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New Ownership Models Shaping the Electricity System Transition

Evidence from Sweden

Master's thesis in the Master's Programme Management and Economics of Innovation

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ABSTRACT
It is becoming increasingly clear that with the transition to an electricity system based on renewable production, not only the production units will be replaced, but the socio-technical system will also have to be resketched. Thus, questions of how to efficiently organize the system structure arise. The possibilities are vast; both production and ownership could to various degrees be decentralized, or remain in the hands of central actors. Consequently, the aim of this master thesis is to examine what ownership models for renewable electricity production are emerging in Sweden, how these relate to the traditional ownership model in the Swedish electricity sector and in what way these new ownership models are changing the system. Secondary literature sources are used to construct a design space, allowing for visualization of different possible ownership models. Using data from semi-structured interviews with respondents from both the industry and academia, different ownership models within the Swedish electricity system are conceptually mapped. The findings from this thesis suggest that the Swedish electricity system faces socio-technical lock-ins to a centrally owned large-scale production, but that decentralized ownership models are increasingly becoming part of the Swedish electricity system. Thus, the Swedish electricity system appears to incorporate a hybrid solution, where decentralized ownership of small-scale production, in the form of prosumer-to-grid solutions, exists alongside large-scale centrally owned production.

Keywords: Ownership models, Socio-technical system transition, Renewable electricity production, Decentralization, Smartgrid, Supergrid, Off-grid, Design space

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Sincerely,
Linn Karlsson and Anna Viktorsson

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1. Introduction

Electricity systems in most industrialized countries have evolved into centralized systems, with power plants and grid infrastructures owned and operated by a few regulated monopolies (Hannon, Foxon, & Gale, 2013). This is also the case in Sweden, where the electricity system was built as a centrally owned and operated value chain. However, the centralized electricity design is changing with the increasing penetration of renewable energy technologies and storage at both the production and consumption side of the value chain. As a consequence, the ownership and operation of electricity production, networks and storage is increasingly decentralized (DNV GL, 2019; Miglani, Kumar, Chamola, & Zeadally, 2020; Pinson et al., 2017). The decentralization trend can also be spotted in Sweden (Byman, 2017). In particular, the installed photovoltaic (PV) capacity has increased in recent years. According to Lindahl and Stoltz (2018), the cumulative installed PV power in distributed on-grid systems was about 294 MW in 2017. Especially the share of distributed on-grid PV installations has increased rapidly in recent years, and accounts for the by far largest market share (96%) within the PV sector in Sweden (Lindahl & Stoltz, 2018). In the shift towards renewables, the sector experiences an increasing variety of investors (Bergek, Mignon, & Sundberg, 2013). In fact, Bergek et al. identify that a considerable amount of the investments in Swedish renewable electricity production has come from emerging investor types, which typically do not correspond well to the conventional image of energy investors.

The shift from a fossil-fuel based electricity system to renewables has been extensively studied by the sustainable transition and innovation scholars (Bidmon & Knab, 2018; Bolton & Hannon, 2016; Engelken, Römer, Drescher, Welpe, & Picot, 2016; Hall & Roelich, 2016). Although most of the transition and innovation research has been preoccupied with the development and diffusion of renewables, it is becoming increasingly clear that renewable energy transition is not only about replacing electricity generation technologies. Instead, the change in technical components of the electricity system is influenced and accompanied by changes in actor structures and institutions that govern their interaction (Bidmon & Knab, 2018; Bolton & Hannon, 2016; Boons & Lüdeke-Freund, 2013; Farla, Markard, Raven, & Coenen, 2012; Sabatier, Craig-Kennard, & Mangematin, 2012; Smith, Voß, & Grin, 2010). In fact, the research focus on the importance of social and institutional change in the renewable energy transition has increased recent years. In particular scholars argue that the shift from fossil fuel-based electricity generation is challenged from the socio-technical lock-in of dominant technologies (Jacobsson & Bergek, 2004); i.e. their embeddedness in social and institutional structures. It is therefore argued that the shift in generation technologies must be accompanied with a societal shift. Such a perspective has been advocated by numerous scholars, who conceptualize the renewable energy transition as a socio-technical process (Bidmon & Knab, 2018; Brown, Hall, & Davis, 2019; Jacobsson & Bergek, 2004; Smith, Stirling, & Berkhout, 2005).

For example, the connection between new business models and diffusion of renewables is increasingly studied (Bolton & Hannon, 2016; DNV GL, 2019; Engelken et al., 2016; Hall &

Roelich, 2016). Scholars believe that business model innovation can change the institutional arrangement of actors in the electricity industry, and can facilitate the breakthrough of renewables from a niche to the mainstream market (Bidmon & Knab, 2018; Doganova & Eyquem-Renault, 2009; Massa & Tucci, 2013) as well as disrupt change-resistant ‘unsustainable’ industries (Bidmon & Knab, 2018; Johnstone et al., 2020).

However, the role of business models in relation to the renewable energy transition and the influence on the configuration of the future system based on renewables remains unknown (Bidmon & Knab, 2018; Hall & Roelich, 2016). We argue that to better understand the role of new business models in shaping the renewable energy transition, one needs to take a step back and study the increasingly complex ownership and operation structures in renewable electricity systems (generation, network and storage) that have a direct influence on how costs and benefits are redistributed, and arranged in new business models.

1.1. Aim and Research Questions

While it is clear that the previously centralized ownership and operation structure of the Swedish electricity system is changing, little is known about the new structures that are emerging (Byman, 2017). This thesis aims to contribute to a better understanding of new ownership and operation structures and their influence on the Swedish electricity system transition towards renewables. Hence, in this master thesis we aim to answer the following research questions:

- What ownership models for renewable electricity production are emerging in Sweden?
- How do new ownership models relate to the traditional ownership model in the Swedish electricity system?
- How are new ownership models changing the Swedish electricity system in the transition towards renewables?

1.2. Thesis Outline

The thesis is structured as follows. First, a background provides an overview of the Swedish electricity system and the technological enablers challenging the established system. Next, a literature study presents the more recent focus on socio-technical dynamics. Based on the literature review, we build our analytical framework. Next, the methodology describes our data collection and analysis processes, followed by the analysis of our qualitative interview data. The findings are discussed in the discussion section and finally summarized in the conclusions.

1.3. Background

To understand the electricity system transition in Sweden, we argue that one first has to get an overview of how the sector up until now has been organized, as well as how recent technological advancements bring new preconditions.

1.3.1. The Swedish Electricity Sector

The electricity-generation that has been dominant for the past decades in most developed countries is, at an aggregated level, primarily represented by centralized, large scale power technology (Brown et al., 2019; DNV GL, 2019; Nordling, 2017; Smith et al., 2005). Internationally, the traditional electricity system is powered predominantly with fossil-fuel based technologies such as coal-fired steam turbines and gas-fired combined cycle turbine systems (Smith et al., 2005). In Sweden however, the share of electricity generated from fossil fuel is low, and instead a large amount of the electricity is generated from nuclear plants. In 2018, 41 percent of the Swedish electricity came from nuclear plants (Statistiska centralbyrån, 2019), making it the predominant electricity generation in the country.

As of now, the Swedish electrical grid is divided into three categories; the national grid, the regional grids and the local grids (Nordling, 2017). The national grid is a transmission grid, whereas the regional and the local grids are so called distribution grids (Nordling, 2017). Svenska kraftnät, the Swedish transmission system operator (TSO), is responsible for the national grid, but also holds responsibility for the entire Swedish electricity system including delegating the responsibility for the, from a technical perspective, crucial system balance (Nordling, 2017).

The three largest electricity producers in Sweden, Vattenfall, E.ON and Fortum, are multinational energy companies that together still produce a majority of the electricity in the country (Lauber & Sarasini, 2014). Vattenfall, E.ON and Ellevio are the three largest grid companies and have a strong market position, as they are responsible for the supply of more than half of Sweden's electricity users (Nordling, 2017). A large share of the Swedish grid companies have less than 15,000 customers, making the grid both a fragmented market and a market with natural monopolies (Nordling, 2017). In the absence of competition between grid companies, the Swedish Energy Markets Inspectorate has the responsibility to ensure that customers are not overcharged (Nordling, 2017). Additionally, the Swedish market is regulated from EU level to counteract the occurrence of natural monopolies. Through the regulation of unbundling, i.e. separating network operators from production, trade, metering, sales and other core activities (R. Künneke & Fens, 2007; Wizelius, 2014), one tries to achieve fair competition.

1.3.2. Technical Advancements Challenging the Status Quo

New technologies allow for the energy system to become more complex by, for instance, connecting actors and systems in new ways (Hall & Roelich, 2016). Examples of such technologies are smart meters and energy management systems (Hall & Roelich, 2016). Thereto, the rising mass production of PV technologies has led to steep learning curves, which in turn opens up for longer operation times and thus new applications (Engelken et al., 2016). Moreover, the prices of PV's are decreasing, enabling further diffusion of the technology (Lindahl & Stoltz, 2018; Ren21, 2019). As an effect, market structures are changing. In particular, as stated by Miglani et al. (2020), distributed electricity resources such as PV's allow for energy producers to generate and sell electricity at end user level instead of relying on top-down, centralized, utilities. For example, consumers are becoming prosumers, i.e. actors that both produce and consume electricity, by investing in decentralized energy resources and trading the electricity between themselves (Morstyn, Farrell, Darby, & McCulloch, 2018; Zafar et al., 2018). Hence, technical development enables a decentralization of the electricity system.

However, technical development has also enabled further centralization of the electricity system. Today, large wind power plants have great scale benefits and generate electricity at a notably lower cost than what can be achieved using small scale wind power (Nordling, 2017). Hence, it is not likely that local or small-scale units of wind power will appear in the future (Nordling, 2017), which makes it difficult for smaller actors to enter this market (Mignon & Bergek, 2016). The increasing amount of wind power plants, which have lower variable cost compared to electricity plants such as nuclear plants, lead to changing cost structures (Byman, 2017). Specifically, in windy periods, markets with high levels of wind power generation experience decreased prices (Byman, 2017). In these periods, electricity plants with high variable costs will experience fewer operating hours, making investments in these plants less popular (Byman, 2017).

Although new technologies offer potential for the Swedish electricity system, previous studies indicate that integration is not seamless. Lacking grid connection made many Swedish projects for new renewable energy technologies more expensive, which could be seen as a system-level challenge for adoption of new renewable energy technologies (Mignon & Bergek, 2016). Moreover, it typically takes a long time for investments in renewable energy technologies to reach break-even, and the low, fluctuating electricity prices in Sweden increase the financial risks (Mignon & Bergek, 2016).

From a technical perspective, one of the issues that the production of renewable electricity is faced with is that the production can be uneven and difficult to match to demand (Brijs, De Vos, De Jonghe, & Belmans, 2015; Quiggin, Cornell, Tierney, & Buswell, 2012; Zhang & Feliachi, 2003). Not only does the production of renewable electricity tend to be uneven and dependent on weather conditions (Gordon, 2006; Quiggin et al., 2012), but the demand from customers is often also fluctuating (Strbac, 2008; Zhang & Feliachi, 2003). Thus, the price of renewable electricity is often volatile, and has at times even been negative in some markets (Brijs et al., 2015), including Sweden (Lindholm, 2020). Hence, the difficulty to balance supply and demand appears to be one major technical constraint in the transition to renewable energy (Quiggin et al., 2012). However, the cost decrease of lithium ion batteries has opened up for the possibility to store electricity in new ways, offering a possibility to even out demand and supply (Hartwig & Kockar, 2016; Nordling, 2017).

Today, the Swedish electricity system has the potential to manage sudden loss of large production plants as well as handling plants with high output variety (due to for instance weather changes) (Nordling, 2017). However, according to Nordling, hydropower plants will in the future play an important role as reservoirs for such variations. Sweden has a long tradition of using hydroelectricity, and in 2014 hydroelectricity accounted for nearly half of the generated electricity in the country (Lauber & Sarasini, 2014). However, as most hydro plants are located in the northern parts of Sweden, where also future wind power plants are expected to be built (Nordling, 2017; Svenska kraftnät, 2019), simultaneously as the nuclear power plants in southern Sweden are being phased out (Svenska kraftnät, 2019), significant transmission capacity increases will be required for the transportation of electricity to southern and central Sweden (Byman, 2017; Nordling, 2017; Sataøen, Brekke, Batel, & Albrecht, 2015; Svenska kraftnät, 2019). Otherwise, the cost of operation can increase since generators with high marginal costs will have to be used (Strbac, 2008).

With the integration of more renewable electricity production, the importance of the electrical grid increases. For example, the grid plays an important role by connecting remote plants and balancing the input from renewables, which tend to offer high fluctuations (Nordling, 2017). Additionally, Nordling suggests that if increasing amounts of electricity from prosumers would flow into the Swedish grid, a more complex grid role would be required. Higher energy efficiency, better load control and more advanced battery technology together with new production technologies may turn local grids into self-sufficient units (Nordling, 2017).

Hence, with the emergence of new technology and goals to completely decarbonize the electricity system being set world-wide (Bidmon & Knab, 2018; Georgeson, Maslin, & Poessinouw, 2016; Johnstone et al., 2020; Smith et al., 2005; Wegner, Hall, Hardy, & Workman, 2017), the preconditions of the system structure are changing. Thus, just like other countries', the Swedish power system undergoes a rapid shift, following from political decisions and the development of new technologies, as well as the succeeding changes in user patterns and new application areas for electrical power (Svenska kraftnät, 2019).

2. Literature Review

Although technological evolution has been important in enabling a possible change in the electricity system, a technological perspective is not enough to fully understand system changes (Bidmon & Knab, 2018; Bolton & Hannon, 2016; Boons & Lüdeke-Freund, 2013; Farla et al., 2012). In particular, the electricity system suffers from strong lock-in effects in the form of policies favoring established technologies (DNV GL, 2019; Jacobsson & Bergek, 2004), negative externalities that are not fully priced by the market (OECD, 2003; Pearson & Foxon, 2012) and the occurrence of natural monopolies (R. W. Künneke, 1999; Wizelius, 2014). Therefore, a wider, socio-technical perspective is necessary when studying the electricity transition. There are essentially two different strands of research used to conceptualize socio-technical transitions: technological innovation systems and the multi-level perspective (Markard & Truffer, 2008). Essentially, these two conceptualizations use different perspectives to examine processes of innovation and socio-technical transformation, but offer complementary approaches (Markard & Truffer, 2008). In the following section, these two different strands of research will be introduced. Thereafter, the three electricity futures that are typically pictured will be presented and a conceptual representation of these three electricity futures is given. Finally, the importance of ownership is discussed.

2.1. Technological Innovation Systems

From a technological innovation system perspective, there are three component categories that together form the basis for the diffusion, adoption and application of a certain technology, namely actors, institutions and networks (Markard & Truffer, 2008). Thus, the systematic interdependencies of technologies, actors, institutions and networks form the basis to understand the emergence of a specific technology field (Bergek et al., 2015). In a sense, the technological innovation system perspective could be seen as an inward focused tool, analyzing the internal functions of new technological systems, rather than the external context it operates in (Simmie, 2016).

From a technical innovation system perspective, all blocking mechanisms preventing new technology to enter the market suggest that policy plays an important role in guiding the direction of search and stimulating market growth (Jacobsson & Bergek, 2004; Pearson & Foxon, 2012). Previous studies have shown that creating successful policies for the integration of renewable electricity production is complicated but nonetheless very important (Jacobsson & Bergek, 2004; Standal, Talevi, & Westskog, 2020; Wizelius, 2014). In particular, policies enabling ownership of actors outside of the dominant energy system have been an important precondition for the transition towards renewable power systems (Wizelius, 2014). As of today, studies indicate that small actors in Sweden are facing obstacles such as a complicated and expensive process of connecting to the grid (Mignon & Rüdinger, 2016), further illustrating the need for policy support. However, policy formulation requires high coordination between agencies throughout the existing system, but if successfully managed, policies can create positive feedback loops (Jacobsson & Bergek, 2004).

Still, Jacobsson and Bergek (2004) suggest that pricing policies and other economic incentives are not sufficient to cause the institutional alignment needed for system change to take place.

Jacobsson and Bergek claim that supporting variety in knowledge creation, market formation and legitimacy building for the new technology are institutional efforts needed for new systems to emerge. Some scholars argue that intermediaries play an important role in creating alignment of interests, building capacity and forming markets (Lukkarinen et al., 2018). In particular, technological innovation system researchers have examined the role of intermediaries in the Swedish electricity sector, and concluded that intermediaries that facilitate the investment process for the adopters are more common in Sweden than in many other countries (Aspeteg & Bergek, 2020; Mignon & Bergek, 2016). Other scholars argue the importance of local authorities to reach energy policy goals (Betsill & Bulkeley, 2007; Collier & Löfstedt, 1997; Keirstead & Schulz, 2010). In Sweden, local authorities have been actively involved in the electricity system by, for example, owning companies that produce and distribute electricity (Collier & Löfstedt, 1997).

2.2. The Multi-Level Perspective

In a sense, the multi-level perspective looks for a wider societal explanation to socio-technical transitions compared to the technological innovation system approach (Simmie, 2016). In particular, the multi-level perspective pictures technological change as an evolutionary process that takes place at three conceptual levels, the landscape, the regime, and technological niches (Geels, 2002; Smith et al., 2010). In the multi-level perspective, technological niches are seen as ‘incubation rooms’ for radical innovations, where the innovations are allowed to mature in terms of technical performance, cost and gain support from a network of supporting actors (Geels, 2002) and thus gain stability to compete with other mainstream technologies (Smith et al., 2010). Technological niches are protected from socio-technical regimes, which are to be understood as dominant socio-technical structures formed from a co-evolution of knowledge, investments, technical artifacts, infrastructures, values and norms spanning along technology or sector specific production-consumption system (Smith et al., 2010). Both niches and regimes are influenced by processes at the landscape, conceptualized as an exogenous environment (Geels, 2002), that the niche and regime actors cannot directly influence (Geels & Schot, 2007). The sociotechnical landscape reinforces deep structural trends that typically take decades to change (Geels & Schot, 2007).

The fit to the current socio-technical regime and the sociotechnical landscape determines the survival of novelties (Geels, 2002). Thus, for new technologies, the regime often initially acts as an inhibiting factor (Rotmans, Kemp, & Van Asselt, 2001). However, as the socio-technical regime is not static, changes in the socio-technical landscape may provoke the socio-technical regime to change, opening possibilities for new technologies to find their way into a socio-technical regime (Geels, 2002; Smith et al., 2010).

Regimes may be seen within other sets of regimes, making it of importance to be specific as to what is meant when applying the concept of socio-technical regimes (Smith et al., 2005). For example, at an aggregated level, the electricity-generating regime that has been ruling for the past decades in most developed countries is primarily represented by centralized, large scale power technology (Brown et al., 2019; DNV GL, 2019; Nordling, 2017; Smith et al., 2005). At the level of individual power technologies, the global regime covers a variety of technologies, such as coal-fired steam turbines, the nuclear fuel cycle, large-scale hydroelectricity and gas-fired combined cycle turbine systems (Smith et al., 2005). Within the system, a niche for renewable energy, for example wind and solar power, is emerging (Smith et al., 2005; Wegner et al., 2017). Thus, one could instead choose to view for instance the 'embryonic' wind power niche as a regime, and thereby find assumptions, built-in features and public policy support therein too (Smith et al., 2005).

2.3. Three Future System Solutions

With technical advancements, different conceptualizations of what the future electricity regime might look like have emerged. One of the potential pathways for the electricity system that previous studies have imagined is supergrids. Supergrids are considered to be one of the main options to reach a renewable energy system (van Hertem & Ghandhari, 2010). Ideally, a supergrid could offer unlimited amounts of renewable electricity by connecting remote, large scale renewable energy generation to national grids (Gordon, 2006; Purvins et al., 2011; van Hertem & Ghandhari, 2010). A supergrid could thus be defined as a large scale centralized model, similar to the model that is typically operated today, but with higher transmission capacity (Blarke & Jenkins, 2013). It is argued that a supergrid can even out the fluctuations of renewable electricity generation since it will aggregate the generation over a large geographical area and provide electricity where it is most needed at that moment (Gordon, 2006).

However, the success of a supergrid is highly dependent on governmental support (Gordon, 2006), especially considering the high level of coordination that will be needed (van Hertem & Ghandhari, 2010). Moreover, since investments in a supergrid are large and risky (Macilwain, 2010), it is unlikely that one single actor is willing or able to invest by themselves (van Hertem & Ghandhari, 2010). Thus, some presume that such investment would be done either by a consortium of several large companies, such as generator companies, grid owners or others, or directly or indirectly by governments (van Hertem & Ghandhari, 2010).

Even though supergrids have gained a lot of attention from politicians and the press, there is still skepticism regarding the technological viability of such system (van Hertem & Ghandhari, 2010). That said, one of the technologies offering the largest potential for supergrids are high voltage direct current (HVDC) cables (Nordling, 2017). Today, eight percent of the transmissions in new installations goes via HVDC (Nordling, 2017). However, the technology is promising. HVDC cables are well suited for offshore wind, since it works well in both water and on land, as well as for system integration of large PV plants and batteries, as these produce direct current (Nordling, 2017).

Beside supergrids, smartgrids are considered a possible solution for a future electricity system. Smartgrids are expected to utilize distributed energy resources and advanced information and communication technologies to deliver the cheapest electricity to customers at any given moment (Arjomand, Sami Ullah, & Aslam, 2020; Purvins et al., 2011). By using storage and relocation of electricity, a large amount of the electricity in the smartgrid can be generated from renewables (Blarke & Jenkins, 2013). A smartgrid can be seen as a self-managed energy system which uses smart meters and other ICT solutions to become more efficient (Blarke & Jenkins, 2013). Some claim that the decentralization that a shift towards a smartgrid entails requires more local and regional coordination, making it difficult for large energy companies that are distant from customers to compete (Hvelplund & Djørup, 2019). Also, since the demand variation increases as the size of the network decreases, the balancing problem is expected to increase for decentralized networks (Strbac, 2008).

With the emergence of new technological possibilities, one could also picture an off-grid solution (Cai, Adlakha, Low, De Martini, & Mani Chandy, 2013; Nordling, 2017). Leaving the grid has become an increasingly viable option, as PV's and batteries have become progressively cheaper (Hojčková, Sandén, & Ahlborg, 2018). Hojčková et al. suggest that although off-grid solutions were previously primarily seen as options for poor countries, the attitude towards off-grid solutions has changed. Nowadays, off-grid solutions are increasingly seen as an option for the integration of renewable production within existing electricity sectors (Hojčková et al., 2018). However, studies indicate that off-grid systems are currently both more expensive, and offer lower reliability compared to grid connected systems (Liu, Azuatalam, Chapman, & Verbič, 2019).

2.4. A Conceptual Representation of the Three System Solutions

Hojčková et al. (2018) have created a model in which they distinguish three idealized renewable electricity systems referred to as dependent, interdependent and independent systems of consumers (Figure 1). These three electricity systems closely correspond to the previously described supergrid, smartgrid and off-grid visions.

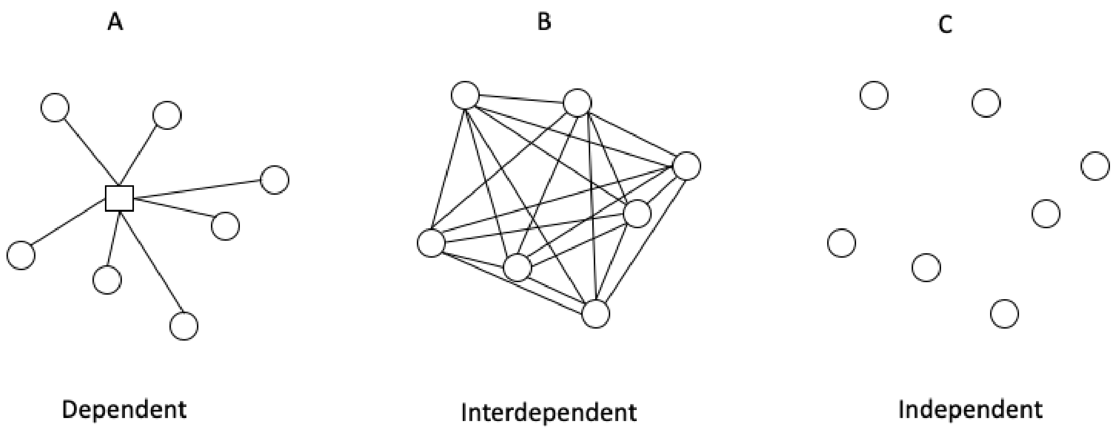

Figure 1: Conceptual illustration of the three idealized renewable electricity systems (Hojčková et al., 2018)

Stankiewicz (2000) argues that a design space can be used to illustrate technological evolution. A design space presents a number of operants that are extended to their limit, thus creating a space of what is theoretically possible, bound by its extremes (Stankiewicz, 2000). In their most extreme formats, the three systems described by Hojčková et al. (2018) are seen as the cornerstones in the design space (Figure 2) constructed at the intersection of the two parameters P (number of electricity production units) and G (the number of individual electricity grids). In its most extreme centralized cornerstone (A), the system consists of one production unit (P=1) and one grid (G=1). In the second cornerstone (B), all production units are also connected by one central grid (G=1), but the number of production units are the same as the number of consumption units (P=N). The third cornerstone (C) is the most decentralized system solution.

In this cornerstone the number of production units and the number of grids is the same as the number of consumption units (P=N and G=N).

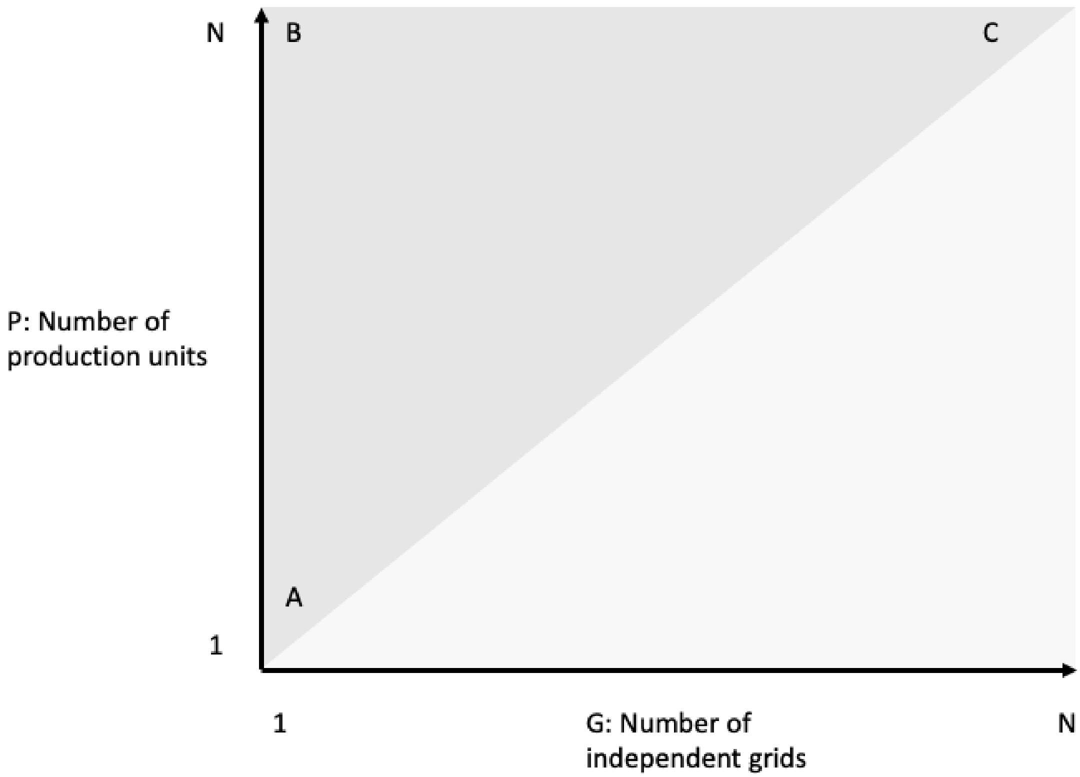

Figure 2: Design space of three idealized renewable electricity systems (Hojčková et al., 2018)

2.5. The Important Ownership Dimension

However, according to several researchers (Haney & Pollitt, 2013; Johnstone et al., 2020; Ofgem, 2015; Wizelius, 2014), an electricity system is not only defined by the number of production units and the number of independent grids, but also on the prevalent ownership structures within the system. As suggested by Haney and Pollitt, the electricity transition poses questions regarding which organizational models that are most capable of handling changes in capital requirements and markets, target social welfare objectives and allocate risks most efficiently. According to Wizelius, a sustainable energy path can be assured if sustainability evaluative criteria can be paired with ownership models and goals. Johnstone et al. and Ofgem also highlight ownership models as an important part of new business models in the electricity sector. Novel ownership models allow new actors, both private companies and publicly owned community organizations, to become investors, owners and producers of renewable electricity (Mignon & Rüdinger, 2016; Ofgem, 2015; Pinson et al., 2017). Some believe that by combining different ownerships, the most benefits may be reaped (Lindahl & Stoltz, 2018). Others suggest that joint ownership combining different owners, for instance public-private initiatives, or public ownership, account for the best system solutions (Haney & Pollitt, 2013).

