It’s smart, but is it sustainable?

A study of circular and social sustainability in smart grids

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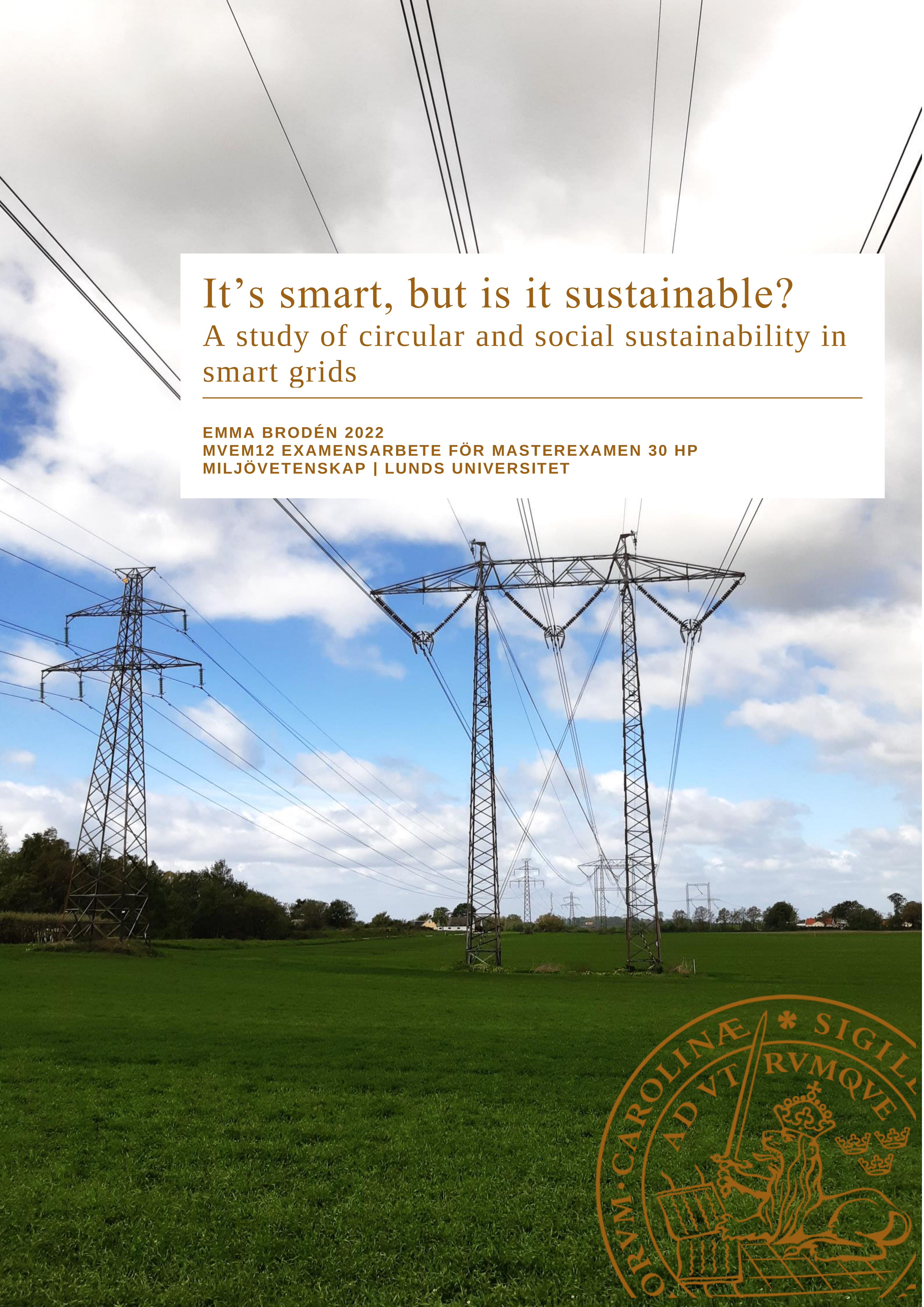

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Abstract

Smart grids are often advertised as more environmentally sustainable compared to their “conventional” counterparts. What is highlighted then is their potential to save energy and integrate more renewables into the grid, thus decreasing CO2-emissions. This thesis investigates two less discussed aspects of smart grids, those of circular economy and social sustainability. An initial literature review was conducted to investigate how these topics have been covered in the academic discussion, whereafter interviews with smart grid developers and experts were held to understand how they perceive these issues.

The results show that smart grid resource issues have been scarcely discussed in the academic literature, the articles found were mainly LCA studies. Most interviewees thought that smart grids are resource efficient since they can be realised with small material inputs and reduce the need for physical grid infrastructure, but to what extent is uncertain. The overall awareness of resource issues in the energy sector seems relatively low, but there are indications that awareness is rising among energy sector professionals, also regarding smart technologies specifically.

Social sustainability and user aspects have been covered to a much greater extent in the literature than resource issues. While the literature review showed a relatively big variation regarding how smart grid users were imagined, most interviewees thought that automation was key to allow for extensive user participation. The dominating user role was that of offering demand flexibility and economic incentives was seen as the strongest motivator. Privacy and security risks were deemed as the most important issues of smart grid technologies by many respondents, but societal concern for these issues seem relatively low in Sweden. Although interviewees acknowledged that some smart grids technologies are not accessible for lower-income households, and affluent people may stand to gain more than others, most believed that smart grids are socially beneficial overall.

Keywords**:** *Smart grids; smart grid users; circular economy; resource use; social sustainability; sustainability*

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Abbreviations

CE – Circular economy

CRM – Critical raw material

EV – Electric vehicle

GHG – Greenhouse gas

ICT – Information and Communication Technologies

LCA – Life cycle analysis

REE – Rare earth element

SG – Smart grid

1. Introduction

Climate change might be the most urgent and grave issue currently facing humanity. Since the 19th century, the planet has been heated with around 1.1 degrees Celsius (IPCC, 2021). The main reason for this development has been the burning of fossil fuels for energy. While fossil fuels have spurred economic growth and are still a very integral part of the world economy, they must now be replaced by carbon-neutral means of energy production (Fankhauser & Jotzo, 2018). The way we produce electricity is included in this much needed change. Renewable energy sources such as solar and wind are quickly on the rise, steadily increasing their share in the electricity mix (IEA, 2021b). Many renewable energy sources are *intermittent*, meaning that they fluctuate over time due to changing weather conditions. The sun does not always shine, nor does the wind always blow. This results in power flows that vary greatly over time with big peaks and troughs, a stark contrast to fossil-powered electricity generation that can be kept at a steady level and is easily regulated to fit demands (Widén et al., 2015).

Climate action also calls for increased electrification of society, not least the transport sector. Electrification and growing economies have led to increasing electricity needs, with demands predicted to rise even further in the future (IEA, 2021a). The increased electricity needs, and use of intermittent energy sources put increasing pressure on the grid (IqtiyaniIlham et al., 2017). The current electricity grid is not sufficiently equipped to cater to the renewable and sustainable energy system of the future (ibid). Many people envision "smart grids" as the solution to these problems (ibid). This thesis will investigate two less addressed issues in smart grids, those of resource use and social sustainability.

1.1 Problem definition

There is no exact definition of smart grids (SGs), rather there are many different ideas of what a future more intelligent grid could entail (Madrigal, Uluski & Gaba, 2017). According to *The International Energy Agency* (IEA), a smart grid is *"an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users"* (OECD/IEA, 2011, p. 6). SGs can be a viable alternative to only extending or reinforcing physical infrastructure, which is costly and disruptive, in the light of a changing energy scenario entailing increased use of renewable energy resources and increased electricity demand (E.DSO, n.d.).

Rather than consisting of specific components, SGs are an evolving set of technologies that will be used to a varying extent depending on where in the world, and in which contexts, they are being developed. Some technologies already exist and are well-used while others are under development (OECD/IEA, 2011). While there are smart elements in the current electricity grid, it is important to stress that the notion of "the smart grid" is, so far, more vision than reality. There are still many questions as to how SGs might develop in the future (Lunde et al., 2016).

Mini-grids, microgrids and nano grids are other concepts relating to SGs. As the names suggest, these are small electricity production and distribution systems that supply local communities, individual households, or just single appliances (Aktaş & Kirçiçek, 2021; Ortega-Arriaga et al., 2021; Yerasimou et al., 2021). Mini-grids and microgrids can operate as independent systems off-grid, but they can also be connected to, and thus constitute important subsystems to, the main (smart) grid (ibid).

While there are many different definitions and ideas about what SGs are and might develop into, the SG sustainability discussion is narrower. What is often discussed then is the environmental benefit of SGs in promoting energy efficiency and integrating renewables (Moretti et al., 2017; Hu et al., 2014). SGs can increase the amount of intermittent renewable energy generation via technological solutions that make the grid more adapted to varying power flows, and by providing flexibility to the energy system, thus allowing for more time-variable energy sources such as wind and solar. Also, SGs may promote energy saving by, e.g., reducing line losses (Hu et al., 2014).

However, there are other aspects of sustainability to be considered, for example, resource use required for SG infrastructure and social sustainability aspects connected to SG use. The latter include issues such as privacy, security, user control and acceptance, and distribution of the benefits of SGs. This study aims to fill research gaps by investigating what aspects of social sustainability, circular economy and resource use are present in the academic discussion, and to contrast these findings and gain a better understanding of the aspects that are missing through empirical research.

1.2 Aim and research questions

The overall aim of this study is to investigate whether SGs can be described as sustainable grids. More specifically, this study will investigate SGs in connection to circular economy (CE) and social sustainability issues, aspects that were chosen since they have not been studied extensively before. By synthesizing academic literature and conducting interviews, this study aims to fill in research gaps regarding sustainability issues in SGs. A literature review lays the basis for the empirical research in this study by providing themes and aspects to investigate further via semi-structured interviews. The interviews will be used to discover how resource use and CE issues are discussed in connection to SGs among relevant stakeholders in the energy sector. In investigating social sustainability, it will be attempted to understand how the different stakeholders envision the SG user, but also what issues and problems they see in connection to SG use. These objectives lead to the following research questions:

1) How are circular economy, resource issues and social sustainability aspects of smart grids investigated and covered in previous academic research?

2) How do different stakeholders in smart grid development and research…
    a) View aspects concerning circular economy and material resource issues?
    b) Imagine the future smart grid user?
    c) Reflect on social sustainability issues in connection to smart grids?

1.3 Scope

The geographical scope of this thesis is Sweden. However, it should be noted that EU policymaking, as well as international developments, influence the Swedish electricity system. The interviewees are mainly from a Swedish context, apart from two respondents that provide a wider European and international perspective on the technological development of SGs. The literature review has a European scope since European countries were expected to have somewhat similar electricity systems and societal contexts as Sweden.

The study is limited to the social and environmental dimensions of sustainability, excluding economic sustainability. This third aspect of sustainability was excluded due to resource- and time constraints and because economic aspects of energy systems have been more researched previously. In investigating social sustainability, this thesis focuses on, but is not limited to, user aspects.

There is no exact definition of SGs, or what components constitute a SG. This thesis has therefore taken an explorative approach and sought to understand how different stakeholders understand the term and what sustainability issues are connected to it.

1.4 Ethical considerations

The main method for this thesis has been semi-structured interviews. The interviewees were informed about the purpose of the project via email before participation, and in the beginning of the interview. Interview recordings were taken only after participants gave their consent. All names and affiliations have been anonymised to let interview participants feel they can express themselves freely. However, there are no expected negative consequences for the interviewees given the nature of the interview questions. The interviewees have been free to withdraw their participation during the research process, although no interviewee has chosen to do so. There has been no collection of sensitive information. The interview material has been stored safely and has not been shared with anyone except for the thesis supervisor.

2. Background

2.1 The Swedish electricity system

Electricity use in Sweden could rise to 310 TWh by 2045, an 120% increase from today, if current investment plans in, e.g., battery factories, fossil- free steel, and electrification of the transport sector are realised (Gode et al., 2021). To handle these future challenges in the electricity system, the Swedish government recently published *Elektrifieringsstrategin,* a document containing strategies for the electrification of society (Regeringen, 2022). *Elektrifieringsstrategin* does not specifically mention “smart grids”, but states that digital solutions that can provide better governance, analysis and optimisation should be promoted (Regeringen, 2022).

To make the electricity system smarter, the old electricity metres are now to be replaced with newer smarter metres. The frequent measurements of the smart metres enable electricity customers to choose hourly-based electricity agreements. These incentivise the customers to adapt their energy use to suit real-time supply (Energimarknadsinspektionen, n.d.). Another smart element in the grid is local flexibility markets, used to solve capacity shortages in the grid (Svenska Kraftnät, 2021a).

For more background about the Swedish electricity system, see Appendix 1.

2.2 Smart grid initiatives and research

Since 2012, when the Swedish government decided to start a committee for investigating the potential of SGs (Regeringen, 2014), there have been various SG programmes and initiatives in Sweden. For more information about these, and the international organisation ISGAN, see Appendix 2.

Swedish research on social sustainability and circularity issues in smart grids

Current and previous Swedish research on social sustainability issues in SGs covers topics such as social justice and integration and the importance of trust in connection to automation. For more information about these projects, see Appendix 3. The research project deemed most relevant for this thesis is *Smart grids - For whom?* (Katzeff et al., 2018), a study containing interviews with initiative takers from Swedish SG pilot projects. Results showed that households were expected to change their energy consumption, i.e., become more flexible, in response to changed tariffs and the visualisation of electricity use. A question raised by the researchers was how SGs could be adapted to suit a more non-active role of households (Katzeff et al., 2018). This thesis is similar to *Smart grids – for whom?* by investigating the views of SG developers but distinguishes itself by including a wider range of SG stakeholders and might thus bring a new angle to SG social sustainability research in Sweden.

While there have been several research projects on social sustainability in SGs, the author of this thesis is not aware of any previous research focusing specifically on resource use or CE in a Swedish SG context. However, there has been research investigating service-based business models in the electricity utility business, although from an economic perspective. In their master's thesis, Sekander and Firmo (2020) investigated the servitisation potential of ABB's cable distribution cabinets and found that current regulations seem to act as a hindrance to increased servitisation. Since network operators are monopolist they cannot charge their customers freely, instead, what they can collect in revenue is based on how much is invested in the grid infrastructure, i.e., CAPEX[1]. Therefore, it is not economically feasible to cease ownership of capital, interviewees stated (Sekander & Firmo, 2020). However, another interviewee said that, under the *Swedish Electricity Law*, grid owners are allowed to rent or buy access to assets and set fees for their consumers freely within certain limits (Sekander & Firmo, 2020). There seems to be some unclarity to what extent current regulations pose a hindrance to increased servitisation of grid utilities. Since service-based business models are often described as central to a CE and could potentially be used for different SG solutions, this calls for further probing into the issue.

[1]"Capital expenditure", for explanation of the term, see Appendix 1.

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3. Research design, material, and methods

Two main methods have been used in this study: a literature review, and semi-structured interviews. These were deemed suitable methods given the nature of the subjects that are investigated. The literature review was conducted to create an overview of the topics. CE and resource issues in connection to SGs have been very little researched before, therefore, semi-structured interviews were seen as a natural method to gain knowledge that is not present in the academic discussion. Social sustainability in SGs has been researched to a greater extent. However, this thesis contributes by exploring these issues from a Swedish context.

3.1 Literature review

A literature review was conducted to map sustainability aspects connected to CE and social sustainability in SG research. The results from the literature review were used as a foundation for the remainder of the study by finding aspects and themes of interest to investigate further through interviews in the empirical study.

3.1.1 Literature search

The scope of the literature review was decided with the Swedish context in mind. Countries within Europe were chosen for geographical scope since they were expected to provide somewhat similar societal contexts as Sweden, regarding incomes, welfare, and other social factors, laws related to energy systems, support schemes for renewables as well as how the energy system is structured. Five years, 2017- 2022, were chosen as a suitable time scope to include the most recent articles within the topic.

Scopus was used as database since it has a larger coverage of journals published outside of the United States compared to Web of Science, and because it provides good coverage of interdisciplinary journals (Iowa State University, 2022). These benefits were considered beneficial considering the scope of this study, Europe, and the interdisciplinary nature of the research.

The final search was made on Scopus on the 7th of February on the search phrases presented in *Table 1.* The search was conducted focused on *title*. Searching on *topic* (including abstract, keywords and title) retrieved thousands of hits, too many results to process considering the time limitations of this study. However, searching on only titles is not unproblematic since it may exclude potentially relevant sources. Therefore, it was attempted to include as many synonyms and related words as possible, for example, *micro grid, nano grid,* and *mini grid* apart from *smart grid*. Using quotation marks in Scopus will also include common variant spellings and most plural forms (University College London, 2021).

The search phrases were found by reviewing keywords and headings of articles that were found to be relevant before conducting the final search. As can be seen in Table 1, the search included phrases with a generic environmental sustainability theme, these were chosen at the beginning of the research process when the plan was to create an overview of overall environmental sustainability issues in SGs.

The search resulted in a total of 294 hits. In the first selection process, title and abstract were screened to determine if the document was eligible for reading, this led to 19 articles on social sustainability and nine articles on CE/resource use. After reading the full articles and excluding irrelevant results, 15 social sustainability articles and six CE/resource articles were chosen for inclusion in this thesis. Most studies found were technology focused.

Table 1. Overview of literature search

No.	Description of steps	
1	**Research question**	
	How are circular economy, resource issues and social sustainability aspects of smart grids investigated and covered in previous academic research?	
2	**Systematically searching for the available literature with explicit criteria for inclusion or exclusion**	
	Type of literature	Article, conference paper, book chapter, review, conference review, editorial, book
	Keywords	*Group 1 – smart grid:* "smart grid" OR "micro grid" OR "nano grid" OR "mini grid" (*title)* AND *Group 2- Circular economy/resource use:* circular* OR "Raw material" OR reuse OR recycl* OR recover* OR "Natural resource" OR waste OR lca OR "Life cycle" OR ree OR "Rare-earth" OR "Rare earth" OR "critical raw material" OR crm OR "physical infrastructure" *(title)* *Group 3- Generic environmental sustainability:* environment* OR sustainab* OR exergy OR "Greenhouse gas" OR ghg OR footprint* OR renewab* OR climate OR green OR pollut* *(title)* *Group 4 – Social sustainability:* democra* OR just* OR including OR inclusive OR user OR empower* OR social OR equal* *(title)*
	Database	Scopus (7th of February 2022)
	Exclusion criteria	- Studies in a non-English language, - Did not include results from European countries - Only included economic or technological aspects

3.2 Semi-structured interviews

Semi-structured interviews with stakeholders were used to gain a deeper knowledge of the sustainability issues found in the literature review. Semi-structured interviews were chosen since they allow for probing, open-ended questions where participants are allowed to give their personal views on different topics (Adams, 2015). They are ideal for examining uncharted territory with unknown issues (ibid). This is useful since this study aims to fill knowledge gaps about issues that have been scarcely studied.

Any information gained from the interviews will be filtered through the views of the interviewees, and the researcher's presence may bias responses (Creswell & Creswell, 2018). In this study, the relatively big sample of interview respondents (17) has allowed for an expression of contrasting views on different subjects, something that has served to mitigate somewhat the issues with subjectiveness that interviews entail.

3.2.1 Interviews: choosing stakeholder categories for interviewing

The interviewees were chosen with the aim of the study in mind - to investigate social sustainability issues and resource aspects connected to SGs. Thereby purposeful sampling was applied (Shaheen et al., 2019). Stakeholders with insight into the SG field were deemed as a suitable interview group to seek knowledge about SG resource issues that are not present in the current academic literature. In only interviewing "experts", the social sustainability issues have been studied from a "top-down" perspective in the interviews. Including users' views and experiences of SGs was accomplished through the literature review.

In the sampling for this study, a diversity of different positions vis à vis SGs was sought to give a broader view of different sustainability issues. In conducting the sampling so that a variety of positions concerning a research topic are represented, differences in experiences may be highlighted (King, Horrocks & Brooks, 2019). Six different stakeholder categories were identified, as presented below.

Smart grid technology producers are at the forefront of SG technology development; therefore, it was deemed as key to investigate their understanding of different sustainability issues in connection to the technologies they are developing. *Government agencies/public bodies* are important in creating the societal conditions that allow for increased SG employment, and they work strategically with implementing SG technologies. *Consultancy firms* hold much knowledge since they are often employed by governmental actors or companies to draft reports on the future electricity system. *Research institutes/researchers*, like consultancy firms, have expertise covering many aspects of SG systems, from technology development to implementation and assessment. *Energy organisations* can host a wide range of actors and therefore have a special insight into energy issues. *Network operators/ energy companies* are practically concerned with implementing SG technologies, e.g., installing smart meters.

3.2.2 Scouting for and contacting potential interviewees

Potential interviewees were found through Google Search and earlier knowledge of actors within the SG field held by either the thesis writer or supervisor. Reports, websites, blog posts and other online resources were used in this process. The stakeholders were chosen on the criterion that they somehow operated in Sweden (except for two exceptions described earlier). The stakeholder mapping conducted in this study has not been exhaustive, there are likely many other stakeholders present in Sweden relevant to the development of SGs.

First contact with the interviewees was taken via email, or if no email was found, via contact form. The same message was distributed to all potential interviewees, with a slight alteration depending on if the media was email or contact form, i.e., not the intended interviewee.

A common purposeful sampling method is 'snowball sampling' (Shaheen et al., 2019). In this thesis, "indirect" snowball sampling was used in cases where intended interviewees declined participation and instead referred to colleagues or other in their opinion better-suited interviewees. Snowballing was also used when contacting people that the interviewees recommended.

In qualitative studies, the sample size will typically depend on the purpose of the study and what can be achieved within the given timeframe and resources (Shaheen et al., 2019). A total of 17 interviews were conducted for this thesis. 43 potential respondents were contacted.

3.2.3 Construction of interview protocol and interview proceedings

The interview protocol was created in cooperation with the thesis supervisor Katharina Reindl and researcher Carl Dalhammar who provided constructive criticism and suggestions for additional interview questions.

The interview introduction was dedicated to getting a picture of the interviewee's background and allowing the interviewee to provide his/her understanding of the term "smart grid". This was seen as important to get a context and to better understand the subsequent answers. The interview questions were divided into a section on social sustainability and a section on CE, see Appendix 4.

All questions in the interview protocols were not posed in all interviews, instead, the interviews were adapted to the interviewees' knowledge and interests. The interview was finalised with some concluding questions meant to inquire about the respondent's thoughts about the future electricity system in a more general manner, and to allow the interviewee to add aspects that he/she felt had not been covered.

3.2.4 Transcribing and coding of interview data

Full verbatim transcription is needed in methodologies that are strongly focused on how language is used and approaches that seek to examine personal experiences in-depth (King, Horrocks & Brooks, 2019). Full verbatim transcription was not deemed necessary in this study since the key focus is not on personal experiences. Notes were taken during the interviews, which were later complemented when listening to the interview recordings. Only sections deemed as essential for the interview subjects were transcribed. Eight of the interviews were fully transcribed by a professional company to save time.

The interview data was coded using the programme NVivo in combination with coding by hand. A mix of deductive and inductive coding was used (Creswell & Creswell, 2018). The interview questions were used for creating initial codes, and additional codes were then constructed when identifying new themes in the interviews.

4.Theoretical framework

4.1 Circular economy framework

A framework for CE has been used to investigate what aspects of circularity are present in the academic SG discussion, how SGs may impact resource efficiency in the electricity system, and to understand what aspects of CE are present in the implementation of SG technologies and systems.

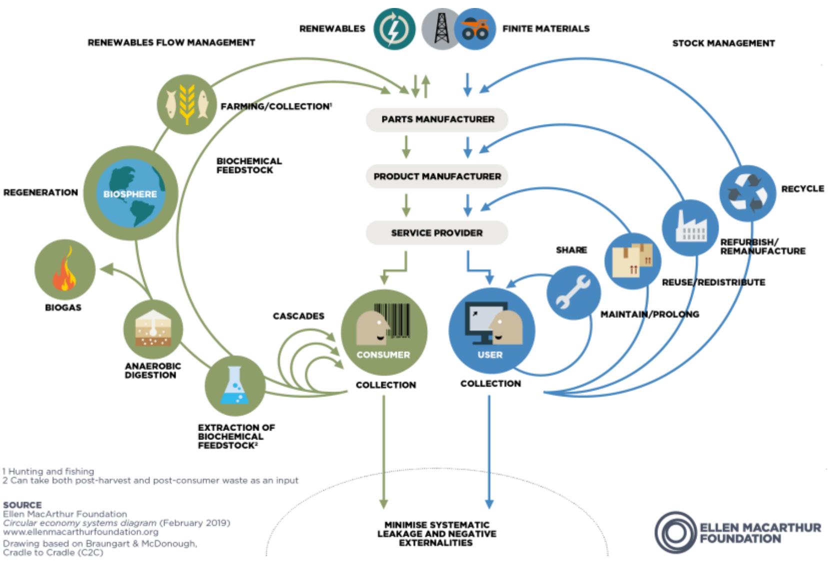

Figure 1. Circular economy systems diagram. Source: Ellen MacArthur Foundation (n.d.).

A CE keeps products, materials, and components in use at their highest possible value (Ellen MacArthur Foundation, n.d.b). As can be seen in Figure 1, courtesy of the Ellen MacArthur foundation, materials are divided into biological and technical cycles, the latter for products made of non-biodegradable materials such as metals). The most effective technical cycles entail *maintaining/prolonging/sharing* and *reusing* products. In these cycles, the value of the products is maintained, and the usage time is increased. It could be repairing a car, thus increasing its lifetime, or arranging a carpool, thus allowing for *intensified use* (Geissdoerfer et al., 2020) so the need for additional cars is decreased (Ellen MacArthur Foundation, n.d.b). These activities are examples of circular business models, which are key to realise a CE (Geissdoerfer et al., 2020). A product may be *redistributed* or *re-sold* to another person, allowing for it to be *reused*. The second most effective technical cycle is *refurbishing or remanufacturing*, for when a product can no longer be used as-is. If this is not possible, *recycling* is the "last" cycle. Here, the value of the product is lost but the value of the materials may be preserved (Ellen MacArthur Foundation, n.d.).

Life cycle assessment or analysis (LCA) is a process for assessing the environmental impacts of a product or a service considering its whole lifetime. LCA can be a good tool for supporting and informing the transition to a CE. However, while LCA is useful for comparing similar alternatives with few unknown variables, the analysis is based on the conditions of the current system. To achieve a CE, system change is needed (Ellen MacArthur foundation, n.d.a).

From a CE perspective it is also relevant to address the issue of resource use in the manufacturing of low-carbon technologies. Technologies meant to reduce climate impact, such as lithium-ion batteries, wind turbines and solar panels, are often quite material intensive, something that is now getting increasingly recognised as climate mitigation activities are accelerating (Xu et al., 2020; Richter, 2022, Liang et al., 2022). This aspect of "material intensity" will be used to analyse SG resource use.

4.2 Social sustainability framework

Vallance' et al.'s (2011) three categories of social sustainability, identified from the academic social sustainability discussion, were chosen as a theoretic framework in analysing the social sustainability literature in this thesis:

Development sustainability has its origin in the *Brundtland Report.* Social sustainability here is understood as addressing human needs, both very tangible needs such as food, clean water, housing, liveable incomes, and aspects such as the distribution of power and influence in society. Prevalent in the Brundtland Report is the idea that social sustainability is a prerequisite for environmental sustainability, it is only when people have their needs met, that ecological concerns can be addressed effectively. This notion is echoed in development sustainability literature. For example, housing research often points out low incomes as a hindrance to increased adaption of renewables. Development is anticipated to alleviate social problems and lead to ameliorated environmental conditions (Vallance et al., 2011).

Bridge sustainability concerns change in behaviour meant to contribute to environmental goals. This literature covers ways to promote eco-friendly behaviour with the goal of building 'bridges' between people and the biophysical environment. Its focus on active alterations of habits and ethics to achieve better environmental conditions distinguishes it from *development sustainability* where positive environmental effects are thought to follow as a natural consequence of social development (Vallance et al., 2011).

Maintenance social sustainability refers to the preservation of cultural characteristics when posed with change, and manners in which people welcome or try to withstand these changes. It concerns traditions, practices, preferences, and places people want to preserve or improve because of their importance to quality of life, social networks, leisure opportunities, etc. Maintenance social sustainability can be described as what people want, contrasted to 'development sustainability' which is concerned with what people need. Understanding what habits and lifestyles different people wish to conserve are vital to gaining social acceptance in implementing environmental measures. If environmental measures are perceived to go against people's preferred way of living, this may lead to resistance or noncompliance (Vallance et al., 2011).

4.3 Socio-technological imaginaries

This thesis is concerned with how experts envision sustainability in SGs, which are, as explained earlier, mostly "in the future" Therefore, the concept of *socio-technological imaginaries* has been used to better understand interviewees' views on future SG developments. Socio-technological imaginaries is a concept first developed by Jasanoff & Kim (2009). The term is used to describe "collective visions of desirable and feasible technoscientific futures" (Ballo, 2011, p. 8). These visions are pivotal in shaping actual socio-technological conditions by steering investments and decisions in the direction of the imaginary, thus helping to realise it (Ballo, 2011).

The imaginaries are created by *techno-epistemic networks* (Ballo, 2011). This concept originates from Haas' (1992) term *epistemic community* which he describes as "[…] a network of professionals with recognized expertise and competence in a particular domain and an authoritative claim to policy-relevant knowledge within that domain or issue-area" (Haas, 1992, p. 3). In the case of this thesis, the techno-epistemic network entails different stakeholders within the energy industry and research, the chosen interviewees. Socio-technological imaginaries are developed by the epistemic community to solve their current problems, so the imaginaries will unavoidably be shaped by their current needs and challenges (Ballo, 2011).

An important part of socio-technological imaginaries is the *imagined public*, the way the techno-epistemic network imagines that "ordinary people" behave and what they might accept**.** In a SG context, the imagined public is how experts imagine SG users. How users are imagined matters because it influences the choices made in SG development (Ballo, 2011).

The theory of socio-technological imaginaries will be used to analyse the interview results of this study and discuss what the respondents' view might entail for future sustainability in SGs.

4.4 Data analysis: Bringing the frameworks together

While the social sustainability and CE frameworks were used on their respective parts, the theory of socio-technological imaginaries was used to understand how stakeholders view future developments in both social sustainability and CE.

The CE and social sustainability frameworks were used in analysing the literature and the interview results, thus providing theoretical concepts for deductive analysis. This deductive analysis was combined with inductive analysis, where different themes were identified, both for the literature and interviews results.

5. Results and analysis

5.1 Literature review results

5.1.1 Circular economy and resource issues

The literature review gave a meagre result regarding studies with a CE or resource-use focus; only six articles on LCA and one analysing critical raw materials.

LCA studies

Symeonidou et al. (2021) evaluated a tool for life cycle assessment of battery storage systems in micro-grids by investigating the environmental impact of different batteries through analysing CO2- emissions from the production, and the use phase.

Rossi et al. (2020) compared different configurations of a nano-grid system. The environmental performance was evaluated with an LCA-method that also includes other factors of environmental impact than carbon emissions, thus placing greater emphasis on the environmental impact of material sourcing (Rossi et al., 2020).

Aleksic & Mujan (2018) analysed the exergy use of ICT components needed for implementing advanced metering infrastructure (AMI) and home area networks (HANs). The authors performed a thermodynamic sustainability analysis that applied an exergy-based life cycle assessment (E-LCA) method.

Wohlschlager et al. (2021), like Aleksic & Mujan (2018), investigated the environmental impact of ICT infrastructure in SGs. Their analysis was made in connection with the rollout of intelligent metering infrastructure and decentralized flexibility markets in Germany, employing attributional LCA (ALCA) in investigating CO2-eq impact of both ICT hardware and data processing (Wohlschlager et al., 2021).

Some noteworthy results, Aleksic & Mujan (2018) found that most of the exergy was consumed in the construction phase. Therefore, they suggested focus should be on *prolonging* the components’ and systems’ lifetime, improving the manufacturing processes and, when possible, employ *existing* communication and data infrastructure instead of manufacturing new components, thus *avoiding* new technologies (Aleksic & Mujan, 2018). Similarly, Wohlschlager et al. (2021) found that ICT hardware had the most significant influence on environmental impact while data processing only had minor impact.

Lamnatou et al. (2022) saw in their review that there is a lack of LCA studies in the SG literature. In future studies, they suggested using LCA models that combine different Life Cycle Inventory Analysis (LCIA) methods and numerous environmental indicators such as toxicity, midpoint/endpoint approaches, and embodied energy (Lamnatou et al., 2022).

Anticipating critical raw material needs in smart grids

David & Koch (2019) wanted to explore the material basis of smart city technologies and their use of critical raw materials (CRM). In so doing, they used SGs as an example since these are vital to accomplish smart cities.

The reviewing and selecting of articles was based on three functions that the authors viewed as integral to SGs: renewable energy production; energy allocation control devices, such as smart meters, and touch-screens; and thirdly, technologies needed for energy accumulation and electricity network stabilisation, i.e. different battery storage devices. Exemplifying CRM, both rare earth-elements (REE) and critical metalloids that are needed for the different SG components, were presented in the study (David & Koch, 2019).

An interesting result from David & Koch (2019) is that China is the source of 95% of the global REE production. While the dependence on critical metalloids can be tackled through avoidance and substitution, the REEs are harder to escape since they have a high cost of substitution. While recovery of both CRMs and REEs is feasible from a lab-perspective, currently (2019) only 1% of REEs are recycled. David & Koch (2019) argued that future efforts to solve problems of resource consumption should be focused on anticipating recycling and substitution capacities needed for smart city technologies, as they will likely produce vast amounts of toxic but valuable waste (David & Koch, 2019).

Summary on circular economy literature

This literature review suggests that very little has been written on SGs and resource issues. All studies but one was on LCAs, which suggests that when resource issues are raised it is mainly from a “technological” perspective. Also, except for Rossi et al. (2020), the LCA-studies used assessment methods based on energy and GHG emissions, thus missing other environmental impacts. David & Koch (2019) differed by both highlighting CRM specifically, and by investigating potential impacts from SGs as systems.

A lot was missing in the literature, however. For example, studies attempting to estimate not only *what* materials but also what *quantities* of different resources would be needed to realise SGs, and what factors, e.g., in product and system design, might influence resource needs. David & Koch (2019) analysed CRM in SGs from a material perspective, but from a CE standpoint, it is vital to consider the circularity of SG *technologies*. Aleksic & Mujan (2018) recommended employing *existing* communication and data infrastructures and *prolonging* technologies' lifetimes. It seems relevant to investigate to what extent existing technologies may be used to realise SGs, how SG components can be kept in use for longer times in the system, and what the role is of circular business models in realising this. Furthermore, what is the role of SGs in a more circular electricity system? These are questions that the empirical interviews will attempt to answer.

5.1.2. Social sustainability

A total of 15 articles about social sustainability were retrieved from the literature search. Vallance et al.'s (2011) categories of social sustainability were applied to analyse the articles. In Table 2 the articles are divided into Vallance's categories. Development social sustainability does not have its own heading, since none of the articles took a strict development sustainability perspective. However, some of the articles had influences of this category. Therefore, as can been seen in Table 2, some articles are present in two columns.

Table 2. The literature divided into Vallance et al.'s (2011) social sustainability categories.

Bridge social sustainability	***Critique of Bridge social sustainability literature***	***Maintenance social sustainability***	***Development social sustainability***
Hansen and Hauge, 2017; Smale et al., 2017; Strielkowski, 2017; Obinna et al., 2017; Egert et al., 2021; Hoffman et al., 2020	van Mierlo, 2019; Wallsten & Galis, 2019; Silvast et al., 2018; Throndsen, 2017	Herranz-Pascual et al., 2020; Milchram, Hillerbrand et al., 2018; Milchram, van de Kaa et al., 2018; Milchram et al., 2020; Diamond et al., 2018	Milchram, Hillerbrand et al., 2018; Milchram, van de Kaa et al., 2018; Milchram et al., 2020; Throndsen, 2017; Egert et al., 2021; Wallsten & Galis, 2019

Bridge social sustainability: Smart grid users

A first category of findings can be understood as works within *Bridge social sustainability* since they investigated how users interact with smart technologies, and what measures should be taken to make user behaviour more aligned with the intended use of different technologies to achieve beneficial effects for the environment.

Another part of the social sustainability literature was dedicated to analysing ideas and preconceptions of users and user behaviour among SG developers and experts. This category of literature was identified by Throndsen (2017) as an important narrative about SG users. He described this narrative as consisting of a social science critique that evaluates how users are imagined and how the imagined users correspond to real users. These articles may perhaps not be so readily put into one of the social sustainability categories identified by Vallance et al. (2011) but can be understood as critiques of research conducted within the tradition of *Bridge social sustainability* since articles in this "critique category" address assumptions about how users may best be guided to contribute to a more sustainable system.

The smart grid user role

van Mierlo (2019) found that demand-shifting is the most imagined user role in SG research. Demand shifting entails users adapting their electricity consumption to correspond better with the availability of electricity on the grid, using less electricity when the demand is high. van Mierlo (2019) identified three other user roles in the SG literature, of co-design, energy-saving and co-provision. However, these are much less prevalent than demand-shifting, and van Mierlo (2019) argued that they are little understood. Regarding co-provision, van Mierlo (2019) meant that while the prosumer role is quite prevalent in SG literature, one should see it as a part of the demand-shifting role since its aim is also to offer flexibility to the grid. van Mierlo (2019) called for research on more active co-production roles, e.g., local energy initiatives, to investigate what effect they may have on the overall energy system. Following this, Smale et al. (2017) criticized the preoccupation with demand-shifting in SG research projects. Since the environmental benefit of demand-side flexibility is limited to the integration of renewable energy sources and avoidance of fossil backup energy, they argued that SG innovations should enable households to adopt a wider range of behaviours including energy conservation, energy efficiency upgrades and investments in renewable energy (Smale et al., 2017).

The other articles in this review partly confirmed van Mierlo's (2019) and Smale et al.'s (2017) observations. Strielkowski (2017) investigated willingness to demand shift following flexible energy tariffs, while Hoffman et al.'s (2020) model to predict demand-shifting also included overall energy loads. The different motivational strategies that Egert et al. (2021) investigated were aimed toward mitigating peak consumption among prosumers. Hansen and Hauge (2017) investigated not only flexibility but also total household energy use among prosumers. Interestingly, while households adapted by using energy when it was most available during the day, total energy use increased after the installation of SG technologies. Producing the electricity themselves and not having to pay for it, the participants felt that they could use electricity more generously and take up luxurious habits (Hansen & Hauge, 2017). Obinna et al. (2017) also investigated both demand flexibility and total energy consumption among prosumers but found that energy use decreased. Co-design, although rare, was present in Hansen & Hauge (2017) since the project participants were able to negotiate further technologies after the project's start, and in Smale et al. (2017) where participants were involved in the co-design of a digital platform.

Activeness level of users

The articles differed regarding what level of user activeness was imagined. Egert et al. (2021) motivated active involvement by stating that sometimes automation will entail citizens giving up their autonomy and freedom of choice, and demand certain technologies that might not be available to everyone (Egert et al., 2021). Smale et al. (2017) propagated a mixed approach, stating that while some household activities, distinct plannable events such as cleaning, are more easily adaptable to active demand-flexibility, "ambiance practices" such as heating, cooling, and lighting are suitable for automation.

Obinna et al. (2017) found that pilot project participants preferred technologies that automatically shifted their energy use since this required minimal effort. This seems to speak for the "technological bypass narrative" that Throndsen (2017) found in much SG research, where consumption is automated and there is no need for user involvement.

Silvast et al. (2018) found that while experts imagined smart metre users as relatively inactive, prosumers were imagined to actively optimise their production, storage, energy use and transit (Silvast et al., 2018)

Regarding the effectiveness of automation vs. active involvement, Hoffman et al.'s (2020) model showed that soft control was nearly as effective as strong control in reducing demand fluctuations and overall energy consumption. Soft control entailed the distribution system organiser (DSO) sending feedback and incentives to the households, hoping that they would thereby change their energy behaviour in accordance with the current energy situation. With strong control the DSO could take control of the energy management system to influence it directly. Hoffman et al. (2020) argued that, given the good performance of soft control, strong control can only be motivated in specific situations.

What motivates the smart grid user?

Several articles were critical about the notion that SG users are effectively motivated by economic incentives. Throndsen (2017) found that while the economic rationality narrative is popular in SG research, it has been proven faulty many times. Users' behaviours are shaped by a variety of factors that hinder them from acting in the way economists imagine. Also, variable tariffs may "punish" consumers not acting on economic incentives, therefore it is important to investigate sustainable non-participation strategies (Throndsen, 2017). Egert et al. (2021) reasoned similarly, high financial incentives can lead to people acting against their will out of economic necessity, which might not only negatively affect the user but also the effectiveness of the scheme in case the economic incentives are later removed. By considering the economic effects on households, Throndsen (2017) and Egert et al. (2021) thus both conveyed a development sustainability perspective.

Interviews with SG project employees in Wallsten & Galis' (2019) study suggested that they were not convinced that emphasising economic benefits of SG use was the most effective way to motivate project participants. This was due to doubts about, among other things, electricity prices fluctuating enough to lead to changed user behaviours (Wallsten and Galis, 2019). Wallsten & Galis themselves were critical of the "commodification" of user activeness seen in SGs, arguing that democracy and collective decision making would increase acceptance for SGs, thereby showing development sustainability views. Strielkowski (2017) was the only article that argued economic incentives, solely, is the best way to motivate users. Strielkowski analysed post-trial survey results from a smart metre pilot that indicated that consumers were more prepared to change energy consumption if this led to reducing the bill, than if it helped the environment. From this, Strielkowski (2017) concluded that consumers are mainly driven by economic self-interest (Strielkowski, 2017).

Smale et al. (2017) argued that emphasizing environmental benefits of SG use could be more effective to get users to engage in environmentally friendly energy behaviour than mere economic incentives, that may not always be that high. For example, in promoting demand-flexibility, communication about how this helps integrate renewable energy into the grid could increase user acceptance for changed behaviour (Smale et al, 2017).

Other than economic incentives, Egert et al. (2021) investigated information and education, nudging and persuasive technologies as motivations. While information and education can empower citizens and enable more informed choices, research has showed that information on its own is not sufficient to change user behaviour. If information can be combined with economic incentives (e.g., smart metres showing energy prices), effectiveness can increase, however. Nudges entailing social comparisons can be effective for energy saving but can also have opposite effects if the neighbours' consumption should turn out to be higher.

Persuasive technologies aim to influence the attitude or behaviour of the user in a conscious manner, encouraging active decisions. Persuasive technologies, like nudging, have been used to influence energy behaviour through social comparison, with positive results (Egert et al., 2021).

Maintenance social sustainability: User concerns and smart grid acceptance

Many of the reviewed articles fit into the *Maintenance social sustainability* subcategory since they were concerned with users' perception of SG technologies. The articles in this category distinguished themselves from the literature within *Bridge social sustainability* by putting emphasis on user experience and subjective values rather than instigating, monitoring or predicting behaviour.

Perceived benefits and risks of smart grids

Herranz-Pascual et al. (2020) investigated participants' perceptions of a SG pilot project in Spain, evaluating whether they saw benefits in using SG technologies. The project included workshops and lectures aimed at increasing the understanding about SGs. At the project's end, the aspects that had the biggest rise in perceived benefits were reduced vulnerabilities to climate disaster and security attacks and allowing for better control of energy consumption (Herranz-Pascual et al., 2020).

Milchram, Hillerbrand et al. (2018) and Milchram, van de Kaa et al. (2018) both investigated public perceptions of SGs. SGs were viewed in a predominantly positive manner when the investigated values were environmental sustainability and security of energy supply while strong privacy concerns surfaced in both studies, reducing the acceptance for SGs (ibid).

Diamond et al. (2018) focused specifically on privacy concerns when analysing an experiment testing residential smart meters. They found that users were most concerned with risks of missing control over data, data security threats, and issues regarding use of the collected data. To counteract these risks, users thought that increased user control of data, transparency in data processing, and sufficient security measures and restraint in the collection and usage of data, were important (Diamond et al., 2018).

To increase acceptance but also convey the risks of SGs, Egert (2021) argued that research needs to explore possibilities for public communication about data collection and privacy protection.

Smart grids from a justice perspective

Milchram, van de Kaa et al. (2018) found that values related to justice were associated with concerns that decreased the acceptance for SG technologies. Milchram, Hillerbrand et al. (2018), however, saw that public attitudes were split. SGs were perceived as increasing justice by enabling more equitable market access and bringing about small-scale energy generation opportunities. On the other hand, the idea that access to SG technologies may be highly dependent on the prosperity of households was prominent (Milchram, Hillerbrand et al., 2018).

SG pilot projects where participants did *not* need their own technologies were deemed as more just in terms of *accessibility*. In the transition phase before different technologies become less expensive, the participants thought that economic support was vital for enabling adoption among lower income households. Collective ownership of battery systems was also seen as more just since it enabled tenants to participate, something that is otherwise quite uncommon in SG pilots (Milchram et al., 2020). By highlighting differing availability for households to participate in SGs due to economic conditions, Milchram et al. (2020), Milchram, Hillerbrand et al. (2018), and Milchram, van de Kaa et al. (2018) partly adapted a *development sustainability* view, although investigating this issue from the perspective of user acceptance.

Milchram et al. (2020) found that increased user control of technologies correlated with them being perceived as more just. To guarantee ease-of-use however, and thereby accessibility, automation was seen as essential. The authors argued that *transparency* may help solve this apparent clash by guaranteeing that users understand the technologies even if they are governed with a high degree of automation (Milchram et al. 2020). These results align with what Obinna et al. (2017) found: participants in the SG pilots wanted more insight into how technologies worked to consciously change their energy behaviour in a more sustainable direction, but simultaneously valued automation for operating appliances with minimal effort (Obinna et al., 2017).

Summary of social sustainability literature

To summarise, the literature suggests that the most researched user role is that of demand-flexibility. When prosumers are investigated, it is mostly from a flexibility perspective. Energy-saving was raised by some articles but seems less prevalent. Pilot projects have shown differing impacts of SGs on energy use, making it relevant to investigate the factors that impact total energy consumption. Co-design was rare. The articles differed in what user activeness level they imagined. Regarding motivation, many were critical towards economic incentives due to concerns about their effectiveness and potential negative social effects. Furthermore, the literature showed that privacy issues are among the main concerns of SG users. Making technologies accessible to less affluent households was important for SGs to be seen as just. Transparency may be key to enable both ease of use and user control. Users seem to associate SGs with environmental sustainability and economic gain.

Aspects to investigate in the empirical study are whether the interviewees have similar views to the literature about SG users, and what issues and problems are seen as important.

5.2 Interview results

In total, 17 interviews were held for this study, one of which was via email correspondence. The interviewees are referred to by individual codes, see Table A1 in Appendix 5.

5.2.1 INTRODUCTION: THE TERM "SMART GRID"

The interviewees were asked to define what they mean by the term "smart grid". Below, Figure 2 summarises the interviewees' understanding of the term.

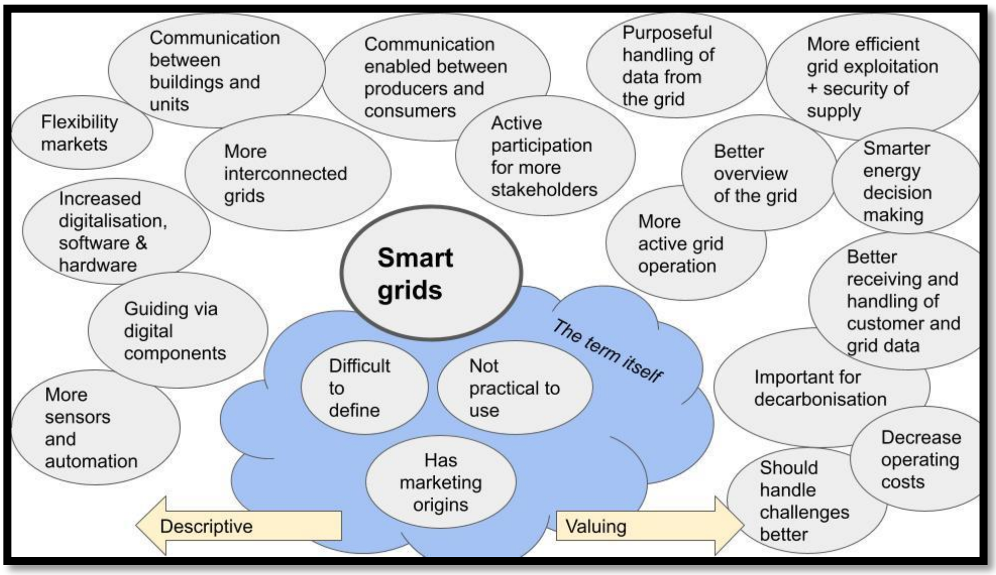

Figure 2. Smart grids as defined by the interviewees. The figure presents different definitions and understandings of SGs. Bubbles in the left of the figure are more descriptive and non-valuing in nature, while bubbles to the right define SGs via their supposed benefits. The blue cloud contains interviewee thoughts about the *term* "smart grids".

It should be noted that the bubbles in Figure 2 are not necessarily individual interviewee statements. As can be seen, interviewees described SGs both in terms of components, and what SGs might contribute to. The latter "valuing" descriptions were mostly connected to grid operation.

The term itself was confusing to many respondents, several expressing that it is unclear what it entails. For example, the employee at the regional council, RC, did not use the term professionally, instead preferring more exact and descriptive words. The analyst at the international organisation, Int.Org., explained that the term has its origins in marketing, and companies try to fit in a wide range of technologies in it advertised as smart.

5.2.2 CIRCULAR ECONOMY AND RESOURCE ISSUES

A background: Resource and sustainability considerations in the energy sector

Judging from the interviews, CE and resource issues are not discussed extensively, neither in SG development nor in the energy sector generally. However, this seems to be changing somewhat. GA1 explained that the government agency she works at pushed for a bigger emphasis on resources when advising in the writing of *Elektrifieringsstrategin* (see Appendix 1 in this thesis). Having formerly mainly focused on energy efficiency, it now has a section specifically dedicated to resource use, which will be prompting further work on this in the future. GA2 felt that resource issues are not talked about in society. Generally, the focus has instead been on energy efficiency, not least in EU product legislation. However, increasing energy efficiency of products will often mean using materials that are worse from a climate perspective. Therefore, there needs to be a bigger consideration of the materials that go into products (GA2). CC2 explained that she had recently started a project with various network operators with the aim to increase sustainability in the electricity industry. First on the agenda will be overseeing company tendering processes. CC2 hopes there is potential to escape the strict cost focus that governs procurement today if the network operators can cooperate and collectively demand higher environmental standards from their suppliers. TC2, who works at a company that supplies network operators with equipment, confirmed the view that product price currently dominates all other considerations.

Resource issues in connection to energy and electrification do not seem widely discussed internationally, either. Int.Org.**,** who works at an international organisation that analyses energy issues, said that they have not been considering resource aspects until recently. The interviewee was part of drafting a report about critical minerals for the organisation, estimating mineral demands from different energy scenarios. While there is a new-found awareness about these issues, Int.Org.

does not think that the organisation has put forward any viable solutions for handling the changed resource needs that the transition to renewables entails.

Smart grids - enabling circular economy in the energy sector: Maintaining, and intensifying the use of, physical grid infrastructure

Many interviewees thought that SGs will increase resource efficiency in the electricity system by bringing a flexibility that help "shave" peaks in the grid, thus construction of extra grid infrastructure can be avoided to some extent (GA1, GA3, RI1, CC2, EC1, EC2). As EC2 explained:

> "Cables are dimensioned after the busiest times of year, so they are not actually "full" most of the time." – *EC2, network operator employee*

Thus, from a CE perspective, SGs could allow for *intensified use* of existing infrastructure and *prolong* the lifetime of cables that would otherwise have needed replacing earlier to meet increased demands. To what extent flexibility may reduce infrastructure needs is unclear, however. GA1 thought that investigating this could be done through using different scenarios, although it would likely be quite difficult.

While it is uncertain to what extent smart solutions may decrease resource use, network operators are already using flexibility to solve capacity problems. EC2 explained that flexibility markets are used for connecting more customers to the grid even though cables are "full". However, flexibility is *not* used for postponing construction of, or replacing, grid infrastructure. Instead, flexibility is seen as something temporary until grid infrastructure is reenforced. RC confirmed this view.

Today, flexibility markets only involve bigger customers, but EC2's company hopes to enable participation also for smaller customers, including households, facilitated by aggregators. RC thought that the biggest unused potential for flexibility lies within households since many industries have continuous processes and cannot offer flexibility without stopping operations. If households can be included in the flexibility markets, these might help to replace grid infrastructure (RC). EC2 said that, for network companies to invest in "virtual grids" *instead of* "conventional grids", she thought that regulations would have to change so that flexibility investments are rewarded the same as capital investments (EC2).

It should be noted that even though many interviewees thought SGs would be important in decreasing resource use, they still thought new grid infrastructure will have to be constructed in the coming years to replace aging components and allow for increased electricity use (GA1, EC2, EC3, EC2, RC).

Another potential positive aspect regarding circularity, EC1 thought that SGs, by enabling increased surveillance and control, may increase the lifetime of equipment - providing that the right incentives are given to keep the equipment for a longer time. SGs can thereby also be seen as a means of *maintaining* grid infrastructure, thus *prolonging* its lifetime. TC2, although hoping that SGs would be used to improve grid maintenance, thought that this was not a prioritised area. Confirming this, EC2 expressed that they already have better systems for checking grid maintenance status, but that grid maintenance is not incentivised with current regulations.

Paradoxically, a smarter grid may *increase the need* for maintenance. TC2 and EC2 thought that maintenance would become more extensive, given that digital components added to the grid, e.g., sensors, will need support and replacing more frequently.

Resource efficient smart grid design: the need for extra components

As discussed in connection to the CE framework, an important issue is that of material use in low-carbon energy technologies. The question is how material demanding SGs will be?

Expressed commonly in the interviews was the notion that SGs are more resource efficient compared to "conventional grids", although this assumption did not always rest on evidence. EC1 expressed this clearly:

> "Constructing an electric grid [means using] iron, copper, and aluminium. Electronics demand other rarer metals, and batteries and other things… In that way [smart grids] have an impact, but the benefit is bigger – without having calculated or being able to verify it in any other way than my personal estimation." – *EC1, Energy company representative*

EC1 thought that the biggest change would be in software. EC2 explained, making the grids smarter will not entail throwing away current grid infrastructure (except for when replacing old measuring equipment), but rather "adding on" extra components. RI3 thought that the resource needs will probably be the biggest in the implementation phase of different new SG technologies. When products are standardised and different functions are built in into products, resource needs will decline.

RI1, however, thought that the number of extra components added will probably *not* be unsubstantial given the need for control and regulation, batteries, and different appliances in the home. RI2 thought that realising SGs will not have to mean using much more equipment if the systems can be kept simple. For example, to achieve a smarter building, a smart metre that tracks energy use in different appliances combined with a smartphone app could be sufficient. Int.Org**.** said that the need for extra resources will depend on at what "level" flexibility is achieved in the system. Smart metres need to be added, but perhaps not in every home, just every neighbourhood, Int.Org. thought. While making our homes smarter (digitalising and connecting many home appliances) would indeed take a lot of extra resources, a smarter grid could be achieved more resource efficiently by instead allowing for flexibility at a higher "hierarchy", i.e. purposefully steering down whole households from the grid during peak hours.

Furthermore, *existin*g infrastructure and appliances can be employed in SGs. Vehicle charging points could provide load balancing, so that the car is not charged at the same time as the household equipment is used the most, RI2 explained. He also hoped that vehicle to grid (V2G) and vehicle to home (V2H) systems will be used extensively in the future:

> "Electric vehicles are essentially batteries on wheels […]. And the reality is that the car stands still most of the time." – *RI2, Researcher at research institute*

Some brands are already manufacturing batteries that can also be de-charged to supply electricity to the grid. A possible problem that RI2 saw is whether EV manufacturers will be willing to replace batteries that have barely been used for driving. There could potentially be other problems like this, RI2 thought, regarding who is responsible for SG technology maintenance.

An interesting resource aspect regarding energy communities emerged. EC1 pointed out, that from a material resource perspective, energy communities are quite inefficient since they entail drawing parallel cables (to the regular grid). RI2 acknowledged this as well, although from an energy resource perspective it is more efficient to be able to send surplus electricity to a neighbour that needs it as opposed to the grid, and GA2 highlighted energy communities' advantage in shaving peak electricity demand by sharing of electricity between households.

Smart technologies: assessing their environmental impact, and managing it through prolonging and recycling

Given that some extra components, e.g., smart metres, will have to be added to achieve smarter grids, how is their environmental impact addressed? Is SG equipment *shared, maintained, and prolonged*?

EC3 explained that his company is conducting LCAs for their smart metres, and that they have given a lot of thought regarding resource use. Considering the large quantities of metres (900,000) they are responsible for, EC3 expressed it is important these are handled in a sustainable manner. Materials from the old meters are retrieved as much as possible, but some is energy recycled. The priority for the new metres has been for them to be able to "sit" for as long as possible – 15-20 years, since the company previously had issues concerning products' lifetimes. EC2, on the other hand, had not heard of any LCAs being conducted in her company. While there is an awareness that technology components will have to be replaced more often, she had not heard discussions about what this entails regarding resource use (EC2). CC2 explained that they had not yet investigated issues of resource demands from smart technologies, but that this could become relevant in the future.

TC1, whose company manufactures smart metres, explained that LCAs are conducted on the most sold products, and they are investigating how material use can be made more sustainable. Increased interest from the public and stricter legislations has pushed the company to consider environmental impacts. The smart metres they produce have a lifetime of 12 years, what happens after decommissioning is up to the utility companies, with recycling depending on the market.

GA2 and EC3 thought that smart metres and other technologies used in SGs usually have a longer lifetime than other technologies. However, RI3 gave an example of quite technologically sophisticated smart metres being replaced simply because they did not have the required HAN-port, thus not qualifying the demands on functionality.

To summarise, it seems that smart metres are recycled to some extent, and there is a will to prolong their lifetimes, although the latter seems threatened by strict product demands.

Circular business models: Sharing and reusing by leasing, renting and second life

The interviewees had not heard of leasing or hiring SG technologies as a means of increasing circularity, but some examples of leasing and renting of grid equipment surfaced, as well as of renewables and EVs.

Batteries are commonly rented from a separate company by network operators to tackle demand peaks during limited time periods until grid infrastructures are reinforced (RC, EC3). Due to regulations (see Appendix 1), grid operators are not allowed to own batteries and are therefore "forced" into this solution (ibid). RC thought that as batteries get cheaper, renting out of batteries will become an important business model.

GA2 explained that there are some examples in Sweden of customers renting out their roof space for solar panels. In EVs, leasing is common, mainly due to previous uncertainties regarding the batteries' lifetime (GA2). He did not know of leasing within energy storage or flexibility but thought that such examples could become more common in the future. However, there are inherent uncertainties with offering flexibility as a service, making third-party financing a challenge. Firstly, there are many potential sources of revenue - frequency regulation, flexibility markets, or working with spot prices. Secondly, it is hard to predict in advance how lucrative it will be to offer flexibility as a service, this will vary greatly from year to year depending on, e.g., weather conditions (GA2).

Another potential problem for service providers in the grid business was raised by TC2. Network operators keep spare equipment in the case of malfunctioning, and it would be difficult for an outside actor to provide these spares given that different network operators usually have different product systems. Service providers would therefore need to have many models of the same component (TC2).

Considering the views of network operators, both EC1 and EC2 stated that current regulations, since they favour capital investments, lead to them wanting to own equipment as opposed to leasing it. EC1 said that there are some possibilities in current regulations to count renting costs as capital investments, but in practice this entails a complicated process with increased administration, constituting an expenditure for the company. EC3 did not think current regulations was a hindrance to new business models as leased/rented equipment can be "counted" as capital, however he did not see any economic advantage in leasing or renting.

Regarding reuse business models, RI2 and GA2 gave the same example of a pilot project in Gothenburg where old bus batteries are re-used in apartment buildings where they serve as storage for solar power. The vehicle industry has strict rules regarding when batteries are seen as fully serving, so they are still fit for energy storage (RI2, GA2).

Summary of circular economy in interviews

Resource use and CE issues in connection to SGs do not seem that discussed among professionals in the energy sector. Awareness of material use appears to be rising somewhat, but still varies greatly among stakeholders. Regarding circular practices concerning smart metres, recycling, considerations of material inputs, and extending technological lifetime were discussed. Examples of leasing/hiring and reuse surfaced in connection to EVs, batteries and solar panels. Current regulations seem to be a contributing reason why network operators do not adapt alternative business models, and there are also challenges for third party stakeholders in the grid business. The overall sentiment was that SGs can be realised with relatively small material inputs and decrease overall resource use in the electricity sector. However, while flexibility is expected to reduce grid infrastructure needs in the future, this is not yet the case.

5.2.3 SOCIAL SUSTAINABILITY IN SMART GRIDS

Smart grid users as imagined by experts

This section concerns how the interviewees imagined the future SG user, in other words, the *imagined public* (Ballo, 2011). Applying Vallance's (2011) categories, one can understand this section as "bridge sustainability" since the different themes address how users are best to contribute to a more sustainable electricity system. However, there are also aspects of "maintenance sustainability", these are highlighted in the text.

The smart grid user role

The interviewees expressed that SG users will mainly contribute by offering demand flexibility, either directly or through a third party, such as an aggregator. After this, the second most common smart user role was that of the prosumer, i.e., many users will also be important as small-scale electricity producers, some interviewees thought. Interestingly, energy saving was not portrayed as an essential SG user role, although this function was brought up briefly in connection to energy communities. Regarding co-design, TC1 expressed that customer opinions are important in designing smart metering solutions at her company, and RI4 hoped for a greater co-creation of energy systems in the future. RI4 and CC1 both expressed that much SG technology development is currently lacking the user-perspective and hoped for increased dialogues with users and other stakeholders, such as network operators, to create more need-based solutions instead of putting resources on technological solutions for which there may be no demand or acceptance.

What motivates the smart grid user?

Most of the interviewees believed economic incentives to be essential in motivating users to participate in SG systems. Many also thought that economic incentives will become increasingly important as the electricity prices rise or fluctuate more due to higher intermittency of energy production in the future (EC1, RC, RI2, GA3, GA2).

Two respondents were not fully convinced of the effectiveness of economic incentives. RI4 thought that if solely costs are to motivate users, price fluctuations would have to be bigger than today. Int.org said that, if SGs were framed as benefiting the environment, this might work better or just as well for motivating people. RI4 thought that while environmental concerns have been, and are, important to get people to in invest in renewables and other technologies, they might not be enough on their own. Other interviewees mentioned environmental values as a motivation, at least for some people, but thought that these would have to be combined with economic incentives to be effective (EC3, EC1, TC1).

Some interviewees thought homeowners with their own technologies (solar panels, heat pumps, etc.) will likely be more actively engaged than will tenants or people without such technologies (EC1, RI4, EC3). EC1 described that people are generally not that interested in how they can interact with the grid, but that this changes when they invest in an EV or their own solar panels. The investments spur an interest to get more actively engaged, and often lead to customers wanting to know what more can be done to optimise their energy use. Similarly, RI4 thought that users that have actual stakes in technologies will more easily see the benefits of SGs. The economic benefits will befall these users more directly, and when technologies are owned collectively, an important source of motivation is also the community good (RI4). In discussing energy communities and microgrids, yet another user motivation emerged: that of increased resilience. RI2 and RI4 thought that this would probably become increasingly important in the future, given that grid connections may not always be as stable as today.

People wanting to preserve the environment, social cohesion, or certain lifestyles are aspects addressed under maintenance social sustainability (Vallance et al., 2011). One can therefore understand the interviewees' discussion about motivations that originate from "deep-lying values", as opposed to (economic) rewards, from a maintenance sustainability perspective.

Activeness level of users: The (not so?) active smart grid user

Most interviewees pictured a future where smart technology use is simplified by means of automation and third-party stakeholders, such as aggregators, taking on the active role. Among most respondents there was a perceived need for simplicity to not de-motivate the user by demanding too much attention, interest, knowledge, or time. In fact, convenience and simplicity of use were seen as just as important as economic incentives by most respondents, and even more important by some (RC, Int.Org.). Also, some expressed that if SG technologies are easy to use, people will probably accept lower levels of economic compensation (EC1, EC2).

GA1 said the government agency she works for does not believe in manual response to economic incentives since studies have shown that this is not effective (GA1). GA2 explained that while around ten years ago the SG user was imagined as more actively involved, this has changed after pilot projects showing that only few households have the possibility to actively monitor their energy use.

Given that so many interviewees expressed the need for automation, it begs the question what is meant by an "active" SG user? EC1 and RI2 expressed that most people will only be "active" in the sense that they make the decision to be flexible with the help of someone else, such as an aggregator, (EC1, RI2), and in deciding which appliances may be used for what and when (EC1, EC2). EC2 thought that, while automation will be important, it should be easy for customers to follow and understand their energy use, thus highlighting the need for transparency. GA3, while thinking simplicity is important, expressed some hesitation regarding loss of user autonomy:

> "I can think, how much of the initiative do you want to give away? […] It is easy to say that the EV is only charging during the night, until there is a crisis, and you need some extra charging to drive to the riding practice."
>
> - *GA3, employee at government agency*

GA3's remark, by addressing that losing a sense of "freedom" could possibly hinder the adoption of energy-saving behaviour, can be understood as an argument within maintenance sustainability.

Two of the interviewees stood out by envisioning a more active SG user. RI4 wanted to challenge the view of the passive consumer, arguing that many people have a keen interest to learn, as has been seen among solar panel owners for example. Increased information and knowledge about the beneficial impacts of changed user behaviour could motivate people to become more active (RI4). TC1 envisioned an active user, at least in the initial time after technology installation. She believed that to be necessary for creating increased understanding among people of energy use and its environmental impact. Interestingly, she was the only one that expressed SGs could be used to accomplish increased environmental awareness by concretising the environmental impact of energy use.

Smart grid issues and problems

The following section addresses different issues that the interviewees saw with SGs and can be understood from a development sustainability perspective since it addresses how social welfare and security may impact, and be impacted by, SG implementation.

Data privacy and cyber security

Many respondents raised concerns around cyber security and data privacy, saying that increased digitalisation of the grid also makes it more vulnerable. Smart metres with high data granularity increase the risks of burglaries since they enable monitoring of different home appliances, making it easy to see when someone is not home (RI3, RI2). Thus, information getting in the wrong hands is a substantial risk in a smarter grid. Despite this, the Swedish public does not seem concerned, GA2 thought. This is a stark contrast from other countries, e.g., The Netherlands, where the smart metres have been greeted with suspicion, many viewing them as surveillance equipment (GA2). Adding to the view of the Swedish public being relatively unperturbed, none of the network operators interviewed in this study expressed that user concern had been an issue in their smart metre rollouts. The lack of integrity concerns in connection to SGs in Sweden could be due to an overall higher trust for the state, GA2 thought.

While technologies for measuring and monitoring can create privacy issues, EC1 said that a bigger risk, security-wise, are different technologies used for remote control of appliances. These technologies increase the vulnerability of electricity systems substantially and would create major problems if they were to be hacked (EC1). For example, if hackers gained control of the software that governs a brand of heat pumps, they could set them to maximum capacity and thereby seriously impact the grid stability (GA2).

GA2 thought that perhaps there should be bigger worries around security issues regarding SG technologies than it is. Attacks towards electricity and heat systems are probable means of warfare in the future (GA2). RI3 expressed that there is a naivety in some sectors with a strong trust in that suppliers follow certain standards, sometimes products are not secure (RI3). Another problem is the question of responsibility in case products are hacked. For example, if an aggregator gains access to a technology to steer it remotely, and the technology is hacked, is it then the aggregator or the technology manufacturer that bears the responsibility (RI2)?

Distribution injustices and energy poverty

Most interviewees acknowledged that there is a differing ability among households to adopt technologies such as solar panels, batteries, and EVs, and that this affects to what extent households can offer flexibility to the grid. This way, it is the wealthy households with the most equipment who stand to gain the most. GA2 stressed that it is also the richer households that use the most energy, and therefore they gain more economically in using SG technologies to peak-shave (or reduce) their energy consumption than do households with lower incomes.

One interviewee expressed that it might not be a problem that some households gain more economically than others if SGs are beneficial for the system as a whole (CC2). Many interviewees, although not downplaying distribution injustices, wanted to stress that while some households might gain more than others, SGs will probably be beneficial for most users. This is because they allow for more efficient and cheaper grid operations (EC1), better control and lower grid costs (RI3), increased affordability and control over household energy consumption (TC1), and increased delivery ability and less grid problems (EC3). However, some interviewees also said that it is important to offer economic support to households that wish to adopt smart technologies, thus allowing more users to become active irrespective of costs (RC, RI4, GA2).

While the consensus seemed to be that SGs will be economically beneficial for users, two risks were raised in the interviews. EC3 meant that an issue could be if economic incentives were designed in a way that hits hard against some customers. Int.org. expressed a concern regarding people living in energy poverty who might become even more vulnerable as utility operations become automatic. In France, where he lives, people are rarely shut off due to non-payment since informal arrangements are made between utility company personnel and customers. A fully automated system lacks these human interactions, and thereby loopholes which protect people.

Energy communities

A subject that surfaced in many interviews was that of energy communities. In Sweden, they have been allowed since the beginning of 2022 following an increased exemption of the concession law,[2] so it allows for low-voltage cables being drawn between residential houses (Axell, 2022). RI2 thought energy communities will now probably increase in number in Sweden (they have hitherto been tested in pilots). Energy communities escape some taxes, therefore network operators may lose revenue. However, the maintenance costs for the grids remain, meaning that the customers who cannot afford to be part of energy communities, may see increased grid tariffs as a result, RI2 thought. GA2 did not think energy communities would have this effect, although we have yet to see their impact. He did, however, agree with RI2 and RI4 that there are injustices regarding who can afford to join energy communities. High costs are not the only issue, RI2 expressed. While you could cooperate with others and thereby not having to own batteries and other equipment yourself, it is still a complicated process to start an energy community (RI2). Apart from investments, you also need interest, time, and knowledge (RI4). Therefore, RI4 hoped that municipalities will take an active role in enabling energy communities for a bigger group of people. He also hoped for incentives to make energy communities contributors to the "big grid", instead of a development towards off-grid communities, as has been seen in other countries.

Social sustainability in the supply chain

Int.org. expressed that the most important social sustainability issue to him is that of people being impacted in the supply chain of different materials needed for the smart technologies. The minerals and metals are oftentimes mined in countries with lower environmental and social standards, child labour being a big issue. When production is outsourced, one can pretend that production is clean, he said, and upon this stated:

> "There is no clean energy, just different impacts". – *Int.org, energy analyst at an international organisation,*

Sustainable mining is progressing due to an increased awareness of these issues among the public, although the positive development is being made from low starting levels, Int.org explained. Also, since covid-19, many countries in Europe and the US are now trying to fortify their supply chains and relocate some of their sourcing, but some materials, e.g., REE cannot be sourced from within Europe.

[2] SFS 2021:976. *Förordning om ändring i förordningen (2007:215) om undantag från kravet på nätkoncession enligt ellagen (1997:857).* https://svenskforfattningssamling.se/sites/default/files/sfs/2021-11/SFS2021-976.pdf

Material resources will therefore continue to be an important issue given the political regimes in the sourcing countries, he thought.

Summary of social sustainability in interviews

Demand flexibility was highlighted as the most important “user function” in the interviews, this tendency was even stronger compared to the academic literature. Prosumers was the second most prevalent user role since many believed decentralised energy production systems, consisting of households or energy communities, will become more common in the future. Co-decision making in SG development was barely mentioned, neither was energy saving (except for in connection to energy communities). Automation and simplicity of use was described as key by many respondents. Prosumers were imagined to be more actively engaged than electricity customers who contribute solely with demand flexibility. Many thought that SGs will be economically beneficial for most people, although there were some concerns regarding fairness of distribution. There seems to be no substantial opposition to SGs in Sweden, despite privacy and security risks. Energy communities were described as beneficial in increasing resilience but could mean injustices regarding who is able to join and benefit economically.

6. Discussion

This thesis has taken a wide approach to SGs, investigating both social and environmental perspectives. Although sometimes seemingly far apart, social and environmental sustainability issues are interconnected and should be addressed simultaneously, as is stated clearly in *The Brundtland Report* (Brundtland, 1987). Figure 3 aims to bring together the themes discussed in this thesis, bridging social and circular sustainability. This section starts with an explanation of the figure. The following discussion will address the problems in defining SGs and their environmental impacts, and furthermore how social and circular sustainability converge in the supply chain of SG technologies and the issue of demand flexibility. Following this, automation is discussed since it was integral to how the respondents imagined the SG future. Lastly, sustainability aspects of SGs are discussed from a socio-technological imaginary perspective.

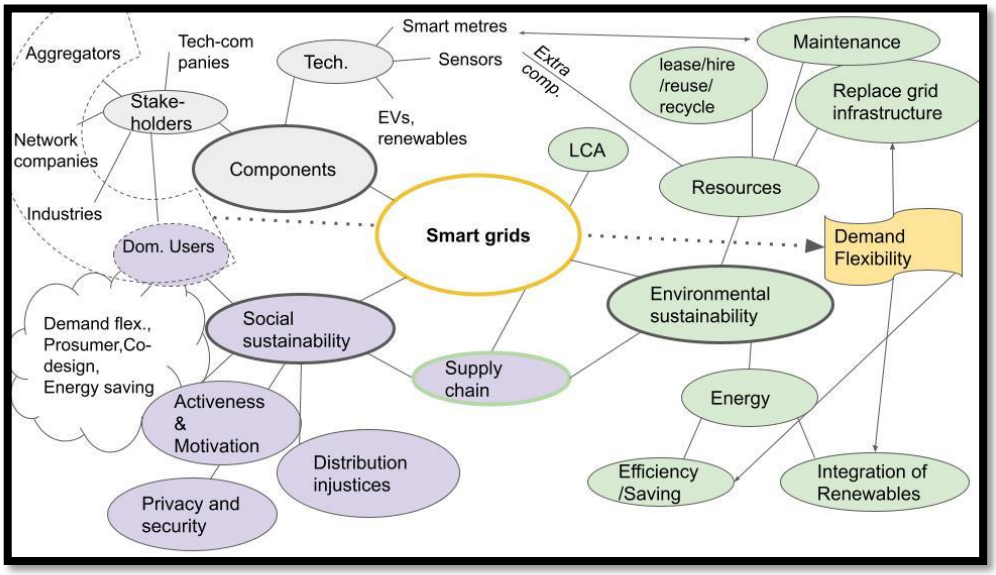

Figure 3. A figure of components, social sustainbilty and environmental sustainability in smart grids.

Bringing the parts together

Starting from the upper right corner in Figure 3, this thesis has shown that SGs may reduce resource use by replacing physical grid infrastructure and facilitate maintenance. However, the smart technologies themselves will likely also need more frequent maintenance. The extent to which SG technologies may replace grid infrastructure is dependent on to what extent demand-flexibility is reached within the electricity system, which in turn depends on whether regulations promote investments in flexibility, and how willing users are to offer flexibility. Here, resource use and social sustainability are connected. Demand flexibility is also pivotal for the integration of renewables and energy efficiency, matters that have not been covered in this thesis.

Social sustainability and resource use also converge in the supply chain of materials. LCA may be used to assess environmental impacts of SG technologies in different parts of the supply chain.

Recycling of SG technologies is done to some extent, and there were examples of leasing/hiring and reusing of EVs, renewables and batteries. SG technologies can be divided into "extra technologies", such as metres and sensors, and components that are "already present" in the electricity system, such as EVs, renewables and energy storage.

Important components in SGs are technologies, as discussed, but also various stakeholders. Aggregators, network operators, industries and domestic users may participate in flexibility markets (the dotted "macaroni-shape"), and domestic users will likely be important in these, participating through aggregators. Domestic users may also offer demand-flexibility "individually", either actively or by automation. Other "user roles" are that of the prosumer, co-designer and energy-saver.

Social sustainability aspects covered in this thesis were user activeness and motivation, privacy and security, and distribution injustices. These are matters that need to be considered for fruitful SG implementation and user acceptance.

Smart grids – what are they, really? And which is their environmental impact?

A problem during the whole thesis work has been the difficulty in defining "smart grids". It can be argued that SGs entail everything from solar panels to batteries to EVs to grid equipment, essentially everything in an electricity system that may in some way be involved in or affected by increased digitalisation. Also, SGs are still very much "in the future", one could imagine many different possible paths for the electricity system. An example is the decentralisation vs. centralisation discussion (Libertson, 2021; Hojčková et al. 2018), here the interviewees showed quite different opinions, some thinking that the future will be more de-centralised while others did not believe this was feasible.

That SGs are so difficult to define also makes it hard to decide what should be included when analysing their environmental impact. Relating back to David & Koch (2019), one could argue that it is technologies for energy allocation control that are specific for SGs and need to be "added" to the electricity system, and perhaps also those that should be evaluated primarily to determine the environmental impact of SGs. On the other hand, energy generation and storage components are very much integrated parts of the "SG system". SGs enable the use of EV batteries in the grid, should the environmental impact of these batteries then be allocated to the SG or the car? The car battery would have been manufactured regardless, but the V2G/V2H function will entail more intensive use of the battery than if it was just employed for driving, and perhaps mean earlier replacement. Similarly, if we are mainly to employ *existing* communication and data infrastructure in SGs, as Aleksic and Mujan (2018) proposed, can we then disregard their environmental impact?

Social sustainability and resource use: Two sides of the same coin?

At a first glance, issues of social sustainability and resource use may seem unrelated, but they clearly converge in the supply chain for the different resources needed to accomplish SGs. Rare minerals and metals are oftentimes found in countries with laxer environmental and social standards, where their extraction have significant impact on local communities and environments. One could argue, as Int.Org. did, that this is the social sustainability aspect that deserves the most attention. Is there a risk that SGs outsource the environmental impacts of our electricity system, adding to the strain on non-European landscapes and natural resources? There is clearly a need for acknowledging both the social and environmental impact of our technologies to a greater extent. A start could be to use LCAs that not only include CO2-emissions, but a wider range of environmental impacts, as Lamnatou (2022) suggested. This would give a fairer view of the impacts of the different materials that are needed for SG technologies.

Social sustainability and resource use also converged in the aspect of flexibility, with user demand flexibility being essential if SGs are to help "dematerialise" our electricity infrastructure. However, to what extent electricity consumers will be willing to adapt seems uncertain. Automation and remote guiding of technologies may simplify flexibility, but will users be willing to give up control, and accept the privacy and security risks connected to it?

Automation: Simplifying user flexibility in a complicated system

The dominating view among interviewees was that automation will be important to enable increased user participation in SGs. The stress on automation was even stronger compared to the academic literature, with many interviewees expressing they did not believe in users acting manually on economic "flexibility incentives" since this would take up too much time and effort. The "technological bypass narrative" that Throndsen (2017) found was very present in the interviews, quite different from Katzeff et al.'s (2018) study, where users were expected to act consciously on economic incentives. In this thesis, the general *imagined public* of the interviewees could be described as "economically motivated with a knowledge and engagement deficit", just as Ballo (2011) found in her study where she investigated how energy experts in Norway imagined the future of SGs. Many respondents in this thesis thought that simplicity of use was just as or even more important than economic incentives.

One could argue, however, that there were *two imagined publics* in the interviews. Prosumers, or those owning technologies such as heat pumps, EVs or solar panels, were imagined by many as more actively engaged in SGs than those without such technologies. However, it seemed that although these users would likely be more interested and actively seek out new technologies, they would still rely on automation for the day to-day task of offering flexibility. Indeed, just as van Mierlo (2019) found, flexibility was seen as important also for prosumers.

Given the emphasis on flexibility, it is perhaps not surprising that automation was stressed so much. Arguably, it is not reasonable to expect users to adapt their routines after fast-fluctuating energy prices. The emphasis on automation, in turn, can help explain why the interviewees were generally more positive to economic incentives than the literature, many arguing that simplicity of use can make users accept lower economic compensation. Economic incentives were seen as a means of getting people to *participate* in SGs, but *not* a tool for getting users *actively* involved.

Automation: Benefits, issues, and concerns

Since automation seems to dominate the SG imaginary, and imaginaries tend to be performative, i.e., self-fulfilling (Ballo, 2011), it is important that this does not lead to a development where users who wish to be active cannot. As EC2, Milchram et al. (2020) and Obinna et al. (2017) expressed, automation should be accompanied by technological transparency that enables users to understand and take control of appliances if they wish to. The literature (Milchram et al., 2020; Obinna et al., 2017) suggested that both *control* and *simplicity of use are* important for creating user acceptance for SG technologies, and an improved user interface could facilitate both. Also, if users were involved as co-designers of technologies and energy systems, one could imagine that automation would be more on their terms.

Automation may be both positive and negative from a social sustainability standpoint. It saves people from having to manually respond to financial incentives, and thereby also from "punishment" if they should fail to do so, as Throndsen (2017) pointed out. One could argue that automation is more just than a system that expects you to make active choices to be rewarded, where those with little lacking knowledge, time, and capabilities miss out economically.

On the other hand, automation entails privacy intrusions, and appliances that can be controlled remotely are especially susceptible to security risks. The literature showed that privacy and security issues are at the top of user concerns about SGs, which raises the question of whether people will so readily accept increased automation if they are aware of the risks connected to it? As was suggested by Egert (2021), research about how these issues may best be communicated to the public is probably needed.

Security and privacy risks might not be the only factor affecting user acceptance for increased automation, however. Loss of convenience could also make people hesitant, as GA3 suggested. The question is whether economic compensation will be enough for people to cease control, even if it seldom leads to real inconvenience? Is economic compensation enough to make up for loss of freedom? The answer is probably that it depends on the magnitude of the compensation, as well as on the user's economic situation. One could imagine that it is those with *less money* that, just as they are more likely to act *actively* on economic incentives such as variable tariffs (Ballo, 2011), will be willing to accept inconvenience and security risks, (providing that they have enough to own the necessary appliances to offer flexibility, of course). Therein lies an injustice, but also a disadvantage for the system since it is usually those with *more money* that consume the most electricity (Oswald et al., 2020), and therefore whose flexibility resources one would benefit the most from using.

Also, it could be worth contemplating if automation could risk creating an unawareness of the connection between energy use and its environmental effects. As TC1 said, activeness could serve a purpose in visualizing and creating awareness about environmental issues.

Then there is the question of automation in connection to resource use. Interviewees expressed that, SGs need not mean adding on that much extra components if systems can be kept simple. But the question is whether a high degree of automation can be realised resource efficiently? If various home appliances are to become smart and controlled remotely, this will likely lead to quite substantial resource use, as Int.Org., thought. Is it then more sustainable, as Int.Org. suggested, to strive for flexibility at a higher "level", perhaps allowing for whole households' electricity supply to be steered down? It does not seem likely that this would be socially acceptable for most people.

Smart grid sustainability imaginaries

Imaginaries are shaped by the current needs and challenges of a techno-epistemic network (Ballo, 2011). This was seen in the interviews, as many imagined smart grids in terms of how they may improve grid operations (see Figure 2). This also shaped how interviewees imagined SGs would be more sustainable than "traditional grids". SGs, by enabling demand flexibility, can both solve capacity shortages and decrease the need for physical infrastructure. In the same way, SGs are imagined as facilitating grid maintenance, which would supposedly allow for longer-lasting equipment. The ways in which SGs were imagined as more *socially* sustainable were also shaped by how stakeholders thought grid operations would change for the better, e.g., through more efficient and cheap grid operations, leading to more affordable and reliably supplied electricity to customers.

Since the dominating view seems to be that SGs are inherently resource efficient as well as environmentally beneficial, it is important that this does not lead to missing to research or address possible drawbacks. It is vital that ideas such as "adding some extra technological components is more resource efficient compared to constructing new grids", do not "disguise" the environmental effects of the extra components, or what can be done to increase resource efficiency in SGs. There is otherwise a risk that the willingness to de-carbonise the electricity system leads to substantial material needs, as previously described is a problem in many low-carbon technologies (Xu et al., 2020; Richter, 2022; Liang et al., 2022).

Methods discussion

Since the literature search was conducted on "title" only, relevant results will have been excluded from this study, both in resource use and social sustainability. Furthermore, more search phrases could have been included, such as terms related to "flexibility".

A problem with interviews is subjectivity. All information given will be from the interviewee's point of view, and the respondent might want to portray its organisation in a better light. The latter issue should have been minimised given that all interview results were anonymised, but it is possible this might still have impacted the results. There was a tendency of interviewees in the private sector to be more "technology optimistic" regarding the different sustainability impacts of SG technologies. The relatively big number of respondents contributed to a variance of answers, however, and helped to reduce the impact of individual biases.

Social sustainability in the supply chain emerged as a theme in the inductive analysis of the interviews but was only brought up by one respondent, which can be understood since the social sustainability interview questions were mainly leaned towards the user perspective.

7. Conclusions

7.1 Conclusions and answers to research questions

1) **How are circular economy, resource issues and social sustainability aspects of smart grids investigated and covered in previous academic research?**
Circular economy and resource issues in connection with SGs have so far not been extensively covered in previous academic research. Most of the identified literature focused on LCA. Of these, only one considered other environmental effects than CO2-emissions. Social sustainability issues have been covered to a greater extent, from the perspective of how users can be made to contribute to the SG system, what aspects are important for SG acceptance among users, and how SG implementation may impact, and be impacted by, issues like for instance household incomes.

2) **How do different stakeholders in smart grid development and research…**

a) **Imagine the future smart grid user?**
Generally, the interviewees imagined a user that mainly contributes with flexibility, is motivated by economic incentives, and relies on automation to simplify use.

b) **Reflect on social sustainability issues in connection to smart grids?**
Interviewees suggested that smart grid use will benefit electricity consumers, although distributional injustices were viewed as a problem by some. Data privacy and cyber security were seen as the most important risks of SG use.

c) **View aspects concerning circular economy and material resource issues?**
The respondents thought SGs are resource efficient due to their potential to decrease the need for grid infrastructure. Overall, problems connected to resource use did not appear that widely discussed, although recycling and life-time aspects in SG technologies seemed to be a rising concern. Some examples of hiring/leasing and reuse surfaced, although not in connection to "specific"[3] SG technologies.

[3] Energy allocation control devices, e.g., smart metres

7.2 Practical Implications and Recommendations

Recommendations to policy makers

1. **Offer economic support and information to households who wish to buy technologies such as PVs, heat pumps, etc.** The literature review suggested that economic support to people who would otherwise not have afforded SG technologies was deemed important for SGs to be perceived as just. Thus, economic support to less affluent households is potentially not only important to decrease distribution injustices and achieve more extensive adoption of small-scale renewables, but also to increase SG acceptance.
2. **Open the discussion about privacy and security issues in SGs.** It seems that public concerns about SG risks is low in Sweden. While this might seem as positive for SG implementation, users should be informed about risks prior to adopting technologies. Otherwise, mistrust could follow, with decreased acceptance for future SG initiatives as a result.
3. **Encourage and support more diverse SG research.** This study has shown that SGs have been researched very scarcely from a circular economy perspective. More research is also needed on how users may contribute with co-design and energy saving.

7.3 Ideas for future research

Due to time and resource limitations, no document study was included in this thesis. A document study would have contributed to a better understanding of Swedish policy contexts for SGs, and served as a means of triangulation, complementing the interview data.

Another idea for further research is aggregators. This was a topic that surfaced in many of the interviews, of which the interviewees had differing opinions. Some saw aggregators as an integral part of the future energy system while others questioned if they are necessary. It also seems unclear, from a regulatory standpoint, which stakeholders may be allowed to become aggregators.

Furthermore, important questions remain unanswered after this thesis, possibly the most pressing being, if SGs are, in fact, more resource efficient than "conventional grids". Estimations of the extra material needed to realise SGs, perhaps using different scenarios of SG system complexity, material recycling levels and technological lifetimes, would help in analysing this. Apart from assessments of SG “material intensity”, estimations of to what extent demand flexibility could decrease physical infrastructure are needed. Also, if SGs should prove to be more resource efficient, how does the environmental impacts of the materials needed to realise them (e.g., REEs, critical metalloids) compare to the materials that they replace (iron, copper, aluminium)?

While this study showed some examples of leasing, renting and reuse, this was not in connection to “specific” SG technologies. It would be relevant to explore the potential of circular business models, other than recycling or increasing the lifetime of products, in reducing environmental impacts from SG technologies.

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Appendix 1. The Swedish electricity system

Electricity use in Sweden could rise to 310 TWh by 2045, an 120% increase from today, if current investment plans in, e.g., battery factories, fossil- free steel, and electrification of the transport sector are realised (Gode et al., 2021). This would mean grid investment needs of 668 billion until 2045, as recent estimations have shown (Krönert & Bergerlind, 2022). 53% of costs would be reinvestments in existing infrastructure that needs replacing. The biggest investments are due 2026-2035 since this is when the technical lifetime of current grids is reached (Krönert & Bergerlind, 2022). Since this prognosis, Swedish energy companies have asked for a discussion of how the investments should be financed. The energy minister stated that, as a part of the solution, a new market model that benefits SGs should be promoted (Borglund, 2022).

To handle these future challenges in the electricity system, the Swedish government recently published *Elektrifieringsstrategin,* a document containing strategies for the electrification of society (Regeringen, 2022). The document states that Sweden's electricity and grid capacity issues must be solved to not hinder the ongoing electrification. Measures in three areas are needed: (1) making more efficient use of the current grid capacity, (2) increasing the construction of new grid infrastructure, and (3) ensuring a sufficient inflow of capacity to the grid. To make better use of the current capacity, increased flexibility is portrayed as key. This can be achieved by increasing energy storage capacity, but also by increasing demand flexibility, i.e., shifting the demand to times that benefits the electricity system. *Elektrifieringsstrategin* does not specifically mention "smart grids", but states that digital solutions that can provide better governance, analysis and optimisation should be promoted (Regeringen, 2022).

The grid is composed of transmission and distribution grids, the latter consisting of regional grids that transport energy from the transmission grids to local grids. Most end-users are supplied by the local grid. The transmission grid is owned by the authority *Svenska Kraftnät,* while electricity network operators (hereafter called network operators) own the regional grids. Network operators have a monopoly on the grid, meaning that it is not possible to choose which operator to connect to. To own and operate a grid, a special permit called a concession, is needed. Concessions are issued by the Energy markets Inspectorate (Ei), the responsible regulatory authority for the network operators (Svenska Kraftnät, 2021b).

Network operators operate under the rules of monopoly, and they are therefore not allowed to participate in the de-regulated energy market. In *3 kap. 1§a in Ellagen* (1997:857), "*The Electricity Law"*, it is stated that network operators are not allowed to produce or store energy, apart from covering grid losses or providing extra power during outages.

The network operators' expenditures are divided into operating expenditure (OPEX) and capital expenditure (CAPEX). OPEX is composed of running costs that the company cannot influence, e.g., taxes, and manageable costs. Examples of the latter are operational and maintenance expenditures, i.e., factors that the network operator can influence. Companies are obliged to reduce their manageable costs by 1-1,82% per annum. There are no such obligations regarding CAPEX. Companies benefit from increasing CAPEX in relation to OPEX (Næss-Schmidt et al., 2017).

Current smart elements in the grid

In 2018, the Swedish government decided to implement new demands on functionality for electricity metres, the old metres are therefore now to be replaced, at the latest by 2025. The main reasons for the switch of metres are to aid consumers that are interested in energy preservation and enable cheaper micro-production. The new meters can measure a greater variety of data and are equipped with a user interface that enables reading of data every 10 seconds, and the metres register the amount of transferred energy every 15 minutes. Furthermore, they register power outages and enable the network operator to upgrade the metres, as well as disconnect the power, remotely (Konsumenternas Energimarknadsbyrå, 2021)

The frequent measurements of the smart metres enable electricity customers to choose hourly-based electricity agreements. These incentivise the customers to adapt their energy use to suit real-time supply (Energimarknasdsinspektionen, n.d.).

Another smart element in the grid is local flexibility markets. A stakeholder, e.g., industry or aggregator[4], that can decrease its use of electricity or increase electricity production temporarily may sell this ability as a flexibility service. The buyers of this flexibility are regional grid owners and *Svenska Kraftnät*, who owns the transmission grids. For them, the flexibility markets are a means of handling local capacity shortages (Svenska Kraftnät, 2021a).

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[4] An energy service provider that either adapts the electricity consumption of a group of consumers to the electricity demand on the grid or operate on behalf of prosumers by selling their excess electricity (Malizou, 2018).

Appendix 2. Smart grid initiatives

The following section will give a short overview of some important SG initiatives and research projects in Sweden and abroad. It should be noted that this list of organisations and initiatives is not exhaustive.

An important international initiative on SG issues is *The International Smart Grid Action Network (*ISGAN). ISGAN is a technology collaboration programme of the IEA that works with SG development and information spreading to governments and actors across the world to promote more sustainable and resilient grids. (ISGAN, n.d.).

In 2012, the Swedish government decided about the committee directive 2012:48: *Samordningsrådet för smarta elnät* ("The committee for smart grids")**.** The committee's mission consisted of holding dialogue forums, establishing a knowledge platform about smart grids, and putting forward suggestions for a national action plan for the development of smart grids. The Swedish government official report SOU 2014:84 *Planera för effekt* was issued in 2014 by the committee, finishing their work (Sveriges riksdag, 2014).

Forum för smarta elnät ("Forum for smart grids") was started in 2016 after a government decision with background in the need pointed out by *Samordningsrådet för smarta elnät* (2012) for a neutral platform enabling broad cooperation around smart grids. During its operation time from 2016 to 2019, the Forum's tasks were to promote and develop a dialogue about smart grid opportunities and develop a national strategy to promote smart grids as a Swedish growth industry. In total, The Forum issued 13 reports on different aspects of smart grids (Energimyndigheten, 2021).

The research programme *Smarta Elnät* ran from 2014-2018 and was led by the research- and knowledge company *Energiforsk*, owned by various Swedish energy companies. *Smarta Elnät* was concluded with a synthesis report of the results of the different research projects that ran during the programme period. One of these projects was *Smarta elnät - för vem**?*** (Katzeff et al., 2018), "Smart grids - for whom", that is described in this thesis.

Appendix 3. Swedish smart grid research projects

The project *Smarta elnät – framtidens elnät för alla?* (Smart grids – the future electricity grid for all?) ran from 2017 to 2021 at Linköping University. This project took a social justice angle at smart grids, investigating questions of income disparities, integration, and social deprivation. It investigated who are at risk of being excluded from smart grids, but also how the identified groups' needs may be used to create smart grids that work against exclusion. (Linköping University, n.d.).

TRUSTnEnergy is a current research project held by Energiforsk aimed at investigating the importance of trust in relation to households' role in smart grids, with a specific focus on automation. The main research questions are: "What factors decide whether trust is created in relation to different actors and technologies in the smart grid?" and "What consequences does the trust in automation of the electric grid have in the development of a sustainable future grid and energy system?" (Energiforsk, n.d.).

A current research programme at Uppsala University is *USER (Uppsala Smart Energy Research Group)***.** The goal of *USER* is to increase the knowledge of electricity customers and prosumers in the realisation of the future smart grid. The research is focused on user behaviour and socio-technological perspectives on demand flexibility, decentralised production, storage, and electric vehicles, as well as products and services related to these areas (Uppsala University, 2022).

Appendix 4. Interview protocol

Intro:

1) What is your role in your company/organisation?

- What do you work with/what are your tasks? For how long have you worked with these?

2) What do smart grids mean for you? How would you define smart grids?
3) Do you work with smart grid questions at your company/organisation?
    - How/in what way do you work with smart grids?
4) How many projects connected to electricity futures and smart grids do you work on?
    - What role does sustainability play in this work?

Social sustainability:

5) What aspects connected to social sustainability do you see as important in the development of smart grid?
6) How do you think that the (end) user will look like in smart grids (for the smart grid technology to be socially sustainable)?
    - What role/roles will the user have (demand flexibility, energy saving, prosumer, as a co-developer of smart grid technologies)?
    - What level of involvement will/should be demanded from the smart grid user (from a very active involvement to a high level of automation)?

- Is the smart grid user on his/her own, separate households, or could there be a development where users cooperate?

7) How should people be motivated into using smart grid technologies? *E.g.: more information, economic incentives, concerns for the environment, making use as easy as possible through automation, nudging, etc?*

8) What problems/possible conflicts regarding social sustainability could be important in the development of smart grids? *E.g., Injustices in how/for whom smart grids are developed and who stand to gain (economically) from the technologies (rich/poor, young/old, tech-savvy/people with limited technology skills); Different perceived risks among users with smart grids (e.g., privacy intrusion, use of data, cyber security) - how can these concerns be mitigated/handled?*

Circular economy / Resource use

9) Some companies that sell high quality equipment to the electric grid would like to have the possibility to lease and provide maintenance for this equipment, making it last for a longer time. However, they don't perceive this as (economically) feasible given current regulations. What is your opinion about this?
10) What do you know about the environmental impact of smart grid technologies when considering the production stage, material use included (e.g., LCA)?
    - Do you think there is a need for more LCA studies? Do you make LCAs?
11) What is your view of material and resource use in smart grids?
12) Are resource questions something that is discussed in your organisation/in the smart grid industry?
    - If so, how? What aspects are raised? *For example scarcity of different materials, waste issues?*
13) How much extra resources will be needed for the realisation of smart grids (if you compare with the resources already needed for, e.g., modern

information and communication technologies or renewable energy technologies)?

- To what extent will it be possible to use existing infrastructure for smart grids, thereby avoiding the need to manufacture new components?
- What different solutions do you see /are discussed in the smart grid industry? E.g., substitution of materials, making components last longer, recycling, development of new business models, etc.?

14) Could smart grid technologies (as opposed to using more resources) make the electric grid more resource efficient, for example by reducing the need for grid extension?

Concluding questions

15) What do you think the future electricity system will look like?
16) Is there anything we forgot to ask, or something you would like to add?

Appendix 5. List of interviewees

Table A1. List of interviewees

Code/name	**Date of interview**	**Interviewee description**
Energy company 1 – EC1	18th of March 2022	Business developer at an energy company, currently working with grid issues. Has also worked with energy issues at the company: solar power, charging, energy storage, energy systems in buildings and flexibility issues.
Research Institute 1 – RI1	18th of March 2022	Researcher and project leader at a research institute where he works with sustainability in data centres. Civil engineer in energy systems with a doctor's degree in energy technology, worked as an electrician before that.
Technology Company 1 – TC1	21st of March 2022	Responsible for ESG (Environmental, Social and Governance) strategy at an international company that manufactures smart metering solutions. The company has around 5000 employees and operates in nearly 30 counties, it also has operations in Sweden.
Government Agency 1 - GA1	22nd of March 2022	Project leader and analyst at a Swedish governmental agency working with energy issues. The interviewee is at the agency's analytics department where she works with investigations, scenarios and a wide range of issues concerning the electricity market and electrification.
County Administrative Board - CAB	23rd of March 2022 (mail interview)	The interviewee is employed at a county administrative board where she is a project leader for a project that is partly concerned with smart grids.
International organisation - Int.Org.	25th of March 2022	Renewable energy analyst at an international organisation that works with energy issues. The interviewee oversees medium-term forecasts for renewable energy capacity. Has a background as a mechanical engineer specialising in energy systems.

Energy Company 2 – EC2	25th of March 2022	Business developer at a network operator, has an engineering degree within energy systems. The interviewee works with designing the grid and planning for new grid connections. Within this work, she looks at solutions to increase flexibility in cases where the grid does not have enough capacity.
Regional Council – RC	25th of March 2022	Works at the department of regional development at a Swedish region. Works with environmental issues and energy supply. Engineering background in machine technology, has also worked in the private sector
Research Institute 2 – RI2	29th of March 2022	Industrial doctoral student at a research institute. Has a background in machine technology. Researches solar energy, battery storage and electric storages in buildings.
Energy Company 3 – EC3	30th of March 2022	Program leader for a smart metering rollout program at a network operator.
Consultancy company 1 – CC1	31st of March 2022 (informal interview)	Management consultant at a consultancy that specialises in digitalisation. Educational background in economics.
Government Agency 2 – GA2	31st of March 2022	Employee at a government agency's research and innovation department. Energy engineering background. Works with flexibility in electricity systems, e.g. flexibility/capacity markets.
Consultancy company – CC2	5th of April, 2022	Partner at a consultancy firm specialising in the power sector. Works with network operators and grid issues in general. Holds a Master of Science in industrial economy.
Technology company 2 – TC2	5th of April, 2022	Manager of product development, and research and development manager at a Swedish technology company that supplies equipment to electric utility companies.

Government Agency 3 – GA3	6th of April, 2022	Analyst at a Swedish governmental agency, works with energy issues.
Research institute 3 – RI3	7th of April 2022	Works at a research institute with smart grid projects, Doctor of Engineering in wind power and frequency regulation.
Research institute 4 – RI4	7th of April 2022	Doctoral student at a research institute, researches energy transition from a societal perspective. Especially interested in local energy systems and de-centralisation.