digital platform can be represented as an application on the information plane: managing (documenting, organizing and storing) energy data, effectively functioning as a bridge between the component and the business layers of NEVE. Buildings in the Arctic environment rely on diverse energy sources, mainly because of harsh environmental conditions and heating being required practically 10–12 months a year. Therefore, digital platforms make the smart grid a part of the habitat of Arctic residents (Table 3).

Table 3. Digitalization of the electricity network and its implications for residents.

Digitalization of the electricity network	Conversion from analog to digital calculations, with microprocessors and digital relay technology	Introduction of digital communication technology, with local area network (LAN)	Emergence of the digital platform, with the smart grids' applications and technologies, with a fully digitalized computerized data network.
Implications for residents	Citizens as passive recipients of electricity	Residents select electricity provider and report electricity consumption	Residents use the smart grid technologies as active digital citizens

Consumer Perceptions and Changing Energy Consumption Habits

This section summarizes the results of the survey conducted among the residents of Rovaniemi, regarding their perception and use of the ASSARI smart grid application. The questionnaire questions can be found in Appendix 1.

In this study, there were 85 males and 41 females with the following age distribution: 20–29 (13.3%), 30–39 (20.3%), 40–49 (23.4%), 50–59 (14.8%), 60–69 (21.1%) and 70– (7%). When looking more closely at who the actual residents were, we found that the typical respondent to the survey was a male, aged between 30 and 69. Although there were female respondents, they were in the minority and younger than the male residents. As all the experts we interviewed during our research were also men, we can conclude that smart grid technologies are being developed by middle-aged, higher middle-class men with a technological education for middle-aged higher middle-class men who own property, and who actually use and benefit from the smart grid technology. As seen in Table 4, residents use the application monthly (28.2%) or more seldom (62.6%).

Table 4. Frequency of usage (log ins) of the smart grid application.

	Frequency	Per cent	Valid per cent	Cumulative per cent
Daily	3	2.3	2.3	2.3
Weekly	9	6.9	6.9	9.2
Monthly	37	28.2	28.2	37.4
More seldom	82	62.6	62.6	100
Total	131	100	100	

Recent studies have considered many factors, such as the usefulness of smart energy applications (Fettermann et al. 2020). In our study, despite ASSARI being used infrequently (Table 4), we found that the residents thought that the smart grid application was useful (Table 5). It was not perceived to be something the company simply forced its residents to use. Our results show that if residents are satisfied, they will recommend the smart grid application to other people. To analyze perceived benefits in practice, we measured correlations between variables of residents' benefits from the

Table 5. Customer satisfaction.

		Customer satisfaction with the application's service content	Would you recommend your friends to use the application?
Customer satisfaction with the application's service content	Pearson Correlation	1	.484**
	Sig. (2-tailed)		0.000
	N	131	131
Would you recommend your friends to use the application?	Pearson Correlation	.484**	1
	Sig. (2-tailed)	0.000	
	N	131	131

**Correlation is significant at 0.01 level (2-tailed)

Table 6. Correlations between resident's perceived benefits of the smart grid application.

		Use of application saves resident's time	Use of application saves a lot of trouble for residents	Use of application reduces the need to contact customer service
Use of application saves residents' time	Pearson Correlation	1	.704**	.573**
	Sig. (2-tailed)		0.000	0.000
	N	131	131	131
Use of application saves a lot of trouble for residents	Pearson Correlation	.704**	1	.625**
	Sig. (2-tailed)	0.000		0.000
	N	131	131	131
Use of application reduces the need to contact customer service	Pearson Correlation	.573**	.625**	1
	Sig. (2-tailed)	0.000	0.000	
	N	131	131	131
**. Correlation is significant at the 0.01 level (2-tailed).				

smart grid application. We found significant statistical correlations, which indicates that the smart grid application as a digital platform is beneficial for the residents (Table 6).

According to smart grid literature, there is an added danger that residents who will not achieve the expected savings, notwithstanding the behavioral change in electricity consumption habits, might consider the whole experience disappointing and frustrating (Hargreaves, Nye & Burgess 2010; Hughes 1987). This might not be the case here, and we are in full accordance with Stern (2011), who proposes that in order to increase resident's acceptance of smart grids, there should be information provision regarding the clear benefits provided through smart grid deployment, including long-term financial benefits, in addition to the ease and simplicity of smart grid technology use.

Table 7. Views whether the smart grid application makes daily life easier.

	Frequency	Per cent	Valid per cent	Cumulative per cent
No reply	2	1,5	1.5	1.5
Strongly disagree	4	3,1	3.1	4.6
Disagree	8	6,1	6.1	10.7
Undecided	39	29,8	29.8	40.5
Agree	57	43.5	43.5	84
Strongly Agree	21	16.0	16.0	100
Total	131	100	100	

The reason why the smart grid application was considered useful was that the residents considered it provided considerable benefits as it saves time and effort and reduces the need to contact customer service. The statistical correlations regarding these benefits were significant. In addition, most of them agreed (43.5%) or strongly agreed (16%) that the application makes their daily lives easier (Table 7). Smart grid technology has also made the development of the system architecture more resident-oriented with the introduction of universal design approaches commonly used for intelligence infrastructure development (Erlandson & Psenka 2014). There are problems in turning the large amount of data from built environments into meaningful services, as this requires combining data streams, such as various resident data and measurement data.

Table 8. How the smart grid application helps to change consumers' habits.

	Frequency	Per cent	Valid per cent	Cumulative per cent
No reply	2	1.5	1.5	1.5
My electricity consumption figures motivate me to change my consumption habits	78	59.5	59.5	61.1
My electricity consumption figures inform my consumption, but I have not changed my consumption habits	27	20.6	20.6	81.7
My electricity consumption figures do not have any effect on my consumption	24	18.3	18.3	100
Total	131	100	100	

According to our results presented in Table 8, only a minority of the respondents (18.3%) stated that the smart grid application has no effect on their electricity consumption, while 59.5% agreed that the smart grid technology has changed their consumption habits. As some authors argue (Hargreaves, Nye & Burgess 2010), electricity is "doubly invisible" for the residents because it is an invisible and abstract force entering the household via hidden infrastructure. In addition, most energy residents' behavior is part of their daily habits, making it difficult to connect behavior to the energy they consume. Based on our results, the smart grid technology seems to change this.

The social acceptability of the smart grid technology also seems to be directly connected to the financial interests of the residents; if the smart grid technology helps to save money, most consumers are willing to accept it, but more research is needed on the nature and distribution of costs and benefits (Darby 2020). The downside is that digitalization can be utilized to develop the instruments of technocratic control (Cooper & Jacobs 2018). It also requires that the residents provide their data for free to the electricity companies and do work previously done by others. In the organization of work, the roles of the electrical network operator and the residents now

Table 9. Reasons for changing electricity consumption habits.

	Frequency	Per cent	Valid per cent	Cumulative per cent
No reply	1	0.8	0.8	0.8
Reducing costs	115	87.8	87.8	88.5
Reducing my carbon footprint	13	9.9	9.9	98.5
Something else	2	1.5	1.5	100
Total	131	100	100	

overlap, which is not possible without mutual trust and transparency in the use of the smart grid application.

We also studied the motivations of users (Table 9). Overwhelmingly, the residents' most important motivation for using the smart grid application was financial (87.8% of the respondents). Pricing also motives the residents to use appliances in a specific timespan; the price of energy is lower between 22.00 and 7.00 o'clock and the spot price of energy varieties (Palm, Ellegård & Hellgren 2018; Hughes 1987). Our finding does not resonate with research suggesting that environmental considerations are important when residents buy electricity (ERGEG 2010; Mah et al. 2012), and maybe even the most important factor in a household's intention to generate its own power (Leenheer, de Nooij & Sheikh 2011). This means that the change towards a sustainable energy system in the Arctic cannot be achieved by using environmental arguments to influence the consumers, unless sustainable energy use is connected to energy tariffs. This is in line with research arguing that environmental concerns must be used in combination with reduction of, or of control over, electricity bills (Gangale, Mengolini & Onyeji 2013).

The residents shared this view, as shown by answers to the open survey questions, such as: "Invoices should also be displayed in the same way as the consumption data for all tariffs in order to make it easy to calculate tariff swaps." The residents also hoped that information would become more real-time, with financial metrics included: "But isn't it possible to present the consumption data in real time?" It would also be interesting to see the euro amounts in real time. This in turn could provide a stronger motivation for residents to change their electricity consumption habits.

The difference between real time pricing and spot prices (sometimes mistakenly perceived or described as real-time prices) should be underlined here. A spot price, defined by matching demand and supply at any given time, is generally described as the specific price of a commodity to be bought or sold for immediate settlement. Although spot prices might vary in time and geographic location, spot prices are relatively homogeneous across the markets, significantly limiting arbitrage speculative opportunities, and allowing for future planning by locking the price ahead of time. In the Nordic power market context, for example, the day-ahead (spot) power market is a textbook example of such a system: power prices are known one day ahead, with relatively limited (and homogeneous) variation in time and across market regions.

Spot prices, though, are representative of energy prices at the utility level. End users' real-time energy prices depend on the subscribed contract type that might only marginally reflect the spot price mechanisms previously described. For example, some contracts have fixed tariffs, others are directly related to the spot price market, while contracts including supply from specific low-carbon sources might vary without necessarily reflecting the spot market behavior. In this context, what the residents referred to was real-time energy consumption data coupled with the energy prices for the corresponding time-window. The availability of such a system would indeed allow for end users to look back on their energy consumption profile and compare the financial performance of different tariffs by coupling them with their recorded energy consumption behavior. People working in NEVE Ltd. indicated that they as a company have started to utilize all the available data to make this potentially happen, but system harmonization takes time. It does not only require resources and expertise, but also new ways of sharing the workload to govern the overall architecture; hidden data of the system architecture should also be captured and made visible to the residents.

Conclusions

A critical element of smart grid development is its architecture with multiple interoperability layers. Users are provided accurate consumption information, which is expected to help consumers to better control their energy expenditure on electricity. Arctic residents view that the digital platforms of the smart grids improve their quality of life, although unplugging from the smart grid becomes difficult (Calzada & Cobo 2015). In the Arctic dispersed built environment, residents are forced to use digital platforms to optimize their energy consumption and behavior. Existing building and energy research highlight the importance of a transition towards renewable energy (Arruda & Arruda 2018; Aandahl, Eriksen & Alfsen 2003; Hertin et al. 2003). However, we found that Arctic residents are not using the smart grid intelligence for environmental reasons, as in Estonia (Vihalemm & Keller 2016). It seems that energy efficient building standards and energy policy are viewed differently in sparsely populated colder areas (Hossain, Loring & Marsik 2016). Smart grid solutions in the Arctic are decentralized, allowing electricity consumption to be optimized so that energy can be produced in carbon-neutral forms. People are the best regulators of electricity which can be harnessed through the smart grid.

Furthermore, current literature points out that digital platforms provide infrastructure for opening up to collective intelligence building (Smith & Prieto 2020). Customers being informed participants of the smart grid is the ideal; however, as our research indicates, the most invested users of smart grid services are middle-aged, educated men. Moreover, their role is mainly to monitor and control their electricity consumption on the basis of information provided by the electricity company. An important concern is the willingness and capacity of older people to change energy consumption habits and adopt smart technologies (Barnicoat & Danson 2015). However, we found that smart grids are best accessible to men with a technological education. Cities enable a variety of ownership regimes for their diverse material components (Sassen 2018), but technical infrastructure seems to empower only those who control it (Innis 2008). Ultimately, smart grids bring stability to the electricity grid, which is especially essential in cold climates, and they also improve access to services in sparsely populated areas. Smart grid technology can provide active citizens with tools to increase their resilience, but achieving this goal in an Arctic environment will require that the consumers are offered financial incentives.

NOTES

1 When describing the early years of the electricity grid, we rely mostly on city history by Ahvenainen (1970) and company history by Jylhä & Torkko (2014). To describe the developments after the 1960s, we rely on the memory of the experts with long work experience we interviewed. We do not intend to provide an official history based on historical documents, but merely to interpret the key trends in the history of the electrical grid.

APPENDIX 1. WEB-BASED QUESTIONNAIRE

User Experience survey

Gender:
Male
Female
Other / don't want to say

Year of birth:

Type of housing:
1. Detached house
2. Semi-detached house
3. Terraced house
4. Block of flats
5. Cottage / villa

I learned about Assari first from:
1. Website
2. Neve customer service
3. Neve's event
4. Water reading card
5. Heard from a friend
6. Other source. What?

I use Assari:
1. Daily
2. Weekly
3. Monthly
4. More seldom

Registering and logging in to Assari went smoothly and did not take me too much time:
1. Strongly disagree
2. Disagree
3. I don't know
4. Agree
5. Strongly agree

I need help / guidance to use Assari:
1. Yes
2. No

If yes, what kind of help / guidance

For what purpose do you use Assari for?
I report my water meter readings
I want to monitor my water consumption
I want to monitor electricity consumption
I want to monitor district heat consumption

I am satisfied with the content of the service provided by Assari:
1. Strongly disagree
2. Disagree
3. I don't know
4. Agree
5. Strongly agree

I am particularly satisfied/dissatisfied with the following:

Customer value survey

The following are statements related to customer value of Assari. Answer them according to your own experience.

Using the application saves my time:
1. Strongly disagree
2. Disagree
3. I don't know
4. Agree
5. Strongly agree

Using the application saves trouble:
1. Strongly disagree
2. Disagree
3. I don't know
4. Agree
5. Strongly agree

Using the application reduces the need to contact Neve customer service:
Strongly disagree
Disagree
I don't know
Agree
Strongly agree

Using the application makes it easier and faster to access Neve services:
Strongly disagree
Disagree
I don't know
Agree
Strongly agree

Using the application makes it simpler to report meter reading:
Strongly disagree
Disagree
I don't know
Agree
Strongly agree

Using the application makes my daily life easier:
Strongly disagree
Disagree
I don't know
Agree
Strongly agree

Using the application informs me about my consumption habits:
Strongly disagree
Disagree
I don't know
Agree
Strongly agree

Monitoring consumption is interesting:
Strongly disagree
Disagree
I don't know
Agree
Strongly agree

Monitoring consumption is a fun pastime:
1. Strongly disagree
2. Disagree
3. I don't know
4. Agree
5. Strongly agree

What motivates me most to change my consumption habits?
1. Reducing costs
2. The impact of my consumption habits on my carbon footprint
3. Something else, what?____________

How can Assari help me change my consumption habits?
1. Consumption data motivates me to pay attention to my behavior and change my actions in relation to my consumption habits to reduce consumption
2. I become aware of my consumption, but I don't care if my consumption decreases or increases
3. Not at all, I continue to use / consume according to my habits

How likely would you recommend the application to your friends? (On a scale of 0–10)___________________________

Development ideas and suggestions for new features:

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