It appears that consumer ownership of electricity resources promotes efficiency, since the ownership helps to educate consumers and makes consumers more involved, committed and responsible (Lowitzsch, 2019). According to Wizelius (2014), there seems to be a trend of customers owning their own power plants and thus producing their own electricity on the Swedish electricity market. This trend manifests itself on different levels. Customer ownership can be on an individual level, meaning that the customers install stand-alone systems without any connections to the electrical grid (Wizelius, 2014). Alternatively, customers can own power plants that are connected to the grid and utilize contractual net metering, meaning that customers have the right to use the same amount of electricity as they fed into the system at a later time (Palm & Tengvard, 2011; Wizelius, 2014). Customer ownership can also be manifested as a cooperative solution, where power consumers (such as households, farmers, companies or similar) own and operate power plants together (Lindahl & Stoltz, 2018; Magnusson & Palm, 2019; Wizelius, 2014). Moreover, both globally and in Sweden, companies have increasingly started to invest in their own power plants and thus produce the electricity that is used in house (Bergek et al., 2013; Ren21, 2019; Wizelius, 2014). For example, real estate companies have used the fact that they can produce, transmit and use electricity tax free, if the electricity is never sold or bought (Wizelius, 2014). Bergek, Mignon and Sundberg identify that a considerable amount of the investments in Swedish renewable electricity production has come from emerging investor types, which typically do not correspond well to the conventional image of energy investors.

However, to our knowledge, no comprehensive framework for ownership and operation models currently exists. Thus, in the following section, a framework based on the design space introduced by Hojčková et al. (2018) is constructed.

3. Design Space

Whilst the two-dimensional framework presented by Hojčková et al. (2018) can provide a tool to explore the diversity of possible renewable energy futures, it does not recognize the importance of the ownership dimension. However, based on the understanding of different possible ownership models and their importance to the system transition, the framework presenting the three idealized renewable electricity systems (Hojčková et al., 2018) can be expanded to include the third operant O, representing the number of operators or owners. According to Stankiewicz (2000), design spaces can be modified, either by adding new operants (i.e. dimensions) or by restructuring and rearticulating. Hence, in this study, we explore the possibility of expanding the design space presented by Hojčková et al. to a three-dimensional model including the dimensions P (number of production units), G (the number of grids in the world) and O (number of operators or owners), which can all range from 1 to N. This model is applied to the Swedish electricity sector. Henceforward, the three-dimensional model is referred to as the POG design space, illustrated in Figure 3. The corners in the POG design space represent six idealized system configurations, or in other words different possible ownership models.

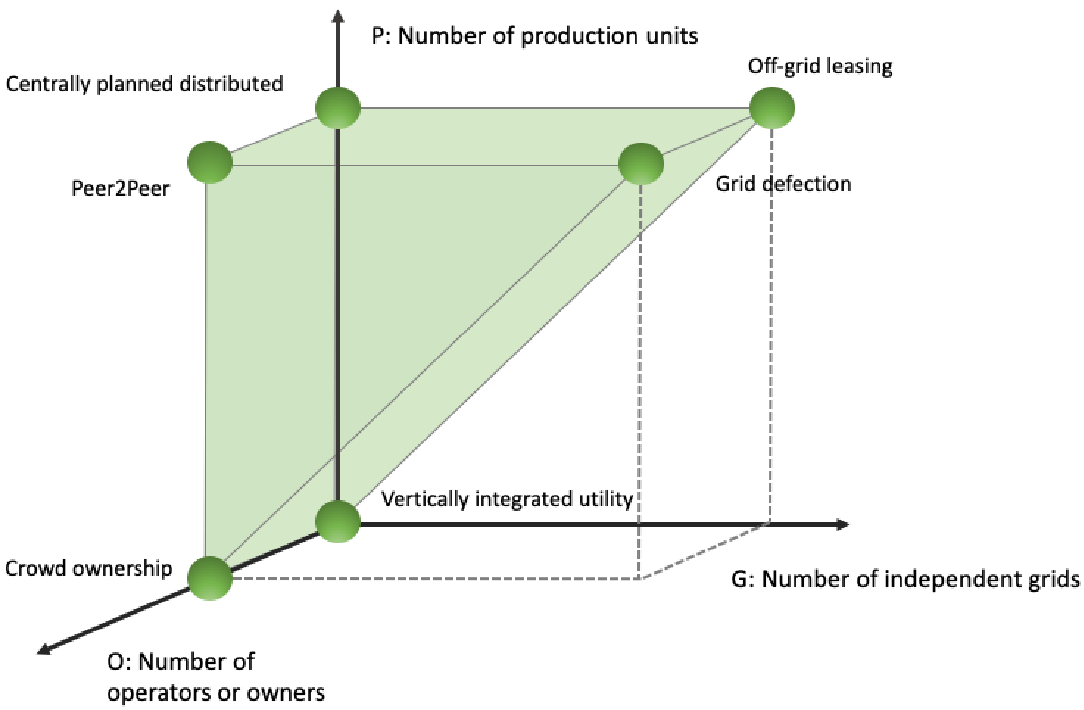

Figure 3: the POG design space with each corner marked and named.

3.1. Vertically Integrated Utility Model

In the corner where all variables are low, we find the model where there are large production plants and grids, while the number of owners remain small. In its most extreme, the corner represents a system with one production plant (P=1), one centralized grid (G=1) and one owner (O=1).

Historically, the Swedish electricity system has been dominated by large scale centralized ownership, similar to the vertically integrated utility model. Today, the Swedish energy market mainly consists of a few, large incumbents, such as Svenska kraftnät, which manage the national grid and Vattenfall, E.ON, Fortum which, together with a small number of large, regional companies, are the main actors in the energy production (Mignon & Bergek, 2016). The large incumbents have gained large influence and often have impact in the energy policy making (Mignon & Bergek, 2016). Thus, these incumbents have extended their role from electricity production and trade, and have become an institutionalized part of the market structure. New entrants are therefore dependent on incumbents such as Svenska kraftnät to connect to the grid, and may also have incumbents that tries to influence the policy making to disadvantage new entrants by making the policies adapted to the incumbents (Mignon & Bergek, 2016). Additionally, Svenska kraftnät is investing to improve and expand the Swedish grid and integrate information technologies (Nordling, 2017; Svenska kraftnät, 2019). In particular, the north-south transmission capacity as well as the capacity in urban areas will be strengthened (Svenska kraftnät, 2019), which makes a continuation of the vertically integrated utility model possible.

3.2. Crowd Ownership Model

In the corner where the number of owners is high (O=N), while the number of production plants as well as the number of grid operators remain low (P=1, G=1), one finds crowd ownership solutions. The type of crowd ownership initiative that is most common in Sweden is wind cooperatives, but some PV cooperatives have emerged in recent years (Lindahl & Stoltz, 2018; Magnusson & Palm, 2019). Examples of wind cooperatives in Sweden are for instance SVEF (Sveriges Vindkraftkooperativ Ekonomisk Förening), Storuman vind and Åre vindkooperativ. Several municipally owned energy companies, such as Mälarenergi and Kalmar energi have started cooperatives which companies or private persons can buy shares of (Lindahl & Stoltz, 2018). In Sweden, renewable electricity cooperatives mainly exist as economic associations (ekonomisk förening) (Mignon & Rüdinger, 2016). Generally, the purpose of most electricity cooperatives is to generate cheap electricity to its members and sell the surplus electricity to the grid (Kooij et al., 2018).

Scholars have claimed that lack of finance, marketing, professionalization and legal constraints are seen as obstacles preventing cooperatives from scaling up (De Bakker, Lagendijk, & Wiering, 2020). Additionally, competitive pressure can put pressure on cooperatives to turn into professional organizations (De Bakker et al., 2020), or give less autonomy to members (Kunze & Becker, 2015).

3.3. Centrally Planned Distributed Model

At the top of the P-axis, the centrally planned distributed model is found, with a high number of production units (P=N) owned by one owner (O=1), connected in one grid (G=1).

Although it appears to be most common that companies or private households own their own PV, an emerging business model is the leasing of PV (Lindahl & Stoltz, 2018). Even though the market for PV leasing currently appears small in Sweden, Lindahl and Stoltz identified three companies, Eneo Solutions AB, Umeå Energi and ETC El, that have emerged in such a business model. Leasing can remove several barriers of adoption, through for example reducing up-front costs and the need for financing, and reducing complexity and risk, and thus reach younger and less affluent parts of the population (Drury et al., 2012).

3.4. Peer2Peer Model

If one takes the centrally planned distributed configuration but increases the number of owners, one ends up in the corner where the model referred to as Peer2Peer (P=N, G=1, O=N) is located. The number of customers equals production owners and operators collaborating on a centralized grid.

A decentralized energy system where individual prosumers collaborate by producing and trading energy amongst each other is typically referred to as Peer2Peer (Giotitsas, Pazaitis, & Kostakis, 2015; Hackbarth & Löbbe, 2020; Sousa et al., 2019). One may also imagine that several smaller Peer2Peer networks can be connected through the grid into a larger system (Giotitsas et al., 2015). In a Peer2Peer system, any prosumer could theoretically exchange electricity with any other prosumer (Pinson et al., 2017). Since all participants in such a system negotiate simultaneously, prices of electricity will converge towards a common value (Pinson et al., 2017). Although the viability of Peer2Peer systems is being questioned, some believe that the rise of Peer2Peer platforms has lowered the transaction costs enough to make Peer2Peer trading a possible system set up (Morstyn et al., 2018).

Some scholars claim that the electricity security in a Peer2Peer system is high, since the system will be able to produce and distribute electricity even if one part of the system collapses (Giotitsas et al., 2015). Moreover, energy losses can be minimized since most of the electricity will be produced and consumed locally (Giotitsas et al., 2015; Hackbarth & Löbbe, 2020). In addition, Hackbarth and Löbbe argue that Peer2Peer electricity trading and dynamic pricing can incentivize prosumers to adapt their electricity consumption based on real time prices, but also drive investments in energy storage systems. Peer2Peer trading may reduce the overall cost of the community using it, and even more so the more diverse the demands within the community are (Hackbarth & Löbbe, 2020).

3.5. Grid Defection Model

All of the hitherto mentioned four configurations, or design space corners, are built on the assumption that there is essentially one independent grid. If one increases the number of independent grids while remaining at a system solution with a high number of owners and production plants, this ends up in a typical off-grid configuration. That is, in the extreme case, each and every one provides themselves with their own electricity (P=N, G=N, O=N). Thus, this corner will from now on be referred to the grid defection corner, and corresponds to the most extreme off-grid scenario.

Some scholars argue that with the emergence of the prosumers, electricity users may end up self-sufficient, and eventually go off-grid if the benefits of staying connected to the grid appear small (Cai et al., 2013; Morstyn et al., 2018; Nordling, 2017). As the number of prosumers increases, the consumed electricity from the grid decreases (Cai et al., 2013). However, the utility companies have large fixed costs that do not decrease proportionally with the consumed electricity (Cai et al., 2013). Thus, the electricity prices are likely to increase as consumption from the grid decreases, driving more consumers to becoming prosumers (Cai et al., 2013). Due to higher urbanization, the price of electricity for those staying in non-urban areas is increasing, which could further drive an off-grid movement (Nordling, 2017). Besides an economic incentive to go off-grid, some adopters of small-scale production want to go off-grid as a step towards self-sufficiency or a protest towards the establishment (Palm & Tengvard, 2011).

3.6. Off-grid Leasing Model

Lastly, if one pictures an electricity system solution where the number of owners remain low (O=1), while at the same time there is a very decentralized production (i.e. a high number of production plants, P=N), and a high number of independent grid operators (G=N), one would end up in the corner that is henceforward known as off-grid leasing. The typical example of this ownership model in a Swedish context would perhaps be that state owned Vattenfall, or perhaps the Swedish TSO Svenska kraftnät, leased PV to customers while remaining in control of the entire system. Although there are some examples of companies pursuing a business model reminding of this system model solution, for instance Werel (Tångring, 2016), the overall interest for system off-grid leasing system solutions in Sweden seems limited.

4. Method

In this section the method used in this thesis will be explained. Firstly, the research design of this study is introduced. Thereafter, the data sampling method is explained, before the data collection process as well as the data analysis process are described. Lastly, questions regarding the research quality are discussed.

4.1. Research Design

In this thesis, a qualitative research process was used. A qualitative approach allows to examine a field of research to establish variation, rather than to quantify it (Kumar, 2011). Semi-structured interviews were used as primary data source, containing a mix of standardized and open questions, allowing for comparison between the interviews while providing flexibility to adapt the questions as needed (Walliman, 2017). As the subject of this thesis appears to be underexplored (Bidmon & Knab, 2018; Hall & Roelich, 2016), semi-structured interviews are suitable, although time consuming, as they make it possible to study a uncertain field of research where quantifications are difficult to establish (Kothari, 2004).

In this thesis, a design space is expanded and tested towards a set of interview data. Hence, the research process began with constructing an analytical framework, the POG design space, based on literature review. In the following, the interview guidelines were constructed and interview transcripts were analyzed having our analytical framework in mind. Thus, the research process corresponds to a typical deductive approach, meaning that we started with a theory that later resulted in specific conclusions (Gauch, 2013; Tracy, 2019), as illustrated in Figure 4. While we are aware of alternative forms of reasoning, such as inductive and abductive, we chose a deductive approach. Since our literature study suggested that there might exist a third variable determining the shape of different system solutions, we chose to first build on existing theory, and then test the viability of it in a Swedish context. Thus, after we had expanded the design space to include a third operant, we tested the design space to appraise how validly it could offer a categorization of different system configurations.

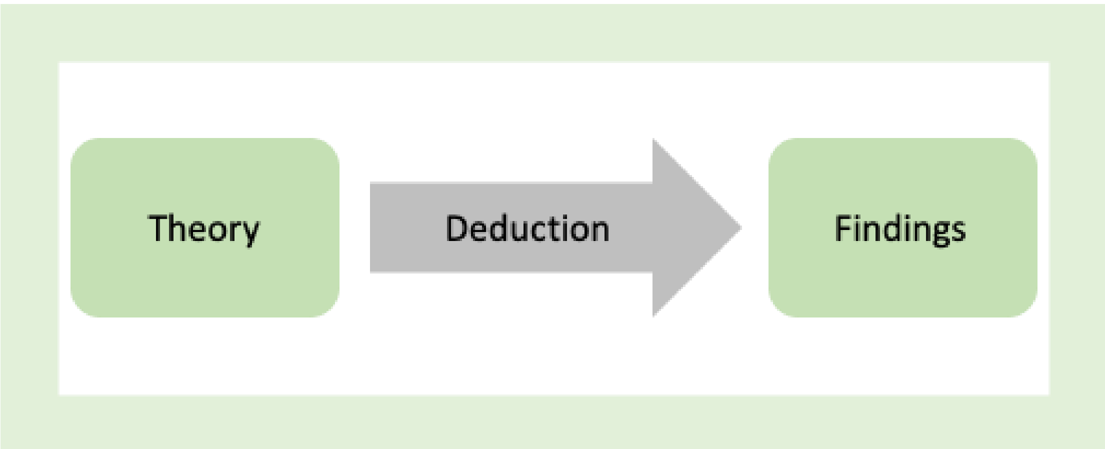

Figure 4: Process of deduction

4.2. Data Sampling

When conducting research, it is typically difficult to sample all parts of the population relevant for the study (Walliman, 2017). Consequently, choosing a consistent sampling process is of high importance, since poor sampling can lead to validity issues (Walliman, 2017).

Considering the focus of the thesis on the transition and innovation in the Swedish electricity sector, non-random i.e. judgement sampling method was used to identify selected experts and industry representatives with exclusive knowledge that can provide valuable insight in the sector. Judgement sampling is based on the idea that logic, common sense and sound judgement is enough to form a representative sample (Habib, Pathik, & Maryam, 2014).

Our goal was to interview a broad set of actors, including representatives from incumbent firms, smaller new firms, cooperative experienced professionals and researchers from the energy field. Moreover, we aimed at finding respondents who could provide diverse perspectives on the electricity sector. Some of the respondents had both experience from academia and the industry, making it difficult to give exact numbers of the two different groups, but approximately half of the interviewed sample came from academia.

Initially, we had contacts to two respondents working within the field of renewable electricity production in Sweden. In addition, our supervisor, Kristina Hojčková and our examiner, Björn Sandén, were helpful in connecting us to people working with, or researching, renewable electricity. Some of the respondents were found without any prior contact or suggestion, based on our judgement that they could provide valuable insights. This corresponds to convenience sampling (Etikan, Musa, & Alkassim, 2016).

In total, twelve respondents participated in this study and out of these, ten respondents were interviewed individually, while the last two were interviewed at the same time. The reason two participants were interviewed simultaneously was that these two respondents had worked together in a project that was of specific interest to us. Actually, only one of the two was first contacted, but this person asked to be accompanied with his/her colleague. For this study, the comfort of the respondents, and thus adhering to their preferences, was judged more important from a methodological perspective than carrying out eleven identical interview settings.

4.3. Data Collection

We created two standard interview guides, one in English and one in Swedish, that can be found in Appendix B and C. Although the interview template was standardized for all the interviews, we decided to add individually tailored questions that were deemed necessary to gain additional insight. As semi-structured interviews are by definition flexible in terms of additional and unforeseen input from respondents, we believe that adding individualized questions was methodologically sound.

Before carrying out the interviews, a pilot interview with a person working in the power industry was conducted. This person works as a project manager within an established engineering consultancy firm in Sweden. After the pilot interview had taken place, the respondent was asked how the interview felt and if something could have been done differently. Based on this discussion some minor corrections were done in the interview template. The pilot interview also made it possible to test if the number of questions and the time frame were reasonable. From this pilot interview, we found that approximately 30 minutes were sufficient to go through our interview questions.

However, as we progressed with our interviews, it became apparent that the time needed varied a lot from respondent to respondent. The most distinct and quick interviewee answered all questions in about 15 minutes, and this can be compared to the 50-minute-long interview that was held with another respondent. As we had no restrictions of time spent on interviewing our respondents, we tried to follow the respondents' pace and stick to the level of efficiency and formality that we felt that each interviewee appreciated.

As suggested by Galletta (2013), we started by making sure that our respondent knew of her or his rights during the interview, more specifically that the respondent could take a pause when needed, did not have to answer any questions and was free to end the interview, and made sure that it was fine for us to record the interview. We argue that we have taken consideration to ethical issues by being as honest as possible throughout the research process, including when conducting the interviews. Moreover, before conducting each interview, we made sure to inform each participant about the aim of the thesis and how their answers would be used. We asked the respondents if they preferred to remain anonymous or if we could give their names. A list of all of the respondents, some anonymous and some with names, is presented in Appendix A. After this information was shared with our respondents, we continued by asking about the respondents' work experiences, as this was both important for our understanding of the respondents' expertise areas, and a subject that the respondent was likely to feel comfortable speaking freely about. We allowed the respondent to speak freely without interruptions, to establish a comfortable setting (Galletta, 2013).

We continued by asking questions that were tailored to provide input for our research questions. To begin with we focused on the respondent's past experiences. Here, we tried to steer the respondent towards the topic relevant for our research questions. Eventually, we also started asking more general questions, while searching for connections between general statements and their personal experiences, as suggested by Galletta (2013). To finalize the interviews we allowed our respondents to express additional inputs and thoughts, which Galletta claims is important. Specifically, the respondents were asked if there was something they thought we had missed out on, or if there was something else they thought might be of importance for us to understand the topic. We finished the interviews by thanking the respondents for their inputs.

4.4. Data Analysis

There are a number of steps to take when analyzing qualitative data. We followed a process that was proposed by Galletta (2013). Thus, first, after every interview, we carefully reflected on our experience and impressions as well as what could be improved. Next, we organized, transcribed and stored the interview data to keep it accessible for analysis, but also to ensure the confidentiality of the information. We thereafter manually transcribed all of the recorded interviews. After we had transcribed, we highlighted interesting quotes in each interview to find thematic patterns. To do so, we used a data analysis tool, Mindomo, to systemize these quotes in a mind map. The six corners in the POG design space were used as nodes. We added subnodes if quotes were connected to more than one of the six corners in the design space. All of the nodes and subnodes were bound together by lines representing connections, to illustrate which quotes were important for several of the corners in the POG design space.

When analyzing the results, we searched for patterns suggesting different understandings from researchers and professionals. Apart from the fact that the researchers sometimes provided more theoretical analysis to their answers, we were only able to distinguish one difference between researchers as a group and professionals as a group. This difference related to the practical integration of different components, something that two of the industry professionals highlighted as time consuming and complex. For researchers, and also for industry professionals not working closely to the technical integration of components, what mattered was that the integration could be done, rather than to what extent and to what cost it could be done.

4.5. Research Quality

At first sight, one might suggest that our thesis is trying to predict the future, and thus could be categorized as futures studies. However, we suggest, similarly to Cuhls (2003), that what some call foresight may, when looking closer, actually tell us more about the present than about the future. Thus, we argue that reflecting our interview data to a possible idealized future is a reasonable approach, and should not be categorized as futures studies.

To ensure data quality when conducting interviews, we interviewed a broad sample of respondents with various perspectives on the transition to renewable electricity production. As some of the interviewees came from academia, while others were industry professionals, we argue that a broad range of perspectives were included. Additionally, the respondent sample included individuals with experience within the sector spanning from approximately two to thirty years, which we suggest ensures data quality by both accounting for experience, but also newer perspectives. To further validate the data, we looked for compatibility within the data sample and with literature. The different measures taken to ensure data quality are illustrated in Figure 5.

Figure 5: Process of ensuring data quality

4.6. Delimitations

In order to fulfill the aim and answer the research questions, analytical boundaries were set to create a clear course of this study. While there are numerous aspects of the electricity system transition, in this thesis, we delimit our scope to new ownership models in the Swedish electricity sector. We extend a framework categorizing idealized future electricity system scenarios, and add the ownership dimension to provide a deeper understanding of the complex changes in the electricity sector. We trial the framework on the case of the Swedish electricity system. While the scope of this thesis is limited to new ownership models in Swedish electricity system, we recognize that new ownership models could be studied in other sectors and within other countries too.

Moreover, this thesis focuses on the social and market related aspects of the electricity system in transition. As students from Management and Economics of Innovation, we are aware of our limited technology-related knowledge and experience and thus our inability to determine the technical feasibility of different solutions. Hence, we leave the technical judgement to our respondents with the right technical skill set to do so, and make use of our macroeconomic and socio-technical understanding to analyze their responses.

5. Findings and Analysis

In this section, the POG design space will be used to categorize the results from our empirical findings according to the theoretically extreme future scenarios in the POG design space, see Figure 6. This is done by examining what speaks in favor of the system moving in each direction, and what counteracts different system movements.

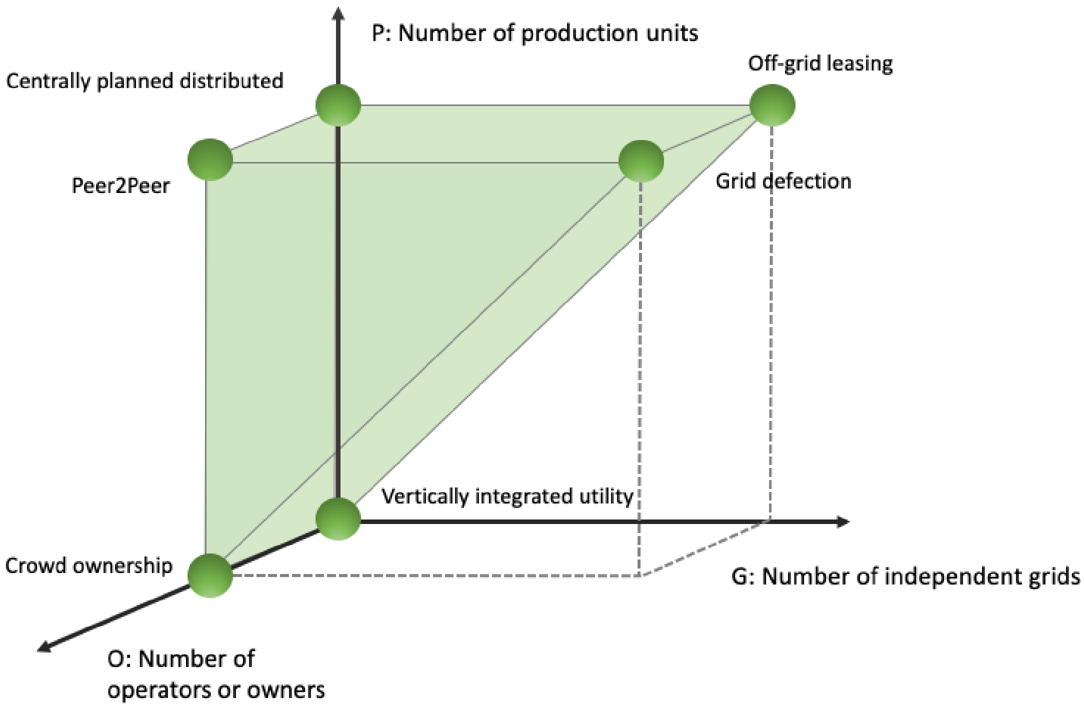

Figure 6: Different potential ownership models in their extreme formats

5.1. The Vertically Integrated Utility

In a Swedish context, the business models related to the vertically integrated utility model, see Figure 7, are similar to the ones on the market today, where customers pay for the electricity produced from large hydro, wind and nuclear plants while leaving all operation to utilities and grid operators.

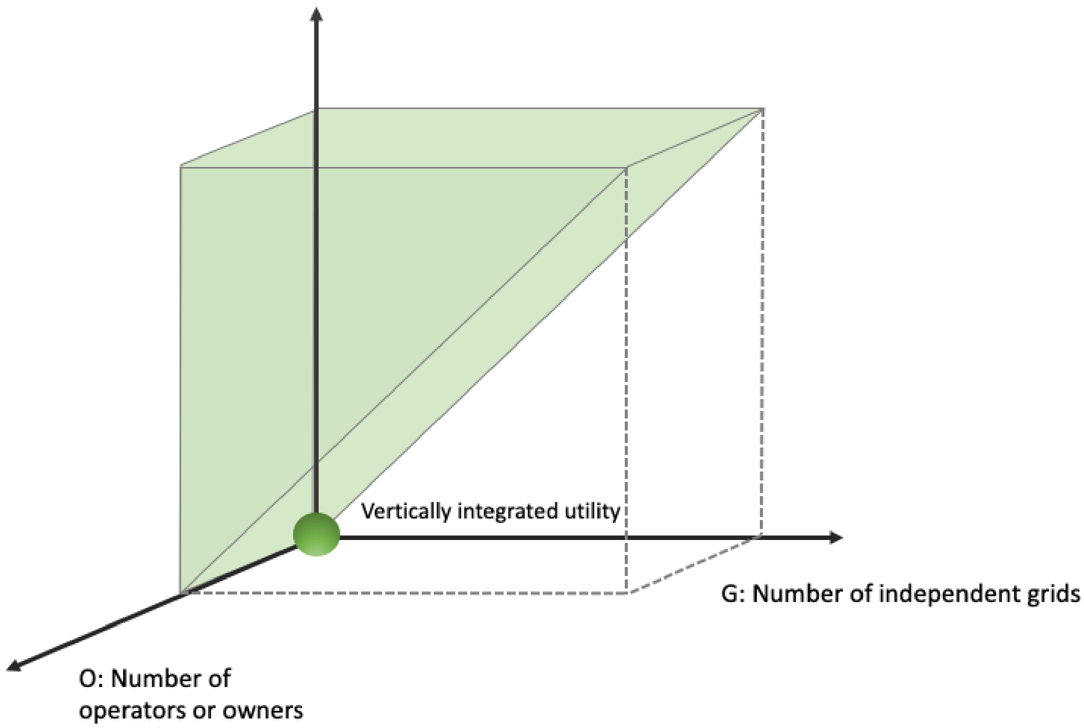

Figure 7: The vertically integrated utility model cornerstone in the POG design space

Incumbent firms, such as Vattenfall, E.ON, Fortum and municipal energy companies, are profiting from the way the sector is currently organized, and are thus naturally inclined towards a future ownership model with high levels of centralization. The vertically integrated utility model is also enabled by the construction of large-scale wind power plants, that are due to their size and costs owned primarily by incumbent energy companies or other actors with large amounts of investment capital (respondents). This ownership model is further supported by the current electricity market regulations that have been tailored for large power plants with a few large owners. Besides the regulatory advantage, one of our respondents argued that large incumbent companies pose substantial influence on regulatory decision making through established connections with politicians.

However, the economic features of centralized, large-scale production, appeal to actors outside of the traditional electricity companies as well. For instance, large companies are often willing to pay a set, predictable, price, even though it might be rather high, to ensure their electricity access (respondents). The respondents seem to perceive a combination of large power purchase agreements and economies of scale production as financial enablers for such predictability. To further eliminate investment uncertainty, subsidized network connections to offshore wind power plants were mentioned as a way to rapidly increase large scale production (respondents).

That said, less extreme forms of the vertically integrated model, as for instance split ownership solutions, are increasing (respondents). Split ownership models were mentioned by our respondents as a compromise between decreasing the risk and the cost of investment by sharing it between multiple actors such as municipally owned energy companies and other large companies, whilst still keeping the number of owners low enough to ensure control. These solutions can thus be seen as a less extreme form of the vertically integrated model, while still allowing for rather centralized ownership and, consequently, control.

While ownership and operation of electricity production are becoming increasingly decentralized, the grid infrastructure in Sweden remains centrally coordinated. However, with the increasingly decentralized electricity production and growing number of new actors in the electricity sector, new debates have arisen calling for legal changes that would open possibilities for new grid ownership and operation models (respondents). More specifically, some of our respondents viewed it as likely that policies would allow for the building of local grids in a near future.

Whilst these new debates have arisen, the current ownership structure is viewed as well functioning and with low emissions (respondent). Consequently, the incentives to change the status quo are weak. Centralized ownership and operation, especially by incumbent electricity companies, is perceived as necessary for safe delivery of electricity. Not only did most of our respondents agree that the current system is well functioning, many also expressed that while more decentralized production may be incorporated, the system will have difficulties without the large-scale production. Additionally, fears that a fragmented market could lead to coordination issues were raised by an industry professional. Thus, most respondents envisioned a future where decentralized production was incorporated to various degrees, but the bulk of the production came from large power plants with a strong owner that could provide stability and security, illustrating lock-in effects to a centralized system with large production.

5.2. Crowd Ownership

In Sweden, the crowd ownership model, as pictured in Figure 8, is mostly supported by cooperatives of small actors, such as individual electricity consumers, that together act as the owners of a large power plant. The number of Swedish cooperatives is today rather limited, but there are some examples of wind and PV cooperatives on the market.

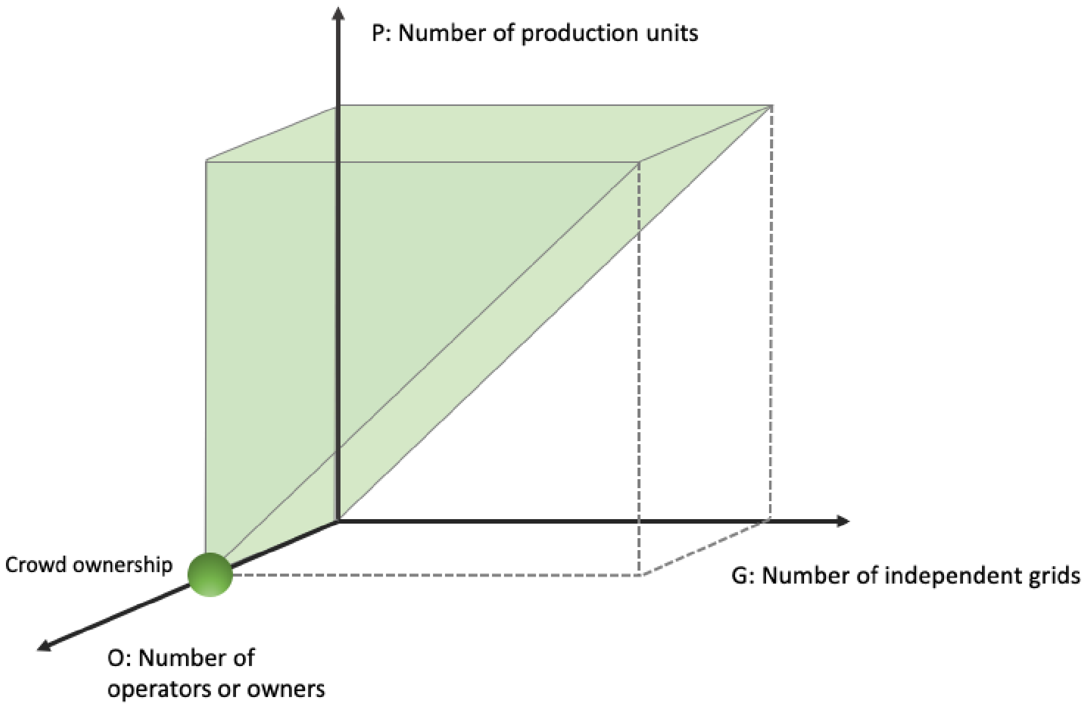

Figure 8: The Crowd ownership cornerstone in the POG design space

In Sweden, cooperatives are predominantly co-owning wind power plants. However, some of the respondents saw a potential in large scale PV parks when paired with cooperative ownership, even though the PV technology does not experience the same large-scale advantage as the wind power technology. Thus, there does not seem to exist any technological constraints to a crowd ownership model, and the ownership model was looked upon rather enthusiastically by some respondents, especially as it allows people who do not own their own houses to take part of a decentralized ownership structure. In fact, the crowd ownership model was by some respondents seen as the most inclusive and fair ownership model.

However, the enthusiasm was not shared by all of the interviewees. One of the respondents, who has studied and worked with wind cooperatives in Sweden for about 30 years, instead described the future of wind cooperatives as bleak. The weak potential of wind cooperatives in Sweden was supported by another respondent, who suggested that although most of the new investments in Germany take place in cooperative solutions, the landscape is different in Sweden. One of the main reasons for this seems to be lack of political support (respondent). Thus, one respondent had identified several wind cooperatives turning into corporations, as symptoms of legislations promoting a centralized ownership. For instance, there is a legal difference between economic associations, which is typically the legal form of cooperatives in Sweden, and corporations in terms of taxes. Specifically, this means that economics associations are subject to higher taxes (respondent). Even though the wind cooperative expert did not know of any instances where the regulation had been enforced, it raised costs by creating uncertainties and increasing the need for an economic buffer. Moreover, wind cooperatives are hindered by long building permission processes with unclear outcomes (respondents). One of the respondents also highlighted the need for contracts spanning long term, as cooperatives need to know that they can place their PV's or wind power plants somewhere for a long period of time. Specifically, this respondent suggested that municipalities may take on the role to lead such initiatives, by for instance signing long term contracts allowing for cooperatives to utilize municipally owned roofs.

Moreover, wind cooperatives cannot own their own electricity grid because a single actor is by regulation not allowed to own both production and grid infrastructure. As a consequence, the cooperatives have to pay high tariffs and taxes for utilizing the public grid to transfer electricity from their wind power plants to their homes (respondent). While the current grid fees reflect the price for long-distance transmission and distribution, cooperatives call for offset solutions that can better account for local electricity production and distribution (respondents).

The crowd ownership model seems significantly hindered by beliefs that centralized ownership is needed to ensure the required control and coordination levels. Some of the respondents even suggested that there has to be a "strong owner". Additionally, as explained by one of the respondents, the price decrease of wind power plants during the early 2000's implied that early cooperative members had difficulties to sell their shares without making a loss (respondent). Consequently, members of early wind cooperatives that invested in wind power plants in the 2000's, believe they paid "too much" for their shares (respondent). Hence, chances are that the public opinion of the cooperative electricity solution was damaged at this stage, which may create a barrier for future initiatives. At the same time, crowd ownership in the form of cooperatives might benefit from political incentives to counteract socioeconomic inequality stemming from a decentralized production, and spill-over effects of EU decentralization directives (respondents).

5.3. Centrally Planned Distributed

In a Swedish context, a centrally planned distributed model, see Figure 9, could entail centrally owned and operated, but at the same time distributed, production. However, in a centrally planned distributed model, the grid remains centrally owned and operated. A hypothetical example in a Swedish context would be that an incumbent, such as Vattenfall, owned distributed electricity resources for example either in the form of small-scale distributed electricity plants or by leasing PV's to customers. To our knowledge, this kind of model is currently not common on the Swedish market.

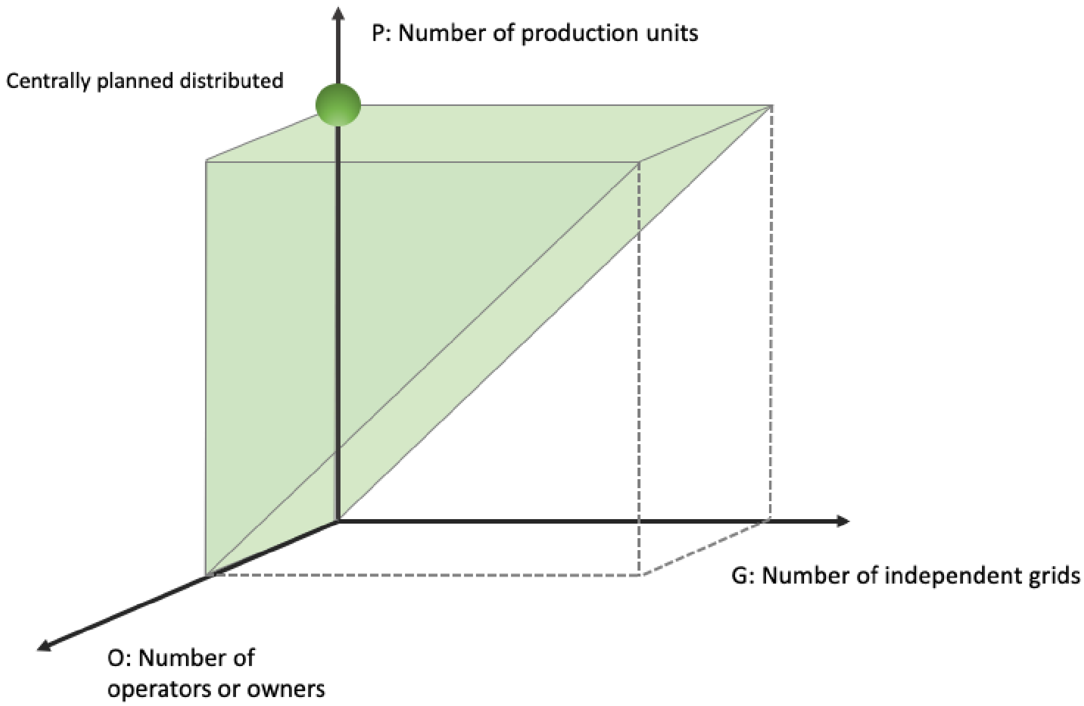

Figure 9: The Centrally planned distributed cornerstone in the POG design space

There seem to be different opinions on whether leasing or power purchase agreements will be the dominant future business model (respondents). However, as one of the respondents pointed out, both leasing solutions and power purchase agreements are very similar in their implementation, and carry practically the same function; to decrease risk and ensure predictability for the customer. Some of the respondents suggested that leasing models, or specifically third-party ownership, where the customers lease PV cells or buys the generated power to a predetermined price, are trending.

Others suggested that Vattenfall, one of the actors in the best position to own and operate distributed production, is selling decentralized solutions to customers. Thus, to some extent, Vattenfall appears to be accepting a future of customer ownership, rather than to strategically position themselves in a position of control, as one of our respondents pointed out. However, other incumbents, such as Umeå energi, have more clearly positioned themselves in a coordinating role by offering on-grid leasing solutions to customers (respondent).

5.4. Peer2Peer

In Sweden, the Peer2Peer model, see Figure 10, corresponds to distributed production units, such as PV's, owned by prosumers. These prosumers are connected by a grid that, with the help of smart technologies, allow for electricity to be traded between the actors. Currently, Peer2Peer solutions do not seem to exist commercially on the Swedish markets, but experimental solutions have been tested. What instead seems to be the current prosumer-based model on the Swedish market is a prosumer-to-grid solution, where prosumers trade with licensed electricity retailers as intermediaries.

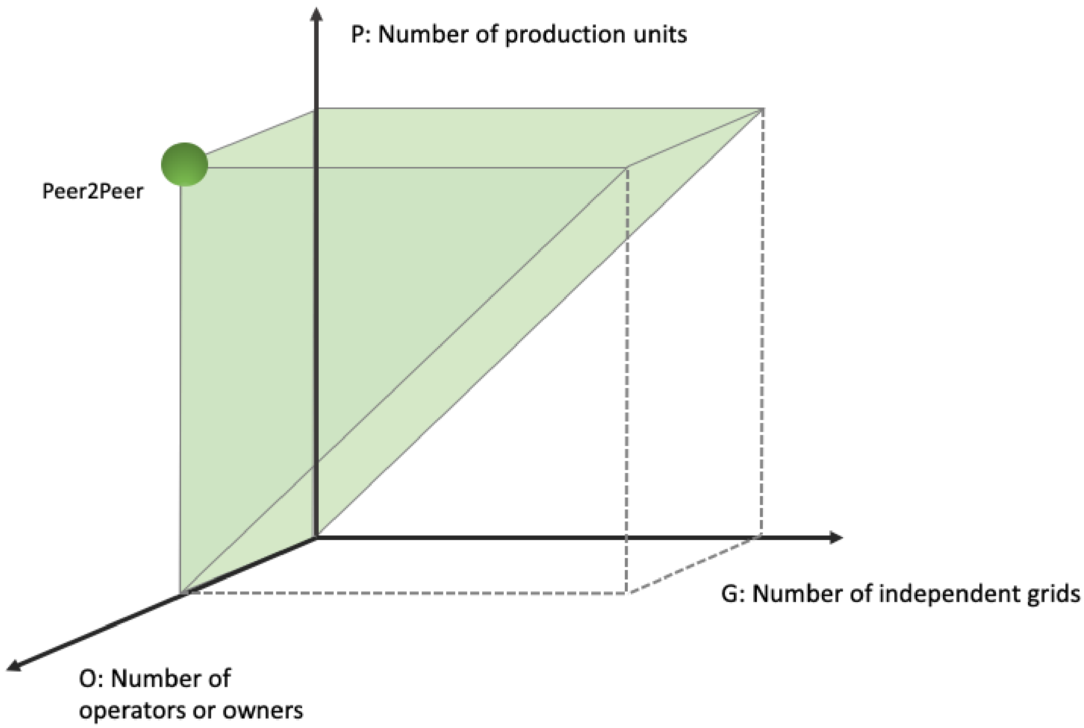

Figure 10: The Peer2Peer cornerstone in the POG design space

Technical developments have opened up for Peer2Peer trading in many ways. Most importantly, the development of PV's allows for decentralized production with a relatively cheap investment and essentially zero variable cost, making it possible for prosumers to generate their own, cheap electricity (respondent). In addition, digitalization is believed to lower the transaction costs and made it technically possible for smaller actors to communicate and trade electricity between each other. Moreover, the development of smart homes and small community initiatives with smart meters and integrated battery storage are supporting this ownership model, as they in the future are believed to make it possible to store excess electricity locally, or sell it to the grid with real time pricing.

To enable the perfect interconnectedness of a large number of prosumers, protocols for seamless smart ecosystem will be needed. However, an issue raised by one industry professional was the absence of protocol standards within the PV industry, preventing different components in a smart ecosystem to communicate with each other and making it difficult to efficiently integrate batteries in a decentralized system. Integrating older infrastructure in a Peer2Peer system was also mentioned, by another industry professional, as a technical difficulty. These interconnection problems affect any system with distributed electricity production, but appear especially strong for Peer2Peer solutions since they depend on seamless interconnection between a large number of prosumers. Thus, such technical barriers could be argued to hinder the potential of building smart ecosystems, which are important for enabling efficient Peer2Peer solutions.

As explained earlier, the Peer2Peer model depends on systems with large number of prosumers. Consequently, developing policies that can enable for more actors to become prosumers; i.e. to invest in their own electricity production units, are seen as an important (respondents). One respondent hypothesized that investments would increase further if housing loans included loans for PV installations. Additionally, the regulatory change giving PV owners the automatic right to connect their PV's to the grid was argued an important change facilitating Peer2Peer systems (respondents). Moreover, the government backed tax relief for small PV system investments could be seen as an enabler for increased number of prosumers in Sweden (respondents).

The Peer2Peer ownership model is supported by evidence that individuals are becoming prosumers not only for environmental reasons but also pure economic reasons (respondent). As Peer2Peer models will allow prosumers to make a profit of their electricity generation in the future, this model is attractive for a variety of prosumers such as housing associations, real estate companies, businesses and individual households. However, the current grid fees and taxes make trading between individual prosumers more expensive than business as usual. Consequently, as of today, the grid fees create incentives from prosumers to buy batteries and store electricity locally rather than selling it (respondent).

If the electricity system was to move towards a pure Peer2Peer solution, a digital trading platform where prosumers could trade electricity directly between each other would have to be developed. IT companies are believed to play a large role in supporting the Peer2Peer model by delivering the platform needed for Peer2Peer trading as well as finding ways to optimize energy usage and improving smart meters (respondents). Some respondents believe that incumbent electricity companies will start moving into the IT industry, whereas others picture that new or existing IT companies will replace traditional utilities. Either way, the electricity companies by regulation act as intermediaries, buying and redistributing the electricity from prosumers to the rest of the grid. Consequently, individual prosumers can only choose from licensed electricity retailers, such as Vattenfall, Fortum or EON, but are not allowed to choose another prosumer as an electricity provider. The design of Peer2Peer platforms is thus hindered by the existing electricity market regulations (respondents), giving utilities a competitive and regulatory advantage in contrast with IT companies.

Despite the regulatory advantage, utilities seem to find this highly decentralized ownership model challenging (respondents) because they are losing control over power production, which in turn affects their ability to ensure system balancing. Some envision that the Peer2Peer model will create a system, in which utilities will not be producers and retailers anymore but will play an important role of grid operators, maintaining the grid infrastructure, balancing demand and supply (respondents). However, not all utilities are comfortable with such 'partial' role (respondents). Still, respondents explain that the regulation-imposed balance responsibility is unlikely to be achieved via the dynamics of a free prosumer market. Thus, there appears to be skepticism towards the potential of the price mechanism to solve system balancing issues in the Peer2Peer model. Consequently, it is currently unclear which actors have the possibility and incentives to take this responsibility (respondent).

Respondents do not seem to believe in the possibility of a completely decentralized production ownership model, as the centralized production in Sweden is believed to remain an important part of the system. Besides the legal aspect of the balance responsibility, as one of the respondents concluded, large-scale production units are important from a technical perspective, to provide capacity when the distributed system based on small-scale intermittent renewables does not produce electricity. Hence, we conclude, there seems to exist both formal and informal institutional lock in effects towards a system with a large-scale ‘strong’ owner that can ensure system balance.

Some of the respondents used the perceived need for a balancing actor that can provide electricity reserves as an argument for the survival of the incumbent electricity producers, and thus potentially hybridizing the pure Peer2Peer model. Others argued that the balance issue might be solved by changing the legal structure to allow grid owners to store power, in for instance batteries, and use them to provide power reserve when needed. Such a legal change would allow for system balance in a system with highly distributed production ownership and operation from the technical perspective, while also legally attributing an actor the responsibility for it. Either way, our respondents seem to believe that a hybridized prosumer-to-grid is more likely in Sweden than a pure Peer2Peer solution. However, several of the respondents expresses that this might change as policies restricting decentralized ownership are changing, and EU initiatives promoting Peer2Peer solutions were seen as likely to be implemented in Sweden.

5.5. Off-grid Solutions (Off-grid Leasing and Grid Defection)

There are essentially two extreme off-grid scenarios, which depend on the ownership dimension. As both off-grid scenarios have been met with the same criticism from our respondents, they are presented together in this section.

Off-grid leasing, see Figure 11, in a Swedish context would mean that one actor, for instance Vattenfall, owns small scale energy systems while leasing them to customers. For example, Vattenfall might offer different small scale off-grid micro solutions including PV’s and batteries to their customers, while retaining the ownership of these micro systems. Today, there seems to be a limited number of companies with off-grid leasing business models (see for instance Werel), however the model does not seem to be well established on the Swedish market.

In a Swedish context, grid defection, see Figure 11, refers to not grid connected electricity consumers who own and operate their own distributed electricity production and storage. Each house thus becomes a separate ecosystem, where electricity production, storage and consumption need to be balanced. Although there seems to be low demand for grid defection solutions, some solutions for summer houses and other remote houses currently exist.

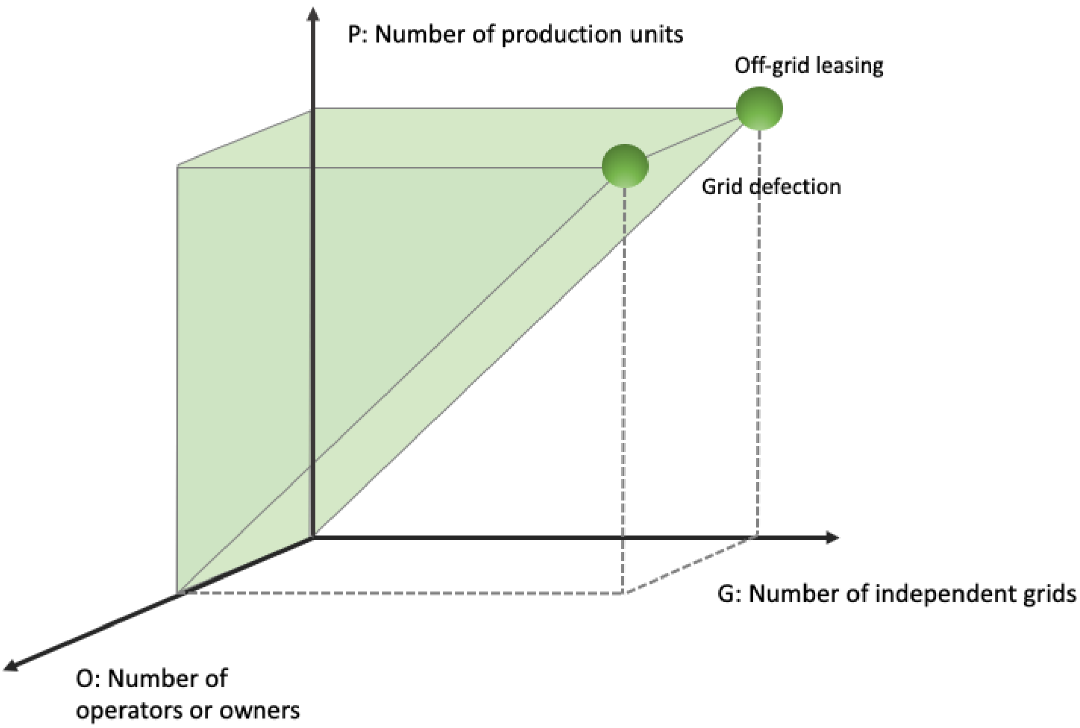

Figure 11: The two off-grid cornerstones in the POG design space

After having interviewed our respondents, it can be concluded that, generally, there appears to be a common belief that there is no demand for off-grid solutions in Sweden. As one of our respondents in the PV industry pointed out, there are only a few households in Sweden which are self-sufficing electricity wise. If Swedes are requesting off-grid systems, the respondent further argued, it is usually to get electricity to a summer house or similar.

Based on the overall skepticism towards an off-grid system that was evident in the interviews, it is perhaps not surprising that the EU initiatives aimed at reinforcing decentralized ownership was also met with skepticism from some of our respondents. One of the interviewed professionals, who has worked with an innovative Peer2Peer project, suggested that the local energy community initiative was a response to some sort of counter urbanization movement and people wanting to go off-grid, while claiming that there is no such demand on the Swedish market.

Many of the respondents pictured smart eco systems (systems integrating PV's, batteries and electrical cars, were commonly mentioned) as plausible in the future, while at the same time remaining skeptical to the potential of complete off-grid scenarios. This somewhat inconsistency could potentially be argued to relate to cognitive lock-in effects, causing the respondents to picture a future with far reaching grid connections. There is also a strong belief that Sweden has a well-functioning grid already in place and that not making use of the available grid capacity would lead to, from a system perspective, suboptimal solutions (respondents). Thus, in a system where citizens trust the incumbent actors in control, it is not surprising that there is skepticism towards off-grid solutions.

6. Discussion

The discussion of this master thesis is divided in two parts. The actual empirical findings suggest what developments in terms of ownership models that the Swedish electricity regime is currently facing, and how these relate to the current electricity system. Thus, the empirical findings will be discussed first. Moreover, the study tries out a new framework, the POG design space, as means to conceptualize the relation between ownership models and the system transition to renewable production systems. Consequently, the viability of the applied framework will thereafter be discussed.

6.1. Empirical Discussion

The technical development in the Swedish electricity sector appears to be moving in two different directions. On one hand, the scale benefits of wind power and the development of HVDC cables which can transfer large amounts of electricity (Nordling, 2017) makes large scale production possible. Likewise does hydro plants support large-scale production. On the other hand, digitalization allowing for instant pricing and trading of electricity may, together with the development of PV's, act towards a more decentralized system solution (Hall & Roelich, 2016; Morstyn et al., 2018; Zafar et al., 2018). Hence, it appears that technological development enables both centralized and decentralized solutions.

Overall, the respondents seemed cognitively locked into a large-scale solution where utilities stay in control of the countries power supply. The cognitive lock-ins are a sign that the model is part of the current socio-technical regime, as argued by several scholars (Brown et al., 2019; DNV GL, 2019; Nordling, 2017; Smith et al., 2005). Consequently, our respondents appeared cognitively anchored to a vertically integrated utility model. Some of the respondents problematized questions of social equity, and although Peer2Peer solutions could to be seen as a democratization of the electricity system by bringing more power to the consumers, our respondents instead seemed to picture risks regarding social equity in Peer2Peer similar models. From a socio-technical perspective (Geels, 2002), one might question if the positive attitude towards large-scale solutions follows from a long tradition of a strong government that acts in the interest of the citizens, making Swedes more resistant to decentralized ownership. Without claiming such causality, one can at least conclude that it appears to be a general idea that as the vertically integrated utility model allows for one-model-fits-all and thus equal preconditions for everyone, it is fair. Thus, even though a decentralized ownership solution opens up for more actors, which has been previously been identified as an enabler for the transition towards renewable power systems (Wizelius, 2014), there is still some skepticism as to how systems with decentralized production and decentralized ownership might cater for socioeconomic equality. Besides this source of concern, decentralized ownership is also met with questions of system reliability and control.

At the same time as the majority of the respondents seemed to have positive expectations and beliefs towards a centralized ownership structure, the Swedish electricity sector is subject to an increasing share of distributed, renewable, production. However, policies built around the vertically integrated utility model do not fully reflect the nature of decentralized production sources. Svenska kraftnät, the Swedish authority in charge of the transmission grid, supplies customers with large-scale production far away from demand. Thus, if the increase in decentralized production continues, Svenska kraftnät might find themselves with fewer customers to pay for the fixed costs of maintaining the transmission grid (see Nordling, 2017). As of now, Svenska kraftnät is planning on strengthening the north-south transmission capacity in the coming years, among other reinvestments and expenditures within the existing system (Svenska kraftnät, 2019). From an economical perspective it would thus be challenging for Svenska kraftnät if local trading between prosumers ends up efficient enough to decrease the need for electricity transfers within the transmission grid, as this would make the transmission grids more expensive per remaining customer, which could further drive a decentralization of the system (Cai et al., 2013; Nordling, 2017). As such, the investments in the transmission grid could be seen as an attempt from Svenska kraftnät to counteract decentralized production by making the vertically integrated utility model cheaper and more efficient, creating further lock-in effects, which Nordling argues is problematic.

The higher level of fragmented production sources could also raise questions of coordination and how to handle integration of different components efficiently. Hence, even though our data suggested that distributed production units were primarily decentrally owned, the centrally planned distributed ownership model might fit well to the Swedish electricity regime. More specifically, as the centrally planned distributed model with state owned actors like Vattenfall could be seen as something resembling the old welfare state, while accounting for decentralized production, there might be a regime fit to such a socio-technical system configuration. When analyzing through the lens of the multi-level perspective (Geels, 2002), this socio-technical fit would simplify a transition. Moreover, as the incumbent actors have succeeded to create a fossil free electricity system, these actors seem to have gained legitimacy and good reputation, which could also, from the multi-level perspective, be seen as an important factor for future system transitions.

The shift from somewhat of a vertically integrated utility model solution towards more of a Peer2Peer solution would require a decentralization in regard to both production units and ownership. Thus, a socio-technical shift towards a Peer2Peer solution might be difficult to envision, as the system is so fundamentally different to the current one. While off-grid solutions are also fundamentally different to a centralized large-scale system solution, we argue that they are not equally challenging to envision, as they are conceptually rather simple to grasp. In addition to the difficulty to conceptually grasp what Peer2Peer solutions essentially are, there are currently no commercial examples within a Swedish context, which we argue makes it even more difficult to envision viable Peer2Peer solutions. Hence, we argue that irrespectively of the possibility for price mechanisms to cater for system balance (Hackbarth & Löbbe, 2020), the viability of Peer2Peer solutions in the current Swedish context is limited.

Besides questions of how the marketplace should be formed, and to what extent price mechanisms will cater for technical system challenges, there are a number of other questions concerning the transition to a Peer2Peer system. Policies enabling market formation and legitimacy building for new ownership models are important for new system solutions to emerge (Jacobsson & Bergek, 2004). Currently, we argue that policies undermine market formation efforts and legitimacy of decentralized ownership models as they enforce high taxes for electricity transfer, which historically has counteracted wind cooperatives, but could also inhibit future Peer2Peer and PV cooperative solutions. However, as the Swedish electricity system undergoes a transition towards more decentralized production, it is plausible that the preconditions could change and thus open up for an increased decentralization of production and ownership.

In the absence of technical standards or a well-functioning large-scale solution to the electricity system, one may argue that off-grid solutions offer the benefit of not being dependent of a synchronous change. That is, every individual would be free to leave the current system at any time, based on the assumption that there is enough technical advancement made to facilitate power supply though an off-grid solution, and thus the socio-technical regime could adapt gradually. Thereby, the need for coordination decreases radically, but potentially at the cost of a less efficient system and a higher system total consumption of electricity, as indicated by one of the respondents. However, from our interviews we conclude that the interest in off-grid solutions is currently small, and that the largest potential for off-grid solutions is seen for houses without an established grid connection. This is not surprising, as Swedes seem to view a centrally coordinated grid as relatively unproblematic. Moreover, as off-grid solutions are typically expensive (Liu et al., 2019), it is possible that the social inequality issues that were raised during our interviews not only exists for Peer2Peer solutions, but also for off-grid solutions. Consequently, we do not judge a system transition towards an off-grid solution as likely. That said, as already mentioned, the cost to sustain the grid capacity increases for each consumer by every person who chooses to go off-grid (Cai et al., 2013; Nordling, 2017). Thereby, if enough actors choose to go off-grid, a feedback loop might be created, making more and more customers unwilling to pay for staying on-grid. However, at the moment none of our respondents deemed this as likely and consequently, they did not discuss any ownership models with off-grid technology as a basis.

Our findings illustrate that hybrid solutions might be a viable option for the future Swedish electricity system. Lindahl and Stoltz (2018) have found similar solutions in their studies. One could imagine both a centrally planned distributed and a vertically integrated utility model in combination, or, as some of our respondents suggested, a Peer2Peer and crowd ownership combination. Both of these solutions entail the same owner configuration, but allow for different levels of decentralization production wise. From a socio-technical perspective, it might be easier to coordinate different levels of production decentralization with the same ownership configuration, since the informal institutions concerning legitimate ownership structures are embedded in the socio-technical regime, which in turn reinforces the ownership structures in place through, for instance, policies. Still, the viability of a Peer2Peer and crowd ownership hybrid model is challenged by a socio-technical regime favoring centralized ownership. Thus, we see more potential in a vertically integrated utility model coupled with something resembling the centrally planned distributed model.

As already argued, the centrally planned distributed model could be understood as a good fit with the existing system. However, some of the utilities seem late to see the potential here, and as already noted, Swedes seem to own their PV's as of today. Thus, one might argue that a decentralized ownership model where prosumers own their own production units has already become the norm. At first sight, this might resemble a Peer2Peer solution. However, what is seen today is a prosumer-to-grid solution, where utilities act as intermediaries and prosumers are not able to trade directly with one another. Consequently, a prosumer-to-grid solution could be seen as a pragmatic compromise which allows for centralized control, just like the centrally planned distributed model, while adapting to an electricity sector facing more and more decentralized ownership. Thus, a viable hybrid solution might be the combination of a vertically integrated utility solution and a prosumer-to-grid solution, which also seems to resemble the future Swedish electricity system our respondents envisioned. In Figure 12, the grey marked area illustrates such a system set up within the POG design space.

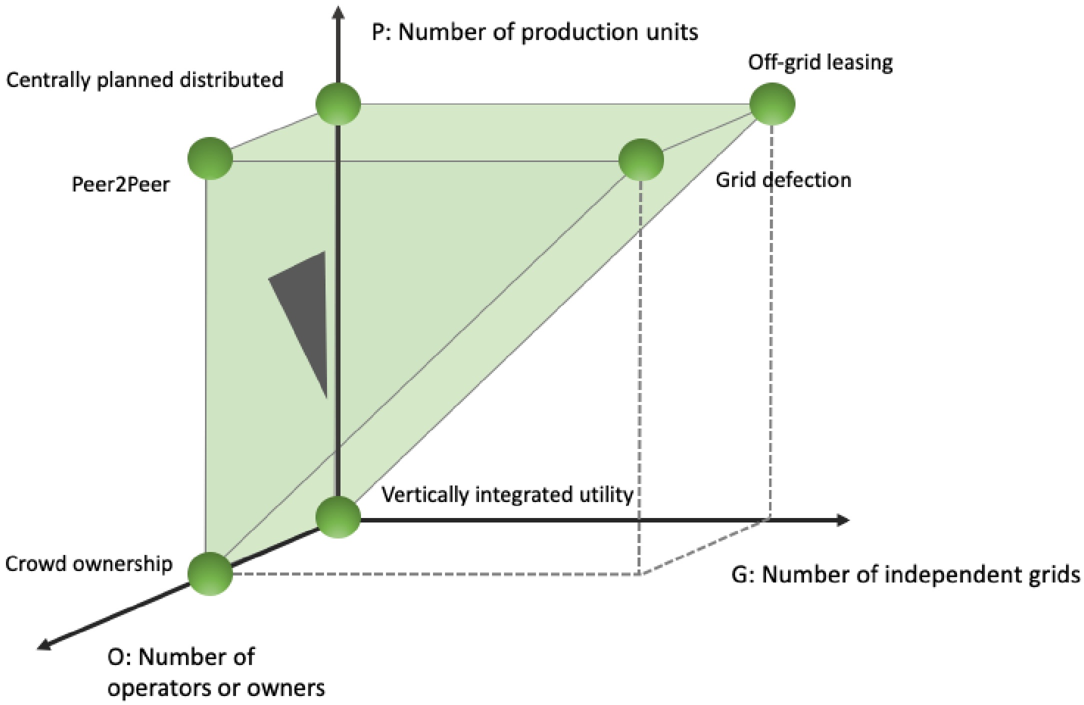

Figure 12:The POG design space with the possible Swedish solution marked in grey

6.2. Conceptual Discussion

The POG design space is built on the assumption that there are three variables which describe system configurations; the number of production plants, the number of independent grids and the number of owners or operators. This model manages to visualize different system configurations in a tidy way, and we have not yet found a system configuration which is not included in the design space. Given the complexity of the electricity system, we argue that the POG design space offers a simple and valuable conceptualization tool.

However, when using the POG design space, one has to define what is meant by the ownership axis, which includes owners and operators. Specifically, it becomes important to distinguish between different system set ups that end up at the same position in the design space. For example, if we face the prosumer-to-grid system solution described earlier, a majority of the Swedes contractually own PV's, while the system is controlled by central actors that handle all trading. In the POG design space, such a solution would end up resembling a Peer2Peer solution due to its large amount of owners, however, due to the low amount of operators, the features of a prosumer-to-grid solution might arguably lay closer to a centrally planned distributed model. Whereas the POG design space assumes that owners and operators can be one actor, our findings illustrate that operators cannot by regulation own production units in the current Swedish system. Thus, our findings indicate that the system in reality is more complex than what the POG design space indicates.

7. Conclusions

Our findings suggest that the large-scale production, primarily from wind power and hydro generation, will be organized in an ownership model similar to the vertically integrated utility model; a system solution corresponding to the traditional ownership model in Sweden. However, with technological advancements allowing for growing production plants, some of our respondents seem to picture ownership structures where a few large actors together own large production plants. At the same time, our findings suggest that there is an emerging decentralized PV ownership, causing the system structure to shift towards a more distributed character. Although a centrally planned distributed model might socio-technically fit well with the existing electricity system, our findings are clearly inclined towards a decentralized ownership of small-scale production, rather than a fully centralized set up. Crowd ownership structures are clearly facing socio-technical challenges, mostly from a policy perspective. Thus, even though there seems to be an enthusiasm about the potential of PV cooperatives, we argue that such an ownership model currently faces legal barriers.

A prosumer-to-grid solution could be seen as a compromise between a Peer2Peer solution and a centrally planned distributed solution, as the ownership is decentralized, while at the same time customers are forced to adapt to central actors acting as intermediaries controlling the electricity system. Our data suggests that the vertically integrated utility model might coexist with a prosumer-to-grid solution. Such a hybrid solution with decentralized ownership through prosumer-to-grid and centrally owned large-scale production seems to correspond well with how our respondents envision the future electricity system in Sweden. This system set up would position itself somewhere between the Peer2Peer solution, the centrally planned distributed solution and the vertically integrated utility model. Hence, it is our belief that the Swedish electricity system will remain centrally coordinated, whilst at the same time incorporate an increasing amount of distributed and decentrally owned production.

Lastly, we acknowledge that since we used the POG design space to categorize our findings, we might be subject to bounded rationality. Specifically, as there might be other, to us yet unknown, variables of importance to fully understand the ownership structure within the system, we might not have covered all potential system solutions in our analysis. Moreover, we are aware that the fact that we only studied the Swedish electricity transition makes it difficult to generalize the viability of the POG design space. For future studies, it might thus be interesting to test the viability of the design space in other settings.

References

Arjomand, N., Sami Ullah, H., & Aslam, S. (2020). *A Review of Blockchain-based Smart Grid: Applications, Opportunities, and Future Directions*. Retrieved from https://arxiv.org/abs/2002.05650?

Aspeteg, J., & Bergek, A. (2020). The value creation of diffusion intermediaries: Brokering mechanisms and trade-offs in solar and wind power in Sweden. *Journal of Cleaner Production, 251*, 119640. doi:10.1016/j.jclepro.2019.119640

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., & Truffer, B. (2015). Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions, 16*, 51-64. doi:10.1016/j.eist.2015.07.003

Bergek, A., Mignon, I., & Sundberg, G. (2013). Who invests in renewable electricity production? Empirical evidence and suggestions for further research. *Energy Policy, 56*, 568-581. doi:10.1016/j.enpol.2013.01.038

Betsill, M., & Bulkeley, H. (2007). Looking back and thinking ahead: a decade of cities and climate change research. *Local Environment, 12*(5), 447-456.

Bidmon, C. M., & Knab, S. F. (2018). The three roles of business models in societal transitions: New linkages between business model and transition research. *Journal of Cleaner Production, 178*, 903-916. doi:10.1016/j.jclepro.2017.12.198

Blarke, M. B., & Jenkins, B. M. (2013). SuperGrid or SmartGrid: Competing strategies for large-scale integration of intermittent renewables? *Energy Policy, 58*, 381-390. doi:10.1016/j.enpol.2013.03.039

Bolton, R., & Hannon, M. (2016). Governing sustainability transitions through business model innovation: Towards a systems understanding. *Research Policy, 45*(9), 1731-1742. doi:10.1016/j.respol.2016.05.003

Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production, 45*, 9-19. doi:10.1016/j.jclepro.2012.07.007

Brijs, T., De Vos, K., De Jonghe, C., & Belmans, R. (2015). Statistical analysis of negative prices in European balancing markets. *Renewable Energy, 80*, 53-60.

Brown, D., Hall, S., & Davis, M. E. (2019). Prosumers in the post subsidy era: an exploration of new prosumer business models in the UK. *Energy Policy, 135*. doi:10.1016/j.enpol.2019.110984

Byman, K. (2017). *Future Electricity Production in Sweden - A project report*. Retrieved from Stockholm:

Cai, D. W. H., Adlakha, S., Low, S. H., De Martini, P., & Mani Chandy, K. (2013). Impact of residential PV adoption on Retail Electricity Rates. *Energy Policy, 62*, 830-843. doi:10.1016/j.enpol.2013.07.009

Collier, U., & Löfstedt, R. E. (1997). Think globally, act locally?: Local climate change and energy policies in Sweden and the UK. *Global environmental change, 7*(1), 25-40.

Cuhls, K. (2003). From forecasting to foresight processes?new participative foresight activities in Germany. *Journal of Forecasting, 22*(2-3), 93-111. doi:10.1002/for.848

DNV GL. (2019). *Energy Transition Outlook 2019: A global and regional forecast to 2050*. Retrieved from https://eto.dnvgl.com/2019/index.html#ETO2019-top

Doganova, L., & Eyquem-Renault, M. (2009). What do business models do?: Innovation devices in technology entrepreneurship. *Research Policy, 38*(10), 1559-1570.

Drury, E., Miller, M., Macal, C. M., Graziano, D. J., Heimiller, D., Ozik, J., & Perry Iv, T. D. (2012). The transformation of southern California's residential photovoltaics market through third-party ownership. *Energy Policy, 42*, 681-690. doi:10.1016/j.enpol.2011.12.047

Engelken, M., Römer, B., Drescher, M., Welpe, I. M., & Picot, A. (2016). Comparing drivers, barriers, and opportunities of business models for renewable energies: A review. *Renewable and Sustainable Energy Reviews, 60*, 795-809. doi:10.1016/j.rser.2015.12.163

Etikan, I., Musa, S. A., & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American journal of theoretical and applied statistics, 5*(1), 1-4.

Farla, J., Markard, J., Raven, R., & Coenen, L. (2012). Sustainability transitions in the making: A closer look at actors, strategies and resources. *Technological Forecasting and Social Change, 79*(6), 991-998. doi:10.1016/j.techfore.2012.02.001

Galletta, A. (2013). *Mastering the Semi-Structured Interview and Beyond*. New York University.

Gauch, J., Hugh G. (2013). Scientific Method in Brief. *Cambridge University Press*. Retrieved from https://ebookcentral.proquest.com/lib/chalmers/reader.action?docID=1113122&ppg=2

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy, 31*(8-9), 1257-1274. doi:10.1016/s0048-7333(02)00062-8

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy, 36*(3), 399-417.

Georgeson, L., Maslin, M., & Poessinouw, M. (2016). Clean up energy innovation. *Nature, 538*(7623), 27-29. doi:10.1038/538027a

Giotitsas, C., Pazaitis, A., & Kostakis, V. (2015). A peer-to-peer approach to energy production. *Technology in Society, 42*, 28-38.

Gordon, S. (2006). Supergrid to the rescue [electricity supply security]. *Power Engineer, 20*(5), 30-33.

Habib, M., Pathik, B. B., & Maryam, H. (2014). *Research Methodology - Contemporary Practices: Guidelines for Academic Researchers*: Cambridge Scholars Publisher.

Hackbarth, A., & Löbbe, S. (2020). Attitudes, preferences, and intentions of German households concerning participation in peer-to-peer electricity trading. *Energy Policy, 138*, 111238. doi:10.1016/j.enpol.2020.111238

Hall, S., & Roelich, K. (2016). Business model innovation in electricity supply markets: The role of complex value in the United Kingdom. *Energy Policy, 92*, 286-298. doi:10.1016/j.enpol.2016.02.019

Haney, A. B., & Pollitt, M. G. (2013). New models of public ownership in energy. *International Review of Applied Economics, 27*(2), 174-192. doi:10.1080/02692171.2012.734790

Hannon, M. J., Foxon, T. J., & Gale, W. F. (2013). The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition. *Energy Policy, 61*, 1031-1045.

Hartwig, K., & Kockar, I. (2016). Impact of Strategic Behavior and Ownership of Energy Storage on Provision of Flexibility. *IEEE Transactions on Sustainable Energy, 7*(2), 744-754. doi:10.1109/tste.2015.2497967

Hojčková, K., Sandén, B., & Ahlborg, H. (2018). Three electricity futures: Monitoring the emergence of alternative system architectures. *Futures, 98*, 72-89. doi:10.1016/j.futures.2017.12.004

Hvelplund, F., & Djørup, S. (2019). Consumer ownership, natural monopolies and transition to 100% renewable energy systems. *Energy, 181*, 440-449. doi:10.1016/j.energy.2019.05.058

Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and Corporate Change, 13*(5), 815-849. doi:10.1093/icc/dth032

Johnstone, P., Rogge, K. S., Kivimaa, P., Fratini, C. F., Primmer, E., & Stirling, A. (2020). Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom. *Energy Research & Social Science, 59*. doi:10.1016/j.erss.2019.101287

Keirstead, J., & Schulz, N. B. (2010). London and beyond: Taking a closer look at urban energy policy. *Energy Policy, 38*(9), 4870-4879.

Kooij, H.-J., Oteman, M., Veenman, S., Sperling, K., Magnusson, D., Palm, J., & Hvelplund, F. (2018). Between grassroots and treetops: Community power and institutional dependence in the renewable energy sector in Denmark, Sweden and the Netherlands. *Energy Research & Social Science, 37*, 52-64. doi:10.1016/j.erss.2017.09.019

Kothari, C. R. (2004). Research methodology: Methods and techniques. Daryaganj: New Age International Ltd. In.

Kumar, R. (2011). Research methodology: a step-by-step guide for beginners. In: Sage.

Künneke, R., & Fens, T. (2007). Ownership unbundling in electricity distribution: The case of The Netherlands. *Energy Policy, 35*(3), 1920-1930. doi:10.1016/j.enpol.2006.05.008

Künneke, R. W. (1999). Electricity networks: how 'natural'is the monopoly? *Utilities Policy, 8*(2), 99-108.

Lauber, V., & Sarasini, S. (2014). The response of incumbent utilities to the challenge of renewable energy. *Syst. Perspect. Renew. Power, Chalmers University of Technology, Göteborg*, 138-148.

Lindahl, J., & Stoltz, C. (2018). National Survey Report of PV Power Applications in Sweden 2017: Photovoltaic Power Systems Programme. doi:10.13140/RG.2.2.15813.91369

Lindholm, K. (2020). Negativa elpriser – Energiföretagen förklarar. Retrieved from https://www.energiforetagen.se/pressrum/nyheter/2020/februari/negativa-elpriser--energiforetagen-forklarar/

Liu, H., Azuatalam, D., Chapman, A. C., & Verbič, G. (2019). Techno-economic feasibility assessment of grid-defection. *International Journal of Electrical Power & Energy Systems, 109*, 403-412.
Lowitzsch, J. (2019). The Consumer at the Heart of the Energy Markets? In J. Lowitzsch (Ed.), *Energy Transition* (pp. 59-77). Switzerland: Springer.
Lukkarinen, J., Berg, A., Salo, M., Tainio, P., Alhola, K., & Antikainen, R. (2018). An intermediary approach to technological innovation systems (TIS)—The case of the cleantech sector in Finland. *Environmental Innovation and Societal Transitions, 26*, 136-146. doi:10.1016/j.eist.2017.04.003
Macilwain, C. (2010). Energy: Supergrid. *Nature, 468*(7324), 624-625. doi:10.1038/468624a
Magnusson, D., & Palm, J. (2019). Come Together—The Development of Swedish Energy Communities. *Sustainability, 11*(4), 1056. doi:10.3390/su11041056
Markard, J., & Truffer, B. (2008). Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research Policy, 37*(4), 596-615. doi:10.1016/j.respol.2008.01.004
Massa, L., & Tucci, C. L. (2013). Business model innovation. *The Oxford handbook of innovation management, 20*(18), 420-441.
Miglani, A., Kumar, N., Chamola, V., & Zeadally, S. (2020). Blockchain for Internet of Energy management: Review, solutions, and challenges. *Computer Communications, 151*, 395-418. doi:10.1016/j.comcom.2020.01.014
Mignon, I., & Bergek, A. (2016). System- and actor-level challenges for diffusion of renewable electricity technologies: an international comparison. *Journal of Cleaner Production, 128*, 105-115. doi:10.1016/j.jclepro.2015.09.048
Mignon, I., & Rüdinger, A. (2016). The impact of systemic factors on the deployment of cooperative projects within renewable electricity production – An international comparison. *Renewable and Sustainable Energy Reviews, 65*, 478-488. doi:10.1016/j.rser.2016.07.026
Morstyn, T., Farrell, N., Darby, S. J., & McCulloch, M. D. (2018). Using peer-to-peer energy-trading platforms to incentivize prosumers to form federated power plants. *Nature Energy, 3*(2), 94-101. doi:10.1038/s41560-017-0075-y
Nordling, A. (2017). *Sweden's Future Electrical Grid: A project report*. Retrieved from Stockholm, Sweden:
OECD, N. (2003). *Nuclear electricity generation: What are the external costs* (9264021531). Retrieved from
Ofgem. (2015). *Non-traditional business models: Supporting Transformative Change in the Energy Market Office for Gas and Electricity Markets Discussion Paper*.
Palm, J., & Tengvard, M. (2011). Motives for and barriers to household adoption of small-scale production of electricity: examples from Sweden. *Sustainability: Science, Practice and Policy, 7*(1), 6-15. doi:10.1080/15487733.2011.11908061
Pearson, P. J., & Foxon, T. J. (2012). A low carbon industrial revolution? Insights and challenges from past technological and economic transformations. *Energy Policy, 50*, 117-127.

Pinson, P., Baroche, T., Moret, F., Sousa, T., Sorin, E., & You, S. (2017). The emergence of consumer-centric electricity markets. *Distribution & Utilization, 34*(12), 27-31.
Purvins, A., Wilkening, H., Fulli, G., Tzimas, E., Celli, G., Mocci, S., . . . Tedde, S. (2011). A European supergrid for renewable energy: local impacts and far-reaching challenges. *19*(17-18), 1909-1916. doi:10.1016/j.jclepro.2011.07.003
Quiggin, D., Cornell, S., Tierney, M., & Buswell, R. (2012). A simulation and optimisation study: Towards a decentralised microgrid, using real world fluctuation data. *Energy, 41*(1), 549-559.
Ren21. (2019). *Renewables 2019: Global Status Report*. Retrieved from https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf
Rotmans, J., Kemp, R., & Van Asselt, M. (2001). More evolution than revolution: transition management in public policy. *Foresight-The journal of future studies, strategic thinking and policy, 3*(1), 15-31.
Sabatier, V., Craig-Kennard, A., & Mangematin, V. (2012). When technological discontinuities and disruptive business models challenge dominant industry logics: Insights from the drugs industry. *Technological Forecasting and Social Change, 79*(5), 949-962.
Sataøen, H. L., Brekke, O. A., Batel, S., & Albrecht, M. (2015). Towards a sustainable grid development regime? A comparison of British, Norwegian, and Swedish grid development. *Energy Research & Social Science, 9*, 178-187. doi:10.1016/j.erss.2015.08.011
Simmie, J. (2016). *Path Dependence and New Path Creation in Renewable Energy Technologies*: Routledge.
Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research Policy, 34*(10), 1491-1510. doi:10.1016/j.respol.2005.07.005
Smith, A., Voß, J.-P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy, 39*(4), 435-448.
Sousa, T., Soares, T., Pinson, P., Moret, F., Baroche, T., & Sorin, E. (2019). Peer-to-peer and community-based markets: A comprehensive review. *Renewable and Sustainable Energy Reviews, 104*, 367-378.
Standal, K., Talevi, M., & Westskog, H. (2020). Engaging men and women in energy production in Norway and the United Kingdom: The significance of social practices and gender relations. *Energy Research & Social Science, 60*, 101338. doi:10.1016/j.erss.2019.101338
Stankiewicz, R. (2000). The concept of 'design space'. In J. M. Ziman (Ed.), *Technological innovation as an evolutionary process* (pp. 234–247). Cambridge: Cambridge University Prese.
Statistiska centralbyrån. (2019). Elektricitet i Sverige. Retrieved from https://www.scb.se/hitta-statistik/sverige-i-siffror/miljo/elektricitet-i-sverige/
Strbac, G. (2008). Demand side management: Benefits and challenges. *Energy Policy, 36*(12), 4419-4426.
Svenska kraftnät. (2019). *En statusuppdatering om läget i kraftsystemet: Systemutvecklingsplan 2020-2029*. Retrieved from

https://www.svk.se/siteassets/om-oss/rapporter/2019/systemutvecklingsplan2020-2029.pdf
Tångring, J. (2016). Leasing ska locka husägare installera solceller. *Elektroniktidningen*. Retrieved from https://etn.se/index.php/nyheter/63023-leasing-ska-locka-husaegare-installera-solceller.html
Tracy, S. J. (2019). *Qualitative research methods: Collecting evidence, crafting analysis, communicating impact*: John Wiley & Sons.
van Hertem, D., & Ghandhari, M. (2010). Multi-terminal VSC HVDC for the European supergrid: Obstacles. *14*(9), 3156-3163. doi:10.1016/j.rser.2010.07.068
Walliman, N. (2017). *Research methods: The basics*: Routledge.
Wegner, M.-S., Hall, S., Hardy, J., & Workman, M. (2017). Valuing energy futures; a comparative analysis of value pools across UK energy system scenarios. *Applied Energy, 206*, 815-828.
Wizelius, T. (2014). *Windpower Ownership in Sweden*. New York: Routledge.
Zafar, R., Mahmood, A., Razzaq, S., Ali, W., Naeem, U., & Shehzad, K. (2018). Prosumer based energy management and sharing in smart grid. *Renewable and Sustainable Energy Reviews, 82*, 1675-1684.
Zhang, W., & Feliachi, A. (2003). *Residential load control through real-time pricing signals.* Paper presented at the Proceedings of the 35th Southeastern Symposium on System Theory, 2003.

Appendix A

Twelve respondents took part of this study:

1. Harald Rohracher, professor at Linköping university with expertise in climate change, resource allocation and renewable energy. Rohracher's research has a socio-technical perspective.
2. Magnus Brolin, Director Electric Power Systems at RISE and former researcher at the Royal Institute of Technology. During his research, Brolin studied the integration and balancing of power systems with wind power, both from a technical and a market perspective.
3. Maria Blarr, a doctoral student at the Division of Environmental Systems Analysis at Chalmers University of Technology. Researches the business models of electricity retailers in Sweden.
4. Johanna Porsö, Product Owner and Product Developer at Vattenfall. Has previously worked as a Business Developer and Project Manager at Vattenfall Eldistribution AB.
5. Jenny Palm, a professor in sustainable urban governance at Lund University who researches the transition of local and regional energy systems. Palm has also contributed as a member of the board at the Swedish National Council for Nuclear Waste, among other honorable missions.
6. Tore Wizelius, a Swedish wind power expert with long experience. Wizelius has written several books on locally owned wind power and wind cooperatives.
7. Tim Ljunggren, engineer working as chief technology officer at Senergia AB.
8. Mile Elez, technical director at Tekniska Verken i Linköping, a municipal energy company.
9. Anonymous respondent, working at a Swedish electricity intermediary.
10. Anonymous respondent with experiences from energy consulting and as project leader for experimental electricity projects.
11. Anonymous respondent, project leader for experimental electricity projects. Has previous experiences from a municipal energy company.
12. Anonymous respondent, post doctoral researcher studying the diffusion of PV's.

Appendix B

Vill du berätta om din nuvarande arbetsposition och vad din roll innebär? / Vill du berätta om din forskning?

Hur länge har du arbetat i el-branschen? / Hur länge har du forskat på x?

Hur kom det sig att du började jobba i branschen? / Hur kom det sig att du började forska inom x?

Har du haft andra roller inom el-branschen innan du började på ditt nuvarande jobb?
vilka roller?

Vad består er primära affärsmodell av? Vad säljer ni?

Hur kommer du i kontakt med förnyelsebar el i din nuvarande roll?

Vad ser du för trender kopplat till förnyelsebar el inom elbranschen?

Vilka resurser äger eller förvaltar ni för att skapa värde för era kunder i er affärsmodell?

- Vem äger vad i värdekedjan?
- Har detta ändrats under senare år? Tror du det kommer ändras framöver?

Upplever du att ni skapar värde för era kunder genom nya typer av affärsmodeller/värdeskapande? Hur då?

- Hur länge har ni gjort detta?
- Gör era konkurrenter samma sak?

Har kunders efterfrågan ändrats under din tid inom branschen?

- Hur då?
- Vad tror du det är som gör att denna förändring i efterfrågan kan ses på marknaden?

Ser du några nya affärsmodeller som kan uppkomma eller är på väg att uppkomma?

Av vem tror du att framtidens resurser på elmarknaden kommer att ägas?

Ser du några nya aktörer på marknaden?

- Vilka typer av aktörer? Har du exempel på projekt med nya typer av aktörer?
- Vad upplever du driver dessa nya aktörer att ta klivet in på marknaden?
- Är ni en ny typ av företag?

Ser du några tekniska framsteg som möjliggör för nya former av ägandeskap? Hur då?

Ser du några förändringar vad gäller policys/lagstiftning inom elbranschen?

- Har ni anpassat era affärsmodeller därefter?

- Hur då?

Hur tror du att de förändringar du sett kan komma att påverka affärsmodeller på marknaden?

Är det något mer du skulle vilja lägga till, som du upplever att vi ännu inte berört under den här intervjun men som är av relevans för oss att förstå ämnet mer?

Appendix C

Can you tell us about your current position and what that entails?

For how long have you worked within/researched the electricity market?

Why did you start to research/work with the electricity market?

Have you previously had any other positions in the industry?

How do you come in contact with renewable electricity in your current position/projects?

What type of trends for renewable electricity have you spotted?

Have you seen new types of business models?

- What types?
- For how long have you seen these trends?
- Who owns what?

Do you think customer's demand have changed?

- How?
- Why do you think that is?

By whom do you think the resources on the electricity market will be owned in the future?

Can you see any new actors in the industry?

- What types of new actors? Do you have any examples of projects with new actors?
- Why do you think these actors have emerged?

Can you see any technical progress that makes new forms of ownership possible? How?

Can you see any policy changes?

- Do you think business models have been adapted to these policy changes? How?

How do you think that the changes you've seen can affect the business models in the industry?

Is there anything that you'd like to add, that you feel we haven't touched on during this interview but could help us understand the topic better?

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