SOCIETAL EMBEDDING OF INDUSTRIAL ENERGY PROSUMERISM IN NORWAY

A case study of two prosumers, two prosumagers and their implications on the electricity system

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ABSTRACT:

To combat climate change the world needs to cut its greenhouse gas emissions rapidly. One strategy to achieve this is through electrification. Electrification in Norway means more renewable energy is needed in addition to severe infrastructure upgrades.

This thesis investigates diffusion of prosumer innovations among industrial actors with high energy consumption, which can help Norway reach its electrification targets. Prosumerism in private households have been the subject of many studies, but few are done on big industrial prosumers. Through interview-based case study research drivers and barriers for diffusion of renewable energy technology innovations in prosumer- and prosumager-configurations have been identified and analyzed with help of societal embedding framework, the Multi-Level Perspective and a whole system-approach. This thesis belongs to the research field of sustainability transitions, where central contributors have called for studies that investigate cases of multiple innovations working together in transitions. The aim of the study is to provide valuable insight about new and promising phenomena in the ongoing sustainability transition for policy makers, regulators, researchers, actors considering adopting prosumer-solutions, and others interested, and it emphasizes the empirical findings made through qualitative case studies.

The data collection showed that there are two main types of energy producing industrial actors, namely prosumers and prosumagers, facing different barriers and with different consequences for the electricity system. The ”fit-and-conform” prosumer-configuration is diffusing without any major barriers, while the “stretch-and-transform” prosumager-configuration causes both new opportunities and problems that needs to be addressed for the electricity system to evolve past the current locked-in centralized architecture. Societal embedding of technology is a central element in socio-technical transitions, and the empirical findings underscores that the embedding of prosumerism involves much experimentation and has not yet established a dominant design. Regulation, business models, technology and user practices co-evolves, and with increasing effects of climate change these processes as part of transitions to sustainability becomes pivotal for the planet’s future habitability. The findings show there is a lot happening in all of the societal dimensions, and right now we find ourselves in times where policy makers need to address increasing pressure and landscape changes, including new ones caused by Russia’s war in Ukraine, that probably will speed up reconfiguration of the electricity system to a more decentralized and resilient one.

ABBREVIATIONS AND GLOSSARY:

BTM = Behind-the-meter (services)

MLP = Multi-Level Perspective

NVE = Norges vassdrags- og energidirektorat (The Norwegian Water Resources and Energy Directorate)

PV = Photovoltaic (the technique of converting solar radiation to electrical power through solar cells)

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1. Introduction

To combat climate change, we need to cut emissions quickly. EU's goal is to reach net zero emissions by 2050, which requires a broad-ranging transition in many sectors. I am looking at the Norwegian electricity system, and the emergence of prosumers and prosumagers. They help cut emissions by producing electricity locally with the use of solar PV technology, in a country already exporting renewable electricity through cables to European countries. There are also many other opportunities that arises for firms that decides to produce electricity on their rooftops – it opens cross-system linkages that were not there before, it creates possible new revenue streams, it can change how the firm relate to energy use, and it signals a forward-looking attitude that can create and strengthen relationships with customers and business partners.

My starting hypothesis is that the increase in commercial/industrial prosumers (businesses that have started to produce some of the energy they use, typically with solar PV systems, often combined with other technologies for storage and increased utilization) has potential benefits not only for the prosumer, but for the energy system as a whole in the sustainability transition.

Another hypothesis I developed after looking into the matter is that landscape changes and the appearance of big prosumers in the socio-technical electricity system in Norway is making the way for a new system configuration that opens for trading of electricity as an asset between actors in the end-use system in what is referred to as micro-grids. I have studied cases of big industrial actors that have become producers of energy. Two of them fit the description of a classical prosumer, two of them fits the description of a *prosumager*, a concept I was made aware of during the data collection phase for this thesis. The first article mentioning the concept prosumager found on Google Scholar is from 2016. Between 2016 and 2019, there were 46 published articles mentioning the phenomena. From 2019 to October 2022, there are 212 hits for "prosumager", indicating that the term, although not widely used, is increasing in popularity among academics. A short description of the two concepts follows:

Prosumer: Produces at least some of its own energy demand with on-site electricity generating technologies, with surplus electricity going to the grid. Every building with a lasting energy demand, that produces electricity with i.e. solar panels would fit this description.
Prosumager: A prosumer that in addition to energy generation also manages the energy as an asset: They store locally produced energy with energy storage systems (ESS) and can optimize their asset for several purposes, including production, charging and usage for different purposes, i.e. trading electricity, trading battery capacity (on the flexibility market), peak-shaving, security of supply, etc. Grid-connected facilities with lasting energy demand, electricity production, ESS, and a control system coupling the three, would fit the description of a prosumager.

1.1 Research questions

1) What are the most important drivers and barriers for diffusion of large-scale prosumer-innovations through societal embedding in Norwegian industry?

2) Based on Norwegian prosumers, prosumagers, technology providers and regulators experiences: How can different combinations of renewable energy technology innovations enable rapid electrification on a whole-system level?

1.2 Scope and delineation

The scope of this study focuses on the *becoming of industrial prosumers and prosumagers* through adoption of renewable energy technologies in different combinations, and this phenomenon's repercussions on the electricity system. This study is exploratory and seeks to link empirical findings up to existing theoretical concepts to better understand a new quite phenomenon in the low-carbon transition.

1.3 Structure of the thesis

The thesis is structured as follows: Section 2 introduces the theoretical frameworks I have used in the research. Section 3 describes the methodology used to answer the research questions. Section 4 introduces the focal actors used in the case study. Section 5 discusses the insights from interviews with the focal actors with quotes from the interviews and with regard to the societal embedding framework and a whole system-approach. Section 6 discusses the theoretical basis for understanding the phenomena in question, as well as predictions for diffusion of them. Section 7 concludes and raises some new questions that would be of relevance to policy makers and researchers.

1.4 Empirical background and context

1.4.1 Electrification in Norway

Electricity in Norway is already quite clean, so the need to replace fossil fuel use is not coming from a push to phase out such energy sources in the electricity system itself. What Norway is doing to reduce its emissions, is to electrify transport and on- and off-shore industry. These measures, according to NVE (NVE 2020), nonetheless puts a pressure on the electricity system as the need for new electricity (in addition to the regular consumption growth) will require an additional production of 22TWh yearly by 2030, and 23.2TWh by 2040. Total electricity generation in 2021 was 157TWh so the lacking electricity amounts to a 14% increase in total electricity generation. According to a report by PricewaterhouseCoopers (PWC), Norway need to replace 95TWh fossil energy with 30-50TWh renewable energy to reduce its emissions by 50% before 2030 (PWC 2022).

In either way, new renewable generation capacity must increase, and it needs to happen fast. Not only will electrification thus require huge investments on the production side, but also require costly development and strengthening of the power grid to meet the increased demand from multiple sectors at once. The traditional way of meeting the demand for electricity has been to develop new hydro power capacity. The traditional way of meeting increased demanind in grid capacity has been to build new grid from “top down”. More capacity in the transmission and distribution grids require cables and wires with higher voltage capacity. In this thesis, I will, based on insights from actors in different parts of the electricity system, discuss path-changing alternatives to these costly upgrades.

1.4.2 Recent developments in the adoption of solar power

The prosumer niche in Norway is growing steadily, and the number of solar powered prosumers has continued to increase despite misconceptions among some that the geographical location is not suitable for solar power. In the last couple of years, we have seen the arrival of prosumer facilities with significant size, a probable sign of a maturing innovation domestically (Norconsult 2022). One of the big challenges with solar power, both in an endogenous prosumer environment and in the electricity system as a whole, is the varying output. Solar PV systems produce a lot of electricity when the sun is up and there are no clouds above. They can produce electricity in cloudy conditions too, but obviously with less output the thicker the clouds are. Therefore, solar PV systems are increasingly combined with behind-the-meter (BTM) energy storage systems (ESS) to balance the varying outputs. BTM means that the technology is an add-on on the user-side of the electricity meter. Different in front-of-the-meter ESSs (i.e. pumped hydro storage in hydro power plants, large mechanical batteries, lithium ion batteries, etc.) are also increasingly adopted in electricity systems around the world, but will remain out of the scope of this thesis, focusing on prosumers and prosumagers ESS's.

2. Theoretical background and framework

To help answer my research question, I have combined analytical elements from different frameworks. In transition studies, Frank Geels has been an important contributor over time, and his much-used Multi-Level Perspective (MLP) is the heuristic backdrop of many studies. I will combine MLP with insights from Strategic Niche Management (SNM) to examine my cases through the framework of *societal embedding of technology*. To answer research question no. 2 – *How can different combinations of renewable energy technology innovations enable rapid electrification on a whole-system level?* – I will need to zoom out, and I find the whole system-approach suitable for the task since it to some degree opens the walls between systems and subsystems and allows for some MLP analysis across different regimes.

2.1 Transitions to sustainability

Sustainability transitions is a field emerging from innovation studies, focusing on transitions of socio-technical systems aimed at tackling the causes of climate change.

In "Reducing energy demand through low carbon innovation" (Geels et al. 2018), the authors identifies some "puzzles" when looking at system-transitioning technology, or what they call diffusion of *systemic innovations*: Systems do not necessarily start to transition from scratch, or following a "point-source dynamic", since new systems can grow out of existing ones. Another one is that system reconfiguration often happens through adoption of multiple innovations, and as in this case, combination of several new technologies at once. In these cases, much of the innovation framework that studies diffusion of specific innovations (like technological innovation systems (TIS), strategic niche management (SNM), i.e.) is not very suitable to understand what's going on when phenomena include simultaneous adoption of a multitude of innovations, since their scopes are built around trajectories for single innovations.

2.2 The Multi-Level Perspective

I am using the Multi-Level Perspective (MLP) to understand the transition in the electricity system, since "the core notion of the […] MLP is that transitions come about through interactions between processes at different levels", namely 1) technological niches (micro-level), 2) socio-technical regimes (meso-level) and 3) socio-technical landscapes (macro-level) (Schot and Geels, 2008). Big socio-technical systems like the Norwegian electricity system can be examined through the concept of socio-technical *regimes*, dominated by incumbents interested in maintaining their position and the regime dynamic's status quo. The end-use side cases in my thesis also belong to such a regime; the established industry regime. In my analysis and discussion I will use models from MLP to explain what effects they do have on each other. To do this I will lean on "whole systems"-literature as explained in chapter 2.5.

The Multi-Level Perspective is a heuristic framework developed to explain the entrance of niche innovations into socio-technical regimes in the study of socio-technical transitions. In addition to the niche-level and the regime, the framework puts the two in an all-encompassing context of a socio-technical landscape. Landscape pressure changes the internal dynamic of ST regimes, creating windows of opportunities for niche innovations to enter. Professor Frank Geels has later used the Multi-Level Perspective when studying sustainability transitions. In *Mapping the winds of whole system reconfiguration* (2019), Andrew McMeekin, Frank W.

Geels and Mike Hodson analyses the whole system reconfiguration of the electricity system in the United Kingdom by developing a "whole-system" analysis and a "reconfiguration approach" using extensions to the MLP with focus on system architecture.

Because transitions in the innovation studies context are broadly understood as changes in socio-technical regimes, the concepts available in the MLP heuristic framework are useful for understanding how such transitions go about. Transitions happens when niche-innovations enter the regime and the regime transforms as a result of this inter-level struggle, and co-evolution of technology, user practices and regulatory structures is a part of this process.

Visualizing change involving a bunch of actors, structures, institutions, technologies, and several other factors is not an easy task. For the insights about such changes to have potential for valuable knowledge creation outside the "inner circle", I believe visualization is a powerful tool, an in many cases a necessary one. The MLP itself is a sort of simple, beautiful metaphor for real evolutionary economic and/or technological change, while it also gives room for infinite complexity, depending on the scope and depth of what you study through it. One of the drawbacks from this simplicity and scalability is that the MLP, like TIS and SNM, work well for single innovation trajectories, but is difficult to apply to the study of regime transition to explain the adoption of multiple different innovations that working together. Therefore, other frameworks are often used as extensions to the MLP to look at processes involved in multi-technology diffusion.

Geels (2018) lists three change mechanisms involved in system reconfiguration that may require reconfiguration of MLP, as the framework is not giving them enough attention. These are 1) "interactions between niche-innovations, e.g. positive alignments […] or competition", 2) "adoption of niche-innovations within existing systems (through add-on, hybridization, or modulator component substitution), which may have knock-on effect and trigger further 'innovation cascades'", and 3) interactions between multiple systems. To address these change mechanisms, I will make use of the societal embedding framework to study interaction between innovations and adoption of niche-innovations in existing systems and apply insights from the "whole system"-approach to focus on interactions between systems.

Geels (2018) explains that "although co-evolution has always been a core concept in the MLP, this is even more important for low-carbon transitions, which are goal-oriented or 'purposive' in the sense of addressing the *problem* of climate change. This makes them different from historical transitions which were largely 'emergent', with entrepreneurs exploiting the commercial *opportunities* offered by new technology." Such co-evolution will be an important part of the analysis and discussion chapters in this thesis, that studies an ongoing purposive transition.

2.3 Niches

In studies of transitions to sustainability that applies the MLP, niches have often been the micro-scope (sic) since innovations developed in and through niches is a prerequisite for transforming regimes. The research field called Strategic Niche Management (SNM) focusing on niche governance and internal niche processes builds on assumptions and insights from evolutionary economic theory and Science and Technology Studies (STS), where technological change is seen as interrelated with the social (Schot and Geels 2008). According to the authors, the SNM approach presupposes that innovation journeys can be facilitated and managed through modulation of niches where regulation, user practices and technology can co-evolve through experiments in these "protected spaces" (Schot and Geels 2008). From the concepts of the SNM analytical framework will especially the distinction between niche innovation empowerment of path-breaking innovations (stretch-and-transform) versus path-fitting innovations (fit-and-conform) be useful in the analysis to identify different embedding processes related to the two types.

2.4 Societal embedding

There are several models one can use to study socio-technical transitions driven by innovation. The societal embedding framework is one of them, and described as a *contextual co-construction model* that focuses on innovations embedded into pre-existing environments (Geels et al. 2018). Rather than focusing on niche development, networks, or adoption, it focuses on the processes leading to diffusion as processes of *embedding* in different societal "dimensions". Since societal embedding of technologies is seen as important for innovations, it is especially important for socio-technical transitions that needs to happen fast. Accelerating the transition through diffusion of renewable energy innovations for instance, is seen as an important part of net zero emission strategies. Therefore, the societal embedding will be used as the main framework for the analysis in this thesis. Unlike many other studies using this framework, the focus here will be on industrial actors and not private citizens.

I draw on work by Kanger et al. (2019) on "Technological diffusion as a process of societal embedding" . Societal embedding is broadly speaking what distinguishes innovations from inventions. An invention is any new technology invented by someone somewhere. An innovation is an invention that also has been embedded into societal practices, markets and so on, and hence brought about change to a broader environment (i.e., regimes in the MLP framework). The first introduction of the societal embedding framework, developed by Deuten, Rip, and Jelsma (1997), conceptualized societal embedding as something happening in three distinct environments or dimensions: 1) The business environment, including all business-related things like business models, markets, supply chains, investments, industry structures and so on. 2) The policy environment refers to all sorts of regulations and formal rules. 3) The cultural environment, including (positive and negative) discourses and wider societal trends.

Later, two more dimensions have been added to Deuten, Rip and Jelsmas framework. The user environment, and the transnational community environment (Kanger et al. 2019). The analysis will explore the embedding through the configuration of the framework introduced by Kanger et al. 2019, and deal with embedding in these five environments: 1) User environment, 2) Business environment, 3) Cultural environment, 4) Regulatory environment and 5) Transnational community environment.

Those inhabiting the user environment will be the firms thas has become prosumers/prosumagers. Those inhabiting the business environment will be the technology providers, the grid companies, and the power companies. Business partners, competitors and neighboring businesses of the prosumers/prosumagers can also be said to belong in the business environment. The cultural environment includes research, media reports and public discourse, including potentially everyone that participates in opinion shaping with or without intent. Representing the regulatory environment in this thesis is RME, the governmental body overseeing the grid companies and grid connections in Norway. Laws, policy proposals, governmental funding (Enova) and other governmental bodies belong in the same dimension.

Most literature on societal embedding focuses on the diffusion of technologies among the population, i.e. private citizens. Kanger et al. (2019), for example, studies the historical diffusion of cars in the US and the Netherlands, to gather lessons for future electric mobility. It would have been very interesting to study the historical diffusion of energy efficiency technologies in two comparable markets to make predictions for the prosumer-tech future, but the scope of this thesis, neither in time nor space, will allow to go back in time and do a deep historical time. There have also been written several articles on societal embedding of renewable energy technologies. They focus mainly on citizens and local communities, and I have not found cases of this framework applied on industrial prosumers and prosumagers. Therefore, in this thesis, the user environment will have more things in common with the business environment than many other case studies, in that the users here are actual businesses, and embedding in i.e. the user's business models or partnerships will be considered embedding *by the user* in this case. Where there is any overlap between these or other dimensions, I will make sure to point it out to avoid any unnecessary confusion. Using the societal embedding-framework on a quite new phenomena will not give the same explanatory outcome as in Kanger et al. (2019), but it will be useful in saying something about the embedding going on right now, as well as what remains in terms of societal embedding for the phenomena to diffuse in the future. The ambition is that the societal embedding coupled with MLP and the "whole system"-approach will create insight about the phenomenon in question that hitherto has not been explored in the literature.

2.5 Whole systems

When McMeekin, Geels, and Hodson (2019) analyzed the reconfiguration of the electricity system in the UK between 1990 and 2016, they used a "case study approach to explore the dynamics of whole system reconfiguration", drawing on the typology by Henderson and Clark (1990) and recalling the transilience framework of Abernathy and Clark (1985) to "find a middle way that accommodates some degree of agency, struggle and non-linearity, while maintaining a focus on whole systems". A whole system approach takes into account all the parts, actors, and artefacts in systems together constituting a big system.

The electricity system is really one big, complex, and integrated socio-technical system that has developed over time to suit contemporary demands. The system includes everything involved from the harvesting of power (mostly from waterfalls here in Norway, but increasingly also from wind in recent years) and transformation of it into negatively charged electrons, their journey through the transmission-, regional- and distribution grids (where a lot get lost on the way), and into homes, streetlights, factories, basically wherever they can find the long lost "plus" they've been seeking. And when they finally reunite with the positive, that's when things happen, what we in this system context call end use, like when you put your phone charger into a power outlet, power your refrigerator, turn your bathroom lights on: That is really these tiny, unseeable electron travelers reaching their destination. Involved in this harvest and journey that is the purpose of the electricity system is also a lot of security measures. You don't want electricity to run through you, especially not through the heart since that can kill you, and on high-voltage grids you don't even need to be in touch with the grid for the electricity to jump at you from a distance, if you provide a source of the opposite charge that it is so keen of. It is also crucial to secure a predictable, continuous flow of this invisible magic, as the infrastructure as well as the end-use applications relies on it. If your bathroom ceiling lights starts flashing, that's annoying. If the same happens at the hospital, with any of the many electrically powered devices there, it's a bit more dire. So you have a lot of wires, switches, ground fault circuit brakers, warning signs, sensors, cables, copper poles for grounding, transformers, backup generators, monitoring systems and fuses. As electricity is a tradable commodity, you also have markets, prices, price predictions, long and short-term contracts, leveraged futures, professional traders, guarantors and more. You have investors, power companies, power grid companies, policy makers, regulators (this list could go on forever) and recently you also have prosumers and prosumagers as part of this system. The point of the whole system approach is to take into account the systems interdependent parts as an integrated socio-technical system. Usually in the transition literature (McMeekin, Geels, and Hodson 2019; Geels 2018; Bauknecht, Andersen, and Dunne 2020) the whole system is considered made up of three systems that each cannot function without the others. The *generation system* entails all the artefacts, nature, people, paperwork, money, and other things that are involved in the harvesting and transformation of powerful forces into electricity. The *distribution system* likewise entails all things, hard and soft, visible and invisible, involved in the distribution of the electricity. The *end-use system* entails all things regarding the user-side of it. Quite easy to grasp. What is not that easy to grasp, is where to put the big prosumagers into this triad of systems, as they are generating power, they are using power, and they want to distribute it themselves as well. For the time being, they belong in the end-use system regulatory wise, and conceptually there more than any of the two others, but they surely seem to stretch the conception of what an end-user possibly can be.

I will draw on the work of McMeekin, Geels, and Hodson (2019) and make use of the MLP heuristic to address landscape changes and regime dynamics that are involved in the adoption of prosumer-technologies. Instead of zooming as far out as McMeekin et al., I will rather link the discoveries on societal embedding in the four cases up to the whole system-concept in the analysis, to allow to make some claims about a possible reconfiguration taking place in the discussion chapter.

3. Methodological approach

The starting point was that I wanted to dive into the phenomena of big multi-technological energy production solutions being adopted by industrial actors, and to understand how they work both in the broader systemic context and in the specific context of the actor (in this case the firm). I read many articles on what I soon realized is being called "prosumerism" in innovation and transition literature (Botelho et al. 2021; Brown, Hall, and Davis 2019; Inderberg, Tews, and Turner 2018; Jackson Inderberg et al. 2020; Weigelt, Lu, and Verhaal 2021), and I read many reports and strategy documents on prosumerism, some also dealing with the topic of industrial prosumerism (Masera and Couture 2015). I did not, however, find any relevant research articles studying the phenomena of industrial prosumerism in light of innovation and/or transition theory. It is a quite new phenomena, and although studies have been conducted on some of the technical aspects relevant for cases like mine (Violi, Beraldi, and Carrozzino 2022; Urbano et al. 2021) there are knowledge gaps here regarding the question of "what happens when a big consumer goes prosumer?" in the socio-technical perspective.

In my interviews, I asked about drivers, barriers, and the experiences with adopting prosumer-technology for the industrial actors. To better understand the different dimensions of societal embedding, I also interviewed technology providers, and a regulatory body, in addition to conducting media searches on the topic.

3.1 Qualitative studies

When studying ongoing phenomena, qualitative case studies can help enlighten things that is not available in statistics. I like the analogy of the smartphone that I heard when studying phenomenology as part of my philosophy bachelor: You can disseminate a phone, taking all the pieces a part, and use tools to analyze the content of it – how many bytes here and there, when was it created, when was it accessed, and from where, and so on. But you cannot access the content through a microscope and measurement tools like you would on the screen. The information *about* the video is in many cases less interesting than the *actual video*, and its substance is only accessible in its qualitative form.

According to Yin (2018, p.127), "The need to use multiple sources of evidence far exceeds that in other research methods" when doing case studies. Attacking a real-world phenomena from different perspectives at once, with multiple sources of evidence, makes it both easier to understand the phenomena, and it strengthens the validity of the findings.

3.2 Data collection

3.2.1 Quantitative data

The data collected from NVE (via Elhub) and SSB provides a snapshot overview of the electricity system and its subsystems in Norway, and some insight into its development trends as some system parts are in motion. These provide context for the case-studies and will make the basis for deductive analysis. The main focus, however, will be on the qualitative data collected through the case studies and inductive arguments based on these.

3.2.2 Qualitative data

To be able to answer the research questions, I obviously had to talk to some big prosumers. I thought it a good idea to find 4-5 cases that recently had invested a big amount of money on rooftop solar panels, preferably with varying innovative configurations including other energy /ESS technologies that I imagined could be useful in relation to the electrification topic.

I have conducted interviews with several actors to identify drivers and barriers for big prosumers and prosumagers: Two big companies that recently became prosumagers, one company that recently became a big prosumer, and one company that was among the very first big prosumers in Norway, now with 13 prosumer-facilites. Additionally, I have interviewed three top representatives from two technology providers and one senior advisor from RME, which has regulatory responsibility for grid connections and overseeing the power grid companies. Combining their insights and answers with the theoretical framework, I will be able to answer my three research questions.

Before I singled out my cases I made preliminary scoping interviews with researchers at SINTEF, FNI and with a senior engineer in NVE. They sent me in the direction where I could find useful quantitative data, from i.e. Enova and Elhub. Enova is the governmental grant program for innovative energy solutions in Norway, Elhub is the domestic database for all electricity consumers and producers. From NVE I got compiled Elhub data with 10,087 connection points with permission to deliver electricity to the grid. All these entries were registered between July 2015 and April 2022. All of these are anonymous, the data set is not all-encompassing, as some of the power grid operators, according to NVE, had not provided sufficient data. Some of these entries will also belong to the one and same actor, as big power systems can have several registered connection points. Preliminary interviews were done in April and May 2022, the case study interviews that required permission from NDE were conducted in August, September and October 2022.

Despite not being the holy grail of prosumer data, the Elhub database definitely was a useful grail. To be able to identify any of them I conducted searches in Enova's databases for projects that were granted funding for "full-scale innovative energy and climate technology". This is where I found the project called OrcaGrid that included Revac AS, TGN Energy and Isola Solar. I also found the CLog Energi-project that included Coop Norge and Multiconsult in this database. By doing media searches I found several other industrial actors that recently have adopted rooftop solar PV systems, among them ASKO Norge and Norske Spirer who both agreed to set aside time for interviews.

In addition to the early scoping interviews, these nine persons were interviewed by me over zoom, with their interviews being transcribed and later analyzed with NVivo.

1. Anders Aas – CEO at Revac AS
2. Tommy Bønsnæs – CEO at TGN Energy
3. Fredrik Andersson – CTO at TGN Energy
4. Per-Olof Andersson Borrebæk – Product Manager at Isola Solar
5. Roy Arne Clausen Rossebø - Corporate Manager Energy Efficiency at Coop Norge
6. Petter Arnestad – Project Manager for CLog Energi at Multiconsult/Coop Norge
7. Carl-Magnus Fjeld Skinstad – CEO at Norske Spirer
8. Aleksander Jørgenrud – CFO at ASKO
9. Bjørnar Araberg Fladen – Senior Advisor at RME

As you can see, the gender balance in my interviews is terribly male dominated. My search methods through databases, media search and the snowball effect have unfortunately not led me to any women in relevant roles. There is also a strong presence of economists among the subjects, as 5-9 all have professional education in economics. 1 is a carpenter, 2 is a lawyer, while 3 and 4 are engineers.

The interview with RME differed a bit from the interview guide, as they have a different role than the prosumers. In this interview I brought up topics that had been mentioned by the other interviewees, which turned out to be quite clarifying regarding some of the issues and topics. Both the technology providers and the prosumers/prosumagers were interviewed following this interview guide:

Q1: What are the reason(s) for your firm's decision to become a prosumer?
Q2: Which technologies are involved, and how do they work together?
Q3: Did your solution end up as planned?
Q3-1: If not, how did the result differ from the plan?
Q3-2: What caused the difference?
Q4: Considering the knowledge you now have gained about prosumption – what would you do differently if you were to do the process over again, from "scratch"?
Q5: What, if any, challenges and barriers did you face in the process?
Q5-1: How did you deal with the challenges and barriers?
Q6: How have the implementation of prosumer technology in your firm changed how you relate to energy?
Q7: How will you describe the relationship with the power grid company in your area?
Q8: Is there anything important I have forgot to ask about?

In addition, there were several follow-up questions along the way, and both TGN Energy, Coop Norge and ASKO Norge used the opportunity to share visual data (videos, graphs, presentations, live monitoring of their system) over the video link, from which I took notes.

During my first interview, I found it necessary to follow the snowball up the value chain to get the answers needed. The CEO of Revac had a good understanding of how the solar PV + battery hybrid solution worked overall, but did not have deep insight into the kind of barriers related to system interaction, preparations and operations of the technology, nor the regulatory ones, as this process was led by TGN Energy. This led me to interviews with both the CEO and the CTO of the aggregator TGN Energy, that had delivered the battery-technology and developed the control system software, and with the product manager from Isola Solar that had delivered the solar PV solution.

During the interview with Coop/Multiconsult I was urged to talk to RME about regulations and the grid companies' incentives for accepting innovations in the electricity system.

After conducting each interview, I made a short summary with a recap of what I found interesting and relevant in the interviewees' answers. As recommended by Dunn (2021), I transcribed my own interviews, and I did it as soon as possible after they were conducted. The interviewees generally had a lot to tell, and the transcription of a single interview was a job that took between one and two days. I transcribed the interviews by listening to the records and writing down what was said, as well as noting laughter, sighs, hesitation, and conversational implicatures like irony or exaggerations when they occurred.

With all my transcriptions finished, I imported the text files into NVivo software, where I went through the text again to categorize answers with use of different "codes". These codes were based on concepts from the theoretical frameworks mentioned in chapter 2, and were placed in hierarchies where for example cognitive, symbolic and practical work had "domestication" as their parent, who then again belonged to "user environment", under the "societal embedding" code. This way, I could more easily compare and analyze the answers in context of theory, and in comparison to the other interviews.

3.3 Research ethics

I have avoided using my own network when looking for cases and inputs for this research, as a former CEO of a small company providing solar, heat pump and battery technology to private and business customers, to avoid any possible discrimination and bias.

My background as a vested actor in the field increases the risk for bias, while at the same time the first-hand experience and tacit knowledge gained from years working with the issue makes for a more in-depth understanding of the empirical cases and technologies.

Before conducting any of the case interviews, I applied to NSD for accept to record and store the interviews. I wrote letters based on NSD's template that all interviewees read and signed. All were given the opportunity of anonymity, but none of the interviewees whished that. In the interviews, third parties were brought up. Names and other characteristics that would identify such third party individuals was edited out of the transcripts, and where third parties are talked about, they are identified only as the public firms or organizations they represent. The excemption is when third parties are interviewed by me in other interviews, when that is the case the name is used as reference. In one case, a former CEO of a neighboring business of one of the interviewees is mentioned. In this case both the person's name and the name of the company is left out so to not make it obvious who this third party actor is.

3.4 Research design and data analysis

The transcribed interviews totaled more than 26,000 words. To help me analyze the content, I used NVivo software to code and categorize the answers and explanations based on concepts from the frameworks I am using in this thesis.

4. Background: Industrial prosumers in Norway

The Norwegian electricity system consists of three systems: The generation system is linked by the distribution system to the end-use system. Prosumers cause a conceptual puzzle since they entail both characteristics until now reserved for the generation system, but as consumers they belong in the end-use system. Prosumagers are also adopting infrastructure elements that typically characterizes parts of the distribution system.

Bauknecht, Andersen, and Dunne (2020, p. 319) also propose that "The shift from analysing emerging niche technologies towards a 'whole system perspective' puts the role of electricity grids or networks in a more central position than previously because these constitute the (physical) architecture of the power sector."

In Norway, distribution is strongly regulated, the grid companies are natural monopolies, and all new development in the whole electricity system must go through this distribution system in the current configuration. This creates bottlenecks for increasing generation and distribution and threatens the pace of the electrification. This is why many have started to look at prosumer solutions as a way of solving capacity challenges. The distribution system is however also involved with the integration of prosumers in the whole system, and as you will see, most of the interviewees point at grid companies, and especially their conservative/reluctant approach and their revenue models when asked about the biggest barriers for diffusion of prosumer innovations.

For the grid companies, prosumers and prosumagers offers two kinds of flexibility. Passive flexibility is offered when consumers produce electricity themselves, reducing demand from the grid. Explicit flexibility is when prosumagers offers their ESS + control system configuration to the grid company for use as infrastructure. Passive flexibility is “easy” to deal with for the grid companies; they lower the demand for electricity when they produce solar powered electricity, and feed the grid when their production exceeds their own consumption. A solution for this was implemented in

4.1 Focal actors

As my initial plan was to conduct interviews with prosumers, but I later discovered the two I had talked with was in fact prosumagers, I sought to find two other cases without the prosumager-configuration. I reached out to many big prosumers that I had found through media search, and ended up with interviewing ASKO, which is the biggest Norwegian prosumer when adding up their facilities, and Norske Spirer, which can be categorized as an actor adopting prosumer-technology in a later maturing step, resembling a part of the early majority. This makes for an interesting analysis, as the nature of the four cases varies on several parameters, although they have much in common.

4.1.1 Revac AS

Revac AS is an actor in the recycling industry. Their factory at Lindestad deals with 70% of electronic waste thrown away in Norway, according to the CEO. The recycling processes requires vast amounts of electricity, and they use on average 3GWh per year. With their new rooftop solar PV installation, they estimate to produce 1.2GWh per year.

4.1.2 Coop CLog

Coop Norge is a big incumbent in the grocery sector, with X stores around the country. Their main logistics center, located at Gardermoen, was newly expanded, and the CLog energi-project was started as a result of this expansion. They expect a yearly production of 2.8GWh from the solar panels, and in total 30GWh of energy from solar and heat production, equal to their average energy consumption over a year.

4.1.3 Norske Spirer

Norske Spirer AS is a family company, owned by two brothers that inherited it from their parents. They have been producing vegetable sprouts since the 1980's, and in the current company structure since 1995. They have 18 employees, and recently bought new facilities, on which they installed solar panels with an estimated yearly production of 680 000 KWh. Their estimated yearly consumption is 1 500 000 KWh (1.5GWh).

4.1.4 ASKO Norge

ASKO is an incumbent wholesaler in the Norwegian food sector, and like Coop, they operate all over the country. 5 out of the 10 biggest solar installations in Norway are located at different ASKO facilities. They are owned by Norgesgruppen, one of two main competitors for Coop Norge. ASKO Norge is the biggest of the ASKO companies, located in Kalbakken, Oslo, where they have a consumption of 7GWh and produce 2GWh from solar power a year. The total solar production from ASKO's facilities is around 10GWh per year.

5. Analysis

As earlier mentioned, the electrification in Norway will require more production of electricity in the coming years. A driver for adoption of solar power in Norway has been to meet the increased demand, without having to rely on expansion or new development of hydro power generation, which requires a lot of resources in the form of time, money, and nature, and on-shore wind power generation which has faced harsh resistance from citizens affected by it. Solar panels on existing roofs is a technology that meets some resistance locally, but in the big picture is quite accepted in all societal dimensions. Solar power contributes with electricity when the sun is up, naturally. In itself it cannot solve the electrification problem within the current electricity system configuration.

The analysis looks at both the niche that is prosumer-technology, and also the whole system that they become part of by adoption of big industrial actors. One out of many moments of realization from the transition literature is that you don't know about the barriers before you hit them. According to Kanger et al. (2019), the characteristics of an emerging socio-technical system is not known in advance (p. 48). Instead, preferences, actors, symbols, markets, regulations, infrastructures are constructed and solidify during the technological diffusion process.

Some general insights from the empirical data relating to the research questions are found in table 1:

Table 1: Case-comparison

	Revac	Coop CLog	Norske spirer	ASKO
Energy production (est. p.y.)	1.2GWh	30GWh (all) 2.8GWh (solar)	0.68GWh	10GWh (all facilities) 2GWh (Oslo)
Average consumption per year	3GWh	30GWh	1.5GWh	7GWh (Oslo)
Sustainability motivation	Yes	Yes	No	Yes
Economic motivation	No	Yes*	Yes	Yes
Replacing fossil fuels directly	No**	Yes	No	Yes
Grid flexibility opportunities	Yes	Yes	No**	Yes
Regulatory barriers	Yes	Yes	No	No***
Fit and conform	No	No	Yes	Yes
Stretch and transform	Yes	Yes	No	No

"*"= Yes, but not the main motivation.

"**" = Not currently, but have plans for it.

"***" = To some degree, but don't consider them important

5.1 Societal embedding

I chose to use the societal embedding framework because the diffusion of technology is about much more than just a process of purchase and installing; it is an active process of co-evolution between the technology, the user, and society. Societal embedding looks at exactly these processes within different domains or dimensions of society.

I will go through the five different dimensions of societal embedding as used by Kanger et al. (2019) and highlight issues that emerged from my analysis to help answer my research questions. The focus will be on identifying main drivers and barriers to the diffusion of prosumer-technology, and how the two different types of configurations (prosumers vs. prosumagers) contribute to electrification.

5.1.1 User environment

In my case, the user environment is focused around the industrial firms that have become prosumers and prosumagers, and hence includes industrial sectors, also implicitly industrial firms in the same situation that are currently non-users. In this section I focus on the following issues: 1) learning curves and price developments for focal technologies, 2) drivers and barriers for adoption of prosumer-technology on the user-side, and 3) cognitive, practical, and symbolic work in the user environment.

Solar PV technology has until some years ago been a niche product mostly used for off-grid cabins in Norway, where electricity has been mostly from renewable sources (hydro power) and relatively cheap compared to other commodities domestically, and compared to European electricity prices. For grid-connected buildings, the cost-benefit calculations have not been rational until the price per kWh went down and made the investment repayment period shorter than the effect guarantees for panels. This happened around 2015 in Norway, but varying electricity prices have contributed to low certainty of the economic outcome of such investments. Batteries for energy storage has also been used in the off-grid segment, but mostly in the form of low-cost, low-voltage lead batteries like the ones you have in cars. The lithium-ion batteries that the prosumagers in this case has adopted, is a newer invention, with the first patents being registered from the late 1970's (Reddy et al. 2020). Lithium-ion batteries are used in a lot of modern technology, with computers, mobile phones and electrical vehicles causing most of the demand. In recent years, stationary lithium-ion batteries for use in BTM prosumager-configurations are seeing increased demand around the world, and some are utilizing used batteries from electrical vehicles for this purpose (Rallo et al. 2020). The phenomenon of grid-connected industrial-sized prosumers is so new that there is no good quantitative data on it yet. The qualitative data I have gathered suggests that there is still a lot of experimenting going on, and both prosumagers learned during their acquisition process that the battery solution could have been designed to fit with regulations better than they currently do.

For Revac's case, as explained by TGN Energy's CEO, the size relation between the battery and inverters were not optimal:

> *It's a small blemish like that, because people have been unsure in these [power reserve] markets, how, and what, are the requirements for you to be allowed to participate in the market. So a while ago there was talk that you must have at least 1MWh of battery capacity, and then you turn it around a bit, and so now you should ideally have very large inverters that must be able to have a discharge rate that is faster than what Revac has, because Revac can drain its battery in two hours. It should probably, with what we know today, be able to drain it in one hour. It should even, maybe optimized, then it should be possible to empty in half an hour. So they have invested tiny mistakes, they should have invested in a smaller battery, and bigger inverters. It's something we've learned, but it hasn't been something we've done wrong, that's only because the regulatory changes.*

In the CLog case, one of the two battery solutions ended up being scaled down from the initial plans, for similar reasons:

> J: Was the system as planned?
>
> *R: Basically, we have to say that, there has been quantity adjustment along the way, in relation to experience data, i.e. scaling has been changed along the way. The large battery in particular was scaled down, the solar cells were carried out as planned, but the snow melting function was somewhat smaller than initially planned.*

For Coop CLog, the embedding is still very much going on, as they had not at the time of the interview yet integrated their technologies as planned into the top control system of the facility:

> J: Both the solar cells and the batteries are up and running?

P: Yes.

J: But they don't have that integration with the grid and such for the time being, or do they?

P: Eeee... the solar cells... you haven't actually integrated them into any grid. After all, they deliver to the boards in the building and if the board is unable to accept what you deliver, that is to say that the consumption is too little, then you go on the grid. All that is approved and trusted. This is the facility in Norway that for the first time in history delivers over a megawatt to the grid. So we are up to 1.2 – 1.3 at the highest delivered so far this year. And then it must be approved by both the grid company and Statnett, and that has not happened before. It is, by definition, a production facility that could stand on a hill. So it's never been done for a building before. When it comes to the batteries, it does have its own management system, but that management system is linked to the top system. We have not started to manage via the top system yet, but we have made manual settings so that we can see that the battery management system is working. So we do peakshaving and we now do the storage of solar production on the batteries, but we do not have that co-operation with, as it were, what effects are taken up with the transformers with forecasts and that type of thing. It is not operationalized yet.

It means there are potential barriers not yet discovered, and possibly much cognitive and practical work waiting ahead to be able to co-evolve with them.

There is not one driver that is common for the four cases I have studied. The prosumers (ASKO and Norske Spirer) mention the prospect of saving money on electricity as an important driver for installing solar panels. The drivers for the prosumagers in my study is rather more environmentally oriented: Coop has a goal for cutting its emissions, and the CLog energi project is an important part of that, both by reducing emissions on-site, but also as a way to gain knowledge going forward with their emission reduction strategy, implementing solutions on other facilities. This has been an important user environment-driver for the technology adoption and experimentation.

For ASKO, notably, there was also expressed a will to go ahead and "drag" the regulatory with them, in a sort of bottom-up societal embedding into both the regulatory and the cultural dimensions, as expressed by the CFO when asked if they had encountered regulatory barriers (touching into the regulatory environment here while still examining the user environment):

> *A: I and we at ASKO have the attitude that we just drive, and then the regulatory stuff can come afterwards. And I believe that we will get help from the current electricity price, that it will make things will go faster. But I wouldn't say that the regulatory thing is a big brake, not for us. But perhaps for itself in relation to exploiting the law, that this has not progressed further than it has. It is probably as much about knowledge as it is about regulatory barriers. We must be positive and think that more will happen in the future, also in relation to the public sector.*
>
> J: How many prosumer plants does ASKO have today?
>
> *A: We have 13 prosumer facilities.*
>
> J: On any of these, do you combine solar cells with other technologies?
>
> *A: What is special is that we charge electric trucks with energy from solar cells. Purely theoretically, we use the electricity to charge electric trucks. And then there is some work in terms of the regulatory aspects, everything is not in place in relation to this here with distributing between buildings and so on, but it will come.*

Regarding research question 2, this answer is interesting for two reasons: 1) They are charging vehicles with *theoretically* self-produced electricity. That is, without ESS technology, only the solar power produced at any given moment is sent through their inverters, via the cables and into the trucks' batteries. Much of this charging typically happens at nighttime when production from the panels is zero. Therefore, most of the actual electricity used to charge vehicles are not locally produced and must be paid grid fees on. 2) They anticipate that regulation will allow them to distribute the electricity between buildings in the near future and see their own adoption of solar PV in this large scale as a driver for regulatory change. This is a reference to ongoing policy debates, explained in 5.1.4.

Investing in significant solar production is not cheap. The economical barrier has obviously been overcome by the firms in my study, but they have emphasized and overcome it in different ways. The Revac CEO clearly had no problems getting help from the bank to finance the investment (answering my question about barriers – covering both user environment and business environment embedding here):

> *A: I feel that we have not encountered any challenges. It's been going really well, and if you think about funding and things like that, everyone is very positive. It is so green and nice that, I believe they would like to .... the bigger, the better.*

Also Norske Spirer had to finance it through an external loan, and said they got it through using a green financing scheme with their bank. Coop Norge financed the Coop Clog project, and also they treated the investment through different criteria due to the environmental benefits of it:

> *R: Initially, when we made this business case, we were allowed to use a slightly lower internal interest rate than is usual for investments, because this gives us experience and it gives us a number of environmental benefits that we are looking for. And then we can get answers to a number of pilots. Having said that, when we see the current energy prices, this business case will fare much better despite some other price increases during the project. If electricity prices persist.*

Digitalization in the electricity system has been an important presupposition for enabling these kinds of innovations and "paved the way" for BTM prosumer-solutions on the end-use side. Embedding of prosumer-technology in the user-environment would therefore be a much more demanding task if it was not for the embedding of digital electricity meters also in the regulatory and business environments. Digital electricity meters became obligatory by law January 1st, 2019.

The comparison between ASKO Norge and Coop Norge is quite interesting, especially since they are so similar in their daily operations: Both are big incumbents, they use most of the electricity for refrigerated storage of food, and they have vehicles leaving and entering the facility in large quantities. Although ASKO have done a pilot project on hydrogen production at their Trondheim facility (ASKO Midt-Norge), they have not embraced batteries as an ESS. They do however charge their vehicles locally, utilizing their solar power in direct electrification by replacing diesel as the vehicles' energy source. Like for Coop CLog, ASKO's facilities are producing a lot of excess heat, but they are not currently utilizing that like Coop does in the form of selling it as district heating to Statkraft. ASKO adopted big prosumer-solutions many years before Coop did, and it is notable how their configuration of solar panels and inverters, without prosumager-solutions, have become somewhat a dominant design for them. I will assume that the potential for utilizing the excess heat in a similar way as Coop has ended up doing as a result of *cognitive work* will be big for the ASKO facilities as well. But this process was not straightforward for Multiconsult and Coop:

> *R: So what is exciting then, is that this is said to have the potential to become Norway's first energy-positive logistics centre. When we look at the consumption before the expansion, which was up to over 15GWh, and then you now get expansion, and then we have to use energy for the heat pumps to raise the temperature of our waste heat up to district heating, but these are heat pumps with a good power exchange , and then we have that electrification. So the sum of the consumption was 30GWh, and when we look at what we now produce and what we deliver out of the building, we are thus a bigger supplier of energy than we are a recipient. So we have a net positive energy flow of 700,000KWh in the theoretical setup that has been done now. Then we'll see what happens when the year is over, but this is an enormous potential for several types of buildings in Norway, if the technology is allowed to be used in more places.*
>
> *P: We can only say that the warehouse didn't think there was enough waste heat available to deliver something, and when we started to look into this more closely, you find reasons why they think that. So when you do something about those reasons, you release a lot of waste heat. So, facts like that, like people believing things, without it being particularly well documented, and when you dive into it, with the right professional expertise, you see that there are opportunities here. I think that was perhaps an eye-opener that means that people may not go so far out on the pitch in being assertive, and then I think that we have opened our eyes to the fact that that waste heat has value, and that it can be a very positive contribution to society. And it was also that*

we facilitate electrification, which is not necessarily a big investment for Coop, but you facilitate it, and that it can mean so much, and then you also help to push the technology forward.

While Coop and Asko are competitors in the grocery sector, it seems they can learn from each other as they are experimenting with embedding technology configurations in their similar user environments. This is deductively an example of different cognitive and practical work leading to different multi-technological innovations, and I inductively assume that the early adoption of solar power for ASKO may have hampered the further "mutation" to prosumager-solutions. ASKO sits on a potential "goldmine" if they can find a buyer for their waste heat, leading us on to the next embedding dimension; that of the business environment.

5.1.2 Business environment

The business environment in this case does not entail the prosumers and prosumagers themselves, although they are businesses. The business environment covers rather the supply and distribution chains, value chains, grid companies, power companies, technology providers, neighboring companies and their business models, and related factors. In this section I focus on the following issues, mainly from the perspective of the technology providers: 1) Supply- and distribution chains, 2) Business models, and 3) industrial development.

There are two kinds of supply- and distribution chains involved here, namely those of the technologies involved, mainly coming from China ending up in the industrial actors' facilities, and the supply of the energy from the sun that the prosumers and prosumagers distributes as an asset internally and externally in competition with electricity from the generation system.

The fact that grid companies have geographical monopoly over electricity infrastructure means they have a lot of power in the business environment. Although there is no immediate competition for customers as they cannot choose their grid operator (if so, only by relocating their facilities to another grid area), the grid companies do measure themselves to the others, and when it comes to allowing innovative solutions, they differ in how far they have come. This means that varying conditions like infrastructure load and levels of supply and demand in different areas within Norway, as well as the individual grid company's willingness and/or capability to try new things, have an impact on the business environment embedding concerning the grid owners, as exemplified by the statement from Roy Rossebø in Coop Norge when explaining the experience with Coop CLog at Gardermoen:

> *Now it should be said that we are nationwide, so we also have projects in other parts of the country. And we talk to other grid owners and power companies who are far more forward-looking and think a little more progressively in relation to the possibilities that lie in the local grid.*

Elvia, which is the grid company in question here, and Norway’s largest considering the number of customers, have recently been merged from two smaller ones. This has, according to Rossebø and the project manager Petter Arnestad, locked up a lot of resources in the grid company to deal with other issues. At the same time, there is reason to believe that this merger has created a window of opportunity regarding innovative solutions and cross-system linkages, that they could have embraced in the process of reshaping the organization, but seemingly have not.

According to the RME senior advisor Bjørn Fladen, grid companies do have incentive to embrace innovative solutions when they are more cost-effective than to keep on upgrading the physical grid, and are expected to if they are both more cost-effective and as safe as the old configuration:

> *B: If the power grid company is not used to thinking about the idea of using flexibility instead of building out grids, then you will always be at the forefront of building out grids and always have enough capacity. The power grid companies would like to have it confirmed that it works with other solutions for capacity growth, and how to achieve that, how to get enough markets to benefit from this here. And the power grid companies must be quite risk-averse, it is important to have a good supply. That they don't gamble with the supply to Oslo, for example. So many will probably think that they are lazy and that their thinking is old-fashioned, but there are some reasons for that as well. But at the same time, they must use the most effective solutions, and they have an incentive to do so and if it is cheaper to use alternatives than to build grids, then they should do it.*

Embedding of prosumer-technology in the business environment is enabled by the earlier diffusion of digital electricity meters, which were made obligatory (overlapping with the regulatory environment here) in 2019 (Lovdata 2022). It allows continuous observation of electricity consumption (and production), and with add-ons these meters can track consumption down to the different electrical appliances, mapping it in a much more detailed way than was possible before the AMS-meter's arrival.

In the following exchange between the RME senior advisor and me, I pass on issues that were raised in interviews with the technology providers. A hypothesis emerging after talking with representatives from TGN Energy, Isola Solar, Revac, Coop and Multiconsult, was that the grid companies' business models were an important barrier for enabling rapid electrification on the whole-system level (research question 2), since they hindered entrance of prosumagers infrastructure components into the distribution regime in fear of weakening their own (and only) income model. The senior advisor brought some nuance to this, although not refuting it totally:

> J: They have invested in batteries rather than triggering the need for a new transformer. They request some form of compensation for not imposing that expense on the power grid company. Could it be something the power grid companies can contribute?
>
> *B: You have that in part today, in that if a customer triggers an investment, the customer must cover the cost of the investment. And if you don't have to make the investment, the customer doesn't get that cost either. So in that sense, the customer has an incentive to do so. And then the problem is that in some cases, the customer says that "we can take measures so that you don't have to set up this transformer", and then the power grid company says that "no, we have to be absolutely sure so we set it up anyway, and you have to pay". So that is probably where we have challenges, and there they have come up with a solution that we call connection on terms. Conditions regarding disconnection or reduced load. Because before this, it was the case that the power grid company had to be able to supply everything that the customer had the opportunity to withdraw, no matter what. But now the power grid company and the customers can enter into an agreement that is voluntary on both sides, whereby the customer actually waives the right to*

always be able to withdraw as much as he wants. The advantage for the customer will be that you save on construction contributions, and that is the advantage for the power grid company as well, because they then have lower costs in the grid network and become more efficient.

J: I know it has been used on ferries. Can you say something about how many have that kind of connection?

B: There aren't very many. As I understand it, only three grid companies have adopted it, and they are Lede, Agder Energi Nett, and Tensio. Lede and Agder Energi Nett operates in Telemark and on the south coast, where there has been a lot of pressure on network capacity, so they are using it to be able to connect more customers before Statnett makes upgrades to the regional grid there. It is relatively new. It is not very extensive, but I would assume that in those areas where there is pressure, it will be used.

J: TGN Energy has had a project where they got the thumbs up to connect four plots behind one meter. It was refused by the power grid company, although given thumbs up from NVE. They point out the power grid company's revenue model as the barrier there. Is that a precise claim?

B: A little unsure if that is actually true. Because they get an income limit, and there are some inputs and some outputs that affect the efficiency of the power grid company. In the distribution grid, one thing that has been measured is the number of customers, and in that sense you could say that it is more profitable to have four customers than one, but I would guess that it is relatively marginal. At least if it can help them lower the cost in their network. It is also cheaper to handle one customer than four. I can't be completely assertive here on the spot, but in such cases it is often that the regulations are an obstacle to it, or that they believe that the regulations are an obstacle to it, not necessarily that there are financial motives behind it. There has been a back-and-forth discussion about summation measurement, which is essentially combining several measurement points. Where it turns out that there has been a slight misunderstanding: The power grid companies have been of the impression that it is no longer legal, when we say that it is *actually legal, but there is no obligation to offer it. So there may also be things like that behind it, without my knowledge of the TGN Energy case.*

A stated motivation for becoming a prosumer in Revac's case, was to strengthen their position and image as an environmental friendly industrial actor. Revac, like Coop, is an early adopter of big lithium-ion batteries in the Norwegian context, and both are seeking to embed their configuration with power companies and grid companies in the electricity supply- and distribution chains:

Skagerrak, they are very involved in this here, because basically we produce enough electricity in Norway, but the problem is that it is in the water reservoirs, because as soon as you start producing it, you have to get rid of it in a way. You cannot store it closer to the end user. And that is what one thinks through these battery packs, that one imagines that the future may be that companies and ordinary residential buildings have battery packs, so that the electricity can be much closer so that you can always be fed in, and when you need electricity you use the battery. So it's a bit about that, as he explained to us, when it's Friday afternoon and everyone has to charge their Teslas at Sem here, on the downside of us, it's a challenge that there's not enough electricity there, and then you can basically sell power from the battery to charge up these Teslas, and then this brain knows that Revac won't start up its machinery until Monday anyway, so on Friday afternoon we can drain that battery completely. And sometime during the weekend, it will be filled up when electricity is cheapest, then it will make a decision on when to start charging the battery again. So that's the idea. And if we had had more such power banks, if we are to call them that, then we would have solved much more of the problem as long as that power was stored much closer to the end customer. That's how it was explained to me. (Anders Aas)

The cooperation with TGN Energy and Isola Solar was highlighted by Revac as a transparent process where they shared a common learning curve:

J: With the knowledge you have now, is there anything you would do differently if you were to start over again?

A: No, well, I would have ordered more then. If I had the knowledge I have today, then I would have filled the 20,000, and produced 2.5 million kWh instead of 1.2, of course. The only other things I have to say are practical things along the way - like you - you've learned, we've learned from the process, so I think it will be the most important: it's that you meet honest and decent people who want the best, and that's what we have. Understand? You can meet professional people who are good at everything they do, but we have met honest and proper people who have done everything they could. And quite honest, as you can see, they have not had such a difficult project as this before. We have had some challenges along the way, yes we have, but they have been solved in a good way, indeed.

For Revac, the prospect of strengthening its position as a contributor to the sustainability transition by producing and storing electricity locally was the most important driver. Answering my follow-up question on whether business partnerships was a driver for going solar, the CEO replied:

"Hmm, hm, hm. It is rather we who have pushed them considering that it was a good argument to sell in the name of municipality-Norway, that it was very positive to use solar energy to recover EE waste. And keep in mind that we made this decision when financially it didn't look like it does today, right, that's when we made that decision. So we made that decision as much for the fact that it gave great green signals about how green it [the operations of Revac] really was, much more so than the economics of it. And then in that year, a year and a half, from when we pressed the order button until it is up and producing, it has turned out that it was a very good decision to make. But that was not the basis on which the decision was made."

I also asked him why and how they decided to invest in solar PV, and how it happened. The answer is long, but gives a story creating great insight into business-to-business relations' role in embedding novel technologies (also touching into the transnational community dimension here):

“Do you want to hear it too? It is really so coincidental that the company next door installed solar cells. A new CEO started there, to tell the story, he had worked in Brazil and built a number of solar plants in Brazil, so when he came as CEO at the neighboring company here, he was much more concerned with solar panels than running that company in anyway, for him, that was all he managed, he got some solar cells set up, and then he disappeared, although that's not part of the story, but he had an idea about those solar cells, and built those solar cells there and that was good, and then he tipped us off and said that you must have solar cells, you must have solar cells. Then we thought about it a bit and concluded that this is not good business for us. But then [sigh] we got there, that we had an idea that with solar cells, it would give a very good impression to municipalities and everyone who delivered waste here. We also started to look for solar cells, and we did get some offers, and then it was actually a mutual acquaintance of ours who runs this shop, who said they knew Tommy [TGN Energy CEO]. Then we made contact, Tommy came to a meeting, and he presented a package with other types of solar cells that were bifacial, with reflective surface and all that. And then we were a bit like, «damn it's much more expensive and all», but we found a very good solution, and it's clear that, remember one thing: This is their [TGN Energy and Isola Solar] first big project, they only had a few pilots like that. And it is clear that for both Isola and Skagerrak and everything, it is really positive when they have built their first large park on top of the factory we have. We are the best at environmental remediation of EE waste in the country of Norway, it appears as a smooth factory that produces these goods in a proper way, and when they can have customers and go on the roof and say that, look, here we produce electricity, and see what they are doing, it is circular economy in practice that is happening under us, it was very positive. So the total package then, when we finally agreed with them, was that we wanted to go ahead with it, and we have not regretted that. It has been a very positive thing, of course a lot because the electricity prices and everything has become as they are, but the overall package is good, because it's a bit of innovative solar technology.”

From Revac's perspective, the involvement from Skagerrak Energi was seen as positive in the business environment embedding. When Tommy Bønsnæs from TGN Energy later was asked on the impact of power companies that invests in niche-innovations, the answer indicates that their involvement was not motivated by driving changes in a sustainability transition:

> *I don't see that it is driven by a desire for change. They take financial positions, they contribute, but it's not... the innovation doesn't come from the top down, that is, now you have to correct me if I'm completely wrong, you who work there (addressed to Per-Olof), but now I am a 10% owner in that company, but I feel that innovation comes from the bottom up. So they probably saw more benefit in forming a renewable energy cluster in Grenland then, because both Skagerrak and Isola are only a quarter of an hour apart, so in that sense, it looks good for the Grenland region, but innovation does not flow out of them (laughter).*

And continues about their business models:

> *When they decide to make an investment and such, it is almost always measured against, «if we instead put the money into hydropower, as we have always done», and assume to earn billions of kroner from it, so it is not a huge willingness to take risks to force the innovations on their part.*
>
> *Now, it is very easy for us to sit and say that, but I have worked all my working life in large companies, and what they are very good at is, for example, letting people out of their companies, to drive innovation on your own, so you have to take the first entrepreneurial risk on your own, and then they're pretty good at buying you up once you've proven you can do it. But the fact that they are running something, no, it is small... I would call it a financial investment on Skagerrak's part.*

About the distribution of Revac's electricity (this goes into the regulatory dimension as well):

> *Revac they have three incoming transformers, which support them. The three of them, they have no other job in this life than to provide power to Revac. Still, we are not allowed, - if the solar cell system, imagine you connect the entire solar cell system in the easiest way down, so that it feeds on*

transformer number 1, so if we go into surplus on transformer 1 when we run power out, then that current will automatically, it's only life for electricity, it takes the easiest path, then it will go into transformer no. 2. But there is a new damned AMS meter, so then Lede takes power grid rent on the way in there again. And that should have been what we had started with, we should have combined the three transformer circuits into one. Now, even Revac is not allowed to distribute its own energy inside its own area through the transformers, of which they also pay 50% to build. So it is also a learning we have done now, that this is something we should have started with in such a large area.

Fredrik Andersson goes deeper into the business model of TGN Energy:

Fredrik Andersson: If you have a 50-60-70 MW that you own, then for example you can start with a number of fun things, you can play with deep learning and all that, but it is something that is in the long term. But the second is pure project sales, get it made here, push it out, then it's a service and maintenance and keep this in operation and develop it, that's what's the model behind it really is. It is clear that the customer has to make money from his battery, it is not us who will take the whole cake here, then it will not be sellable. The thing about the difference is that we like the term "business benefits", there are a lot of people who create projects, but as soon as we start the project we have to see, okay what kind of outcome is it and what is the business benefits in this project.

And it is that they are able to set up something that electro people, or Skagerrak, call "value stacking", these are the services. There are a lot of people who push batteries, like Itachi and ABB, they say «go ahead, the battery is ready». It's there and it works and then there are some on and off-switches within a few days and such, but they are not particularly agile!

5.1.3 Cultural embedding

In this section, I focus on the discourse regarding the technologies involved, and the “fitting” of prosumerism into societal trends.

The discourse about solar PV systems in Norway has developed over time, and currently, with the energy situation in Europe, it is considered a good idea both in contribution to electrification and as an investment both for private households and businesses.
Although The Norwegian Coastal Administration already in the 1980's started to install solar panels on lighthouses, adoption of solar power in Norway has been late compared to other nearby countries like Germany, Sweden and Denmark (Merlet and Thorud 2015). Historically low electricity prices and sufficient supply has been held as a reason not to invest in solar, often combined with the misconception that we "don't have enough sun" up here. The number of sun hours is the same in Norway as other places (except in towns surrounded by shadow-casting mountains), but the distribution over the year differ. The angle of the sunlight hitting earths surface in the geographical realms of Norway, however, is not as optimal as places located closer to the equator. The degree to which you can "harvest" the sun's radiation depends on the angle and location of the panels relative to the earth's curve and distance from the sun, and the traditional way of building roofs in Norway makes the rooftops quite suitable to harvest solar power due to a typical angle of 15-22 degrees. The habit of building homes with roofs tilting in an east-west axis, however, is not as suitable for solar diffusion, as a south-facing surface is the optimal.

The idea that adoption of solar power in Norway would be helpful for fighting climate change started to influence the discourse as the climate change issue became more important in the 2010's, and especially around the "COP21" Paris Climate Change Conference in 2015. In 2017, there was a fire of ASKO's facility in Vestby, causing damage for 200 million NOK (≈20M Euros). This affected the solar PV discourse in Norway, as many were led to believe that the solar plant was to blame for the fire, according to Aleksander Jørgenrud that debunked this misconception in the interview:

> *A: It wasn't the plant that burned, but there was a fire in the building, yes. It was a truck that started to burn. It was probably the fire service that wanted to find some excuses if I may be a bit direct, luckily I have a bit of a clue about that and, the fire service is not allowed to walk on burning roofs anyway. So whether there are solar cells or not is irrelevant. We have of course followed how to do this here, you must have a switch to remove the voltage in the panels. In any case, it will not be completely powerless, if the sun is shining there will be electricity in them.*

The discourse regarding batteries is still contested, as illustrated by Jørgenrud's comments on stationary lithium-ion battery diffusion:

> *We have battery packs, in the form of electric trucks. Everyone is now very concerned about battery packs, I think it is very sad that everyone is concerned about it, it is not environmentally friendly at all. Now everyone must have a very large battery in the garden, and everyone thinks it's great and smart, but it's not. It is about the fact that there are people who do not understand the big picture. So if we had used the best battery we have, which is hydropower, we would have avoided this here. But because we are unable to think smart enough, everyone now has to have their own battery and that requires a lot of cabling and a lot of other things that could be used elsewhere.*

5.1.4 Regulatory embedding

Embedding in the regulatory environment is about the co-evolution of technology and policy. Policies and regulations are often in favor of the socio-technical regimes, but with the entrance of transitions to sustainability and mission-oriented policies, more policies are put in place to help environmentally sustainable niches develop and enter such regimes.

For Coop and Mulitconsult, the subsidy scheme from Enova was what made the CLog Energi project the innovative project that it became (also entering the business environment here with the Statkraft-cooperation), as explained by the project leader:

> *P: I would say that the support from Enova related to the concept study was important, and the support from Enova on the investment side was absolutely crucial, without we would not have done this. Or, we hadn't been able to calculate it home. It would have been a negative case, and then we would not have had Statkraft involved. So the fact that we now see in retrospect that power prices both for heat and what we produce ourselves, what we manage to reduce in terms of electricity, has in a way improved the business case a lot. But no one could have predicted that, so we see that there is still a need*

for Enova for you to set aside resources to investigate things, and that you need investment support to do things that push the boundaries of using different types of technologies. So, all these technologies are relatively well known, but there is interaction and testing of the technologies in a slightly different way. Lightweight panels do exist, but they have never been glued directly to the facade, and heating pipes do exist, but no one has integrated them into a solar panel, as an example. After all, Coop invests in a heating system which is not Coop's core business, they are not supposed to produce district heating, that is not what Coop is set up for, but the support made it interesting, and then we got finance in it and an operating model with Statkraft which also took us several years to develop. In other words, an agreement has been drawn up here that has not existed before, at least not in Norway, which regulates delivery, prices, responsibilities, and that type of thing between the parties. And it also costs money to develop that type of thing, there have been a lot of people involved both from Coop's side and from Statkraft's side, with lawyers and advisers.

The technology providers are asking for changes in the regulatory environment:

> *F: The solution definitely entails a battery, and in the longer term hydrogen, if you want to see a seasonal storage system. And what I'm showing you is, okay lay out the business model: What is this battery supposed to do? and then we program it, and then we have a machine learning behind it, which I call Santa's little helper, which says "Fredrik, if you tweak these things a little and do something like this here, you actually get a greater social optimization. Or you get a greater income optimization." The problem that I have asked about, which Statkraft is unable to answer, is: "What should you optimize around in a machine learning algorithm?" Because should you optimize for a net zero feed through a switch [minimal load], or should you optimize for highest income as possible. These are two quite contradictory issues really, because one allows you to gain access to the reserve market and full speed and a lot of money flows in, while the other makes sure that the grid is loaded as little as possible, so that industry or the residential area can survive. And there is a completely different benefit to society that I don't*

have figures for, so it is incredibly difficult, but the more we learn, the more we can put it into algorithms as well. We work a lot with deep learning, and it's shit in/shit out, sort of. We have to be very detailed when we train such a model.

RME explains the current regulatory environment, and how adopters must embed their technology in it, and where the push for reconfiguration is coming from:

J: Then there is concession. Among some prosumers there has been an opinion that if they produce so much that they must have a concession, it's not a good thing. Can you tell briefly about how to get concession and what it entails?

B: First, you have to distinguish between a concession and a concession. Construction concession is a concession to build grids, and it is granted by NVE. And basically, a construction concession is required for the construction of all grids, and then there are exceptions for specific low-voltage installations. And as soon as you are going to supply other customers or have high-voltage installations, you must have this construction concession. The other one is a trading concession (omsetningskonsesjon), which also has some limits, which we at RME manage. And there has previously been a limit that if you are over 1GWh, you must have a trading concession. Now, in practice, it has changed a little, so that if production is between 1 and 2GWh, you get a simplified trading concession on simplified terms, and then it does not come with any duties. It is a pure registration scheme. If you have more than 2GWh in production, you get it on ordinary terms. What you have to do then is to have an annual report to us, in what we call Erapp. And it's a bit of work, because then you have to separate your accounts, so that you separate out what has to do with power production and turnover from it, so it's a one-off job, and in addition then you have to report this annually. But the way I've been told, once they've split the accounts, you fill in costs and income continuously and then the annual reporting goes smoothly. It is more work when you beat the 2GWh limit, but you have to consider the disadvantages of staying below the limit versus the additional administrative costs of going over the limit. The limit goes for total *production per organization number. An actor can have... Oslobygg, for example, is one organisation, but they have a whole bunch of buildings, schools and nursing homes and all sorts of things. So they exceed that limit, even if they have many small plants in different places.*

J: Who do you feel are the driving forces behind changes in these models and in politics?

B: Linked to the sun, do you think?

J: Yes, linked to solar power and prosumers and the other things you just mentioned.

B: Yes, it is, a bit expanded, the solar industry. Players such as the solar energy cluster, Multiconsult, and a larger part of big players such as Fusen and Solcellespesialisten. They bring us input that we consider. I have some contact with all of these.

The regulatory environment has been important for many cases of early prosumerism, through the governments strategic niche management strategy of subsidizing innovations. Enova, which is the subsidy fund for innovation and renewable energy, have funded projects for ASKO, Coop CLog and Revac because of their innovative nature.

Norske Spirer, whose solar installation is not of the innovative kind that gets funding from the same pot, but from another ad-hoc subsidy scheme that requires application after installation, means that the government should have done more to fund regular prosumer-installations, for example by reducing tax (VAT) like have been done for electrical vehicles:

C: It is absolutely worthwhile for companies to invest in green energy, that is the only way to make it attractive for business. So it is clear that it is important for Norway to implement a lot of green measures. So you have the state saying that we are focusing on green energy, but there has been nothing to get from Enova until now. We are now in the middle of an electricity crisis, so it is a bit behind schedule. It should have been all along. There should have been solar support throughout. A lot more people would have done it then. This is how the state governs us. They allow us to do things, don't they. When they reduce taxes and fees on electric cars, everyone buys electric cars.

That's how they rule us. Then it becomes clear that they do not want the industry to invest in green energy when there is no subsidy for it. And it is quite hair-raising that NOW, okay now, when they are in a crisis, there is an electricity crisis, then we suddenly get subsidies for green energy. It's a bit behind schedule. It should have been a long time ago.

For Coop, the technology used in the CLog project had to be embedded into the system of aviation safety regulation, due to the proximity to Norway's main airport Oslo Lufthavn Gardermoen:

R: Well, there are quite a few other regulatory issues in relation to the fact that we are so close to Gardermoen airport, but the cooperation with the airport has been neat and straightforward.

J: What kind of challenges are there?

R: It goes without saying that when you are going to have such a large solar system so close to the flight, you can have reflex problems. It had to be documented. And then there is, I wasn't really worried about that because it had been done other places, but the size of it can give – what is the name… Frequency interference? So it had to be documented.

P: Yes, it can affect navigation systems and communication systems. That's what we were worried about. When that plant starts producing, noise can be emitted from the inverters, so that was what we were most concerned about, that they are placed in the open air and not in rooms that don't emit any form of radiation.

In ASKO's case, the regulatory embedding includes "fitting" their system with current regulations by using more of the electricity inhouse:

A: Yes, as I said, it has been a bit in relation to the regulatory side. At the start we had to throw away electricity, because we were not allowed to feed into the grid. It has been resolved. Or it has ben partially resolved, because *we get a bad price. Again, the regulatory part doesn't quite add up in relation to how I imagine it could be done. But we don't mean anything in relation to the regulations that are there, a good example is that if there is overproduction right now, then we have to send it out on the grid, get poorly paid, and then I have to buy it again expensively in an hour. It's really short-sighted, because the neighbor may need that power right now, and they pay grid fees for that power. In relation to this with price, it lags behind. For us, this is not very decisive, because we are switching more and more to electric trucks, which reduces our need to send electricity back to the grid.*

5.1.5 Embedding in the transnational community

Unlike many traditional energy sources, like hydro power, coal, gas and oil, the sun as a resource cannot be owned, and hence not belong to any nation. The solar PV niche is making progress in many countries around the world, and different markets are learning from each other. RME brought up Germany as an example that Norway is learning from:

J: If you can look a little bit into the future, if this development continues to accelerate, that there are a lot of industrial buildings that start to produce a lot of solar power, they have battery storage and maybe produce district heating. How will it affect the power system and the players in it, do you think?

B: Yes, it will affect quite a bit. That is why it is important that you think a bit ahead, that you don't think that you are somehow giving a lot of benefits, but that you get the right price signals. And we have seen a bit from Germany, where there has been a lot of solar installed, that it has affected quite a bit. There they have not had particularly correct price signals, we think, with a lot of feed-in in the past. If a lot of people get it, the tide will turn in a way. Now you have a power system that largely means that you drive power from the large power plants, and then it flows to the large consumption points, so there will be much more dynamics with the back and forth of power flow. And a bit like how you see it now in these times, that you *initially have a shortage of energy, but then suddenly it starts to bloom a lot and so on, so then you get big price dips. There will also be a major consequence if you get a lot of unregulated power, such as solar. When it is sunny, it will be in a larger geographical area. Then there will suddenly be a high load in the opposite direction on the grid. It's not like we're maximizing these things here, we're thinking that it's quite a long way to go before we see big challenges with it.*

Roy Rossebø from Coop explains the transnational embedding potential of their investment, in that transnational communities can learn from the CLog Energi project:

We have had great interest both in Norway and internationally in this, it is new technology in Norway, and in a sense in Northern Europe, there is no other building in Northern Europe that is as automated as CLog. Then we have CLog energy, which in connection with the development that has been going on now, we saw the opportunity to make a number of energy efficiency measures at CLog, at the same time as the development was going on. And then we have installed Norway's second largest solar cell system, which was put into use at the end of January this year, and we have a unique project together with Statkraft, using the surplus heat from our refrigeration and freezer production. We are building a central heating plant, and then it must go out to the district heating network. It has also never been done in Norway before, that we have used the excess heat from a logistics center out to third-party customers.

Findings from the study "Challenges for electricity network governance in whole system change" (Bauknecht, Andersen, and Dunne 2020) shows that grid companies do not have the capability and capacity to stimulate innovation internally, despite having access to R&D funding. The authors also found that the grid companies' RD&D projects were not "meant to provide a direct input into the design of the future regulatory system" (Bauknecht, Andersen, and Dunne 2020, p. 328), meaning that R&D funding are not going towards the reconfiguration that many of the interviewees in this case study are asking for.

6. Discussion

Conceptually, it seems easier to deal with a structure that entails three nice substructures with clear borders, than a fragmented monster with no clear integers. We humans tend to divide things into three in our conceptualizations. This is the case in the original societal embedding framework (three dimensions), as well as in the MLP (three levels), and in the whole system-approach to the electricity system (three domains), just to recall concepts already used in this thesis. And outside this realm there is a bunch of triads and trinities, holy and unholy, the three pillars of states, and so on. My point here is that this simplification of what is often complex systems can lead to conceptual barriers when dealing with things like the electricity system. To reconfigure it means the introduction of new technology, practices, and linkages, but also a reconfiguration of cognitive work among all actors, and in the cultural environment. If a trinity is seen as a perfect structure, what must happen to allow someone to mess with it? I think this is a deeply rooted cultural thing, stemming from classical geometry perhaps, where the triangle is the least complex geometrical structure with surface area. Three really seems like a perfect number, but when looking at nature itself, structures often turn out to be a bit more fractal than our conceptual integers and trinities.

What is called fractals, or expanding symmetry or self-evolving symmetry, have been a subject of investigation in mathematics since the 1800's. This mathematical phenomena was first referred to as fractals by Benoït Mandelbrot in his book Fractals: Form, Chance and Dimension (Mandelbrot 1977), first published in French in 1975. Fractals are, according to Mandelbrot, sets of geometric objects with repetitive patterns, visible at all scales. Fractal geometry is found everywhere in nature, as repeating patterns in, for example, trees, arteries, cell structures, weather systems and river courses, to mention some.

So why do I bring up this? Well, firstly because it's an interesting topic that has been a central part of a lot of innovations in our time. Secondly, but in this context more importantly, fractal geometry is the basis on which a proposed solution to the reconfiguration of the electricity system lays: Fractal geometry is what Per-Olof Andersson Borrebæk, the technical manager and product owner at Isola Solar, base his vision of a fractal grid infrastructure on. Fractals are often characterized by the fact that the structure repeats itself in the potentially infinite. A tree has branches which in turn have their branches with new branches, all of which are smaller copies of the tree in which they appear out of. In the same way, a fractal grid would be a structure with a self-repetitive pattern in the form of smaller and smaller modules with its own ESS, in totalt making up the whole infrastructure.

A reconfiguration of the electricity system in the direction of decentralized production and fractal grids, presupposes embedding on the highest regulatory level, as well in all other dimensions. A reconfiguration of the system architecture doesn't necessary affect the user in form of a regular consumer, if the service remains the same for them. If anything, they may see a reduction of electricity price if this new system architecture includes widespread diffusion of prosumagers in it. The trajectory of the grid cost model, where the end user pays increasing fees for upgrades of the grid, may also flatten if costly investments from the grid companies are replaced with more economically sustainable upgrades in the "prosumager" part of the system, paid for by the user, resulting in reduced need for central upgrades compared to the previous (up until ca. 2020) trajectory.

Although fractal grids on first thought seem like a radical innovation that would cause *creative destruction* (Abernathy and Clark 1985) on the electricity system, making the centralized structure superfluous, it is in fact possible to integrate with the existing, making it evolve incrementally over time in the direction of more and more decentralized infrastructure.

One could actually argue that this is what is happening right now, with regulations slowly opening for sharing of electricity between electricity meters (although the caps are too low to roll out microgrids in the current regulatory environment) and actors adopting technology making it possible to become prosumagers with infrastructure utility. The impact of this diffusion is hard to estimate, as "quantification of impacts is difficult within complex social systems" (Geels 2018). Based on the insights from the technology providers and RME, and considering the landscape pressure emanating from both production and distribution demand, and demand for resilience in the national security context, I predict that this development will accelerate and force the grid companies to utilize such innovations as they mature, and the knowledge creation eliminates the uncertainties that they "hide behind" in their decision making.

For Norway, where the pressure to reconfigure is real, but not as urgent compared to many countries more reliant on fossil fuels for generation, there will probably be possible to learn from earlier adopters in the transnational community. Embedding in the transnational community dimension will actively include building on experiences earned elsewhere, like Australia or Germany, to mention two markets that has seen further diffusion of both solar power, energy storage systems, and virtual power plants, as well as the combination of the three in prosumager configurations. Diffusion of these technologies, and new electricity system configurations on the global level will possibly also affect the discourses in the domestic cultural environment. If fractal grid configurations are proven to be safe, reliable and cost-effective in other countries, the threshold for embedding of it in the societal dimensions here will also be lowered as an effect.

7. Conclusions

Both prosumers and prosumagers are contributing to electrification in the Norwegian setting. The newer prosumager configurations are also causing problems for actors in the distribution system, as well as being a potential competitive threat to actors in the generation system, by providing substantial amounts of electricity to the system. Some actors have exploited windows of opportunities in more than one regime, like Coop and Statkraft that now are trading ca. 20GWh of district heating annualy. A reconfiguration of the current system is already happening, slowly, with better premises for small prosumers, and new windows of opportunity will become visible for those who know where to look. As the diffusion continues, there will probably come more regulatory changes that allow for better utilization of these innovations to solve infrastructure challenges caused by electrification.

7.1 Prosumaging – a mutation

It's interesting how firms in a way mutates by adopting the prosumer-niche into their industrial regimes. It is almost like a creature growing a new body part. Unluckily for the prosumager, this body part is currently not allowed to function as a part of the whole system directly, only through flexibility markets that are made to solve grid companies' challenges, and not bring about a reconfiguration of the whole system.

The prosumers, with their fit-and-conform configuration, fits well in with the whole system, especially if they can keep excess production under certain limits.

The prosumagers, on the other hand, by "mutating" further, causes implications for the system architecture: Where do they fit in? How does the other systems deal with their entrance? Can we talk about embedding in whole systems?

In the current regulations, having a battery seems like a good idea since sharing between buildings is not allowed, and withing one building there is a cap on 500KWh. It means that distribution of electricity is limited to inhouse only, and so distribution over time for peak shaving seem like the best contribution to indirect electrification within the current configuration.

7.2 Policy implications

Geels (Geels 2018) claims that “the importance of public engagement, social acceptance and political feasibility is often overlooked in technocratic government strategies and model-based scenarios, which focus on techno-economic dimensions to identify least-cost pathways”.

As Russia’s invasion of Ukraine has showed their willingness to attack civilian infrastructure, and especially the electricity system, is has become clear that such infrastructure is not only threatened by weather, the passing of time and demand for increased capacity. Centralized infrastructure like the electricity system’s is an easy target for a terrorist state with long range missiles. This means that the electricity system becomes part of an even bigger context, regarding national security. In light of this landscape pressure, it is reason to believe that policy makers will have to look at configurations like the fractal grid as not only an electrification issue, but a security issue, and hence take this cross-system linkage into consideration when developing policy for electricity infrastructure.

7.3 Further research

There are many aspects of the data I have collected that would be interesting to analyze within different scopes. I have not given much attention to strategic niche management, for instance, or to policy aspects. A comparative study of the prosumer niche in Norway relative to the development in other countries could also shed light on some interesting issues, like should we prioritize prosumerism in countries that are phasing out fossil fuels for electricity generation? It would also be interesting to look closer at prosumager-configurations that uses other ESS’s than lithium-ion batteries, like mechanical ones, pumped hydro storage, or thermic storage. Especially two of the cases have not been to studied to the depth they deserve due to the scope of this thesis: ASKO and Coop CLog could both easily have been the case of a whole thesis each centered around the socio-technical aspects of their organizations' adoption of technology.

8. REFERENCES:

Abernathy, William J, and Kim B Clark. 1985. "Innovation: Mapping the Winds of Creative Destruction." *Research Policy* 14: 20.

Bauknecht, Dierk, Allan Dahl Andersen, and Karoline Tornes Dunne. 2020. "Challenges for Electricity Network Governance in Whole System Change: Insights from Energy Transition in Norway." *Environmental Innovation and Societal Transitions* 37 (December): 318–31. https://doi.org/10.1016/j.eist.2020.09.004.

Botelho, D.F., B.H. Dias, L.W. de Oliveira, T.A. Soares, I. Rezende, and T. Sousa. 2021. "Innovative Business Models as Drivers for Prosumers Integration - Enablers and Barriers." *Renewable and Sustainable Energy Reviews* 144 (July): 111057. https://doi.org/10.1016/j.rser.2021.111057.

Brown, Donal, Stephen Hall, and Mark E. Davis. 2019. "Prosumers in the Post Subsidy Era: An Exploration of New Prosumer Business Models in the UK." *Energy Policy* 135 (December): 110984. https://doi.org/10.1016/j.enpol.2019.110984.

Dunn, Kevin. 2021. "Engaging Interviews." In *Qualitative Research Methods in Human Geography,* 5th ed. Canada: Oxford University Press.

Geels, Frank W. 2018. "Disruption and Low-Carbon System Transformation: Progress and New Challenges in Socio-Technical Transitions Research and the Multi-Level Perspective." *Energy Research & Social Science* 37 (March): 224–31. https://doi.org/10.1016/j.erss.2017.10.010.

Geels, Frank W., Tim Schwanen, Steve Sorrell, Kirsten Jenkins, and Benjamin K. Sovacool. 2018. "Reducing Energy Demand through Low Carbon Innovation: A Sociotechnical Transitions Perspective and Thirteen Research Debates." *Energy Research & Social Science* 40 (June): 23–35. https://doi.org/10.1016/j.erss.2017.11.003.

Inderberg, Tor Håkon Jackson, Kerstin Tews, and Britta Turner. 2018. "Is There a Prosumer Pathway? Exploring Household Solar Energy Development in Germany, Norway, and the United Kingdom." *Energy Research & Social Science* 42 (August): 258–69. https://doi.org/10.1016/j.erss.2018.04.006.

Jackson Inderberg, Tor Håkon, Hanne Sæle, Hege Westskog, and Tanja Winther. 2020. "The Dynamics of Solar Prosuming: Exploring Interconnections between Actor Groups in Norway." *Energy Research & Social Science* 70 (December): 101816. https://doi.org/10.1016/j.erss.2020.101816.

Jasper Deuten, J., Arie Rip, and Jaap Jelsma. 1997. "Societal Embedding and Product Creation Management." *Technology Analysis & Strategic Management* 9 (2): 131–48. https://doi.org/10.1080/09537329708524275.

Kanger, Laur, Frank W. Geels, Benjamin Sovacool, and Johan Schot. 2019. "Technological Diffusion as a Process of Societal Embedding: Lessons from Historical Automobile Transitions for Future Electric Mobility." *Transportation Research Part D: Transport and Environment* 71 (June): 47–66. https://doi.org/10.1016/j.trd.2018.11.012.

Lovdata. 2022. «Forskrift Om Måling, Avregning, Fakturering Av Nettjenester Og Elektrisk Energi, Nettselskapets Nøytralitet Mv – Lovdata". Accessed November 28. https://lovdata.no/dokument/SF/forskrift/1999-03-11-301.

Mandelbrot, Benoït. 1977. *Fractals: Form, Chance and Dimension*. 1st ed. W.H.Freeman & Company.

Masera, Diego, and Toby Couture. 2015. "Industrial Prosumers of Renewable Energy: Contribution to Inclusive and Sustainable Industrial Development." United Nations Industrial Development Organization. https://www.unido.org/sites/default/files/2015-04/PROSUMERS_Energy_0.pdf.

McMeekin, Andrew, Frank W. Geels, and Mike Hodson. 2019. "Mapping the Winds of Whole System Reconfiguration: Analysing Low-Carbon Transformations across Production, Distribution and Consumption in the UK Electricity System (1990–2016)." *Research Policy* 48 (5): 1216–31. https://doi.org/10.1016/j.respol.2018.12.007.

Merlet, Stanislas, and Bjørn Thorud. 2015. "Solenergi i Norge: Status Og Framtidsutsikter." *Energi Og Klima*, July 1, 2015. https://energiogklima.no/meninger-og-analyse/kommentar/solenergi-i-norge-status-og-framtidsutsikter/.

Norconsult. 2022. "Lillebror på sol i Europa øker kraftig." August 19, 2022. https://www.norconsult.no/aktuelt/nyheter/lillebror-pa-sol-i-europa-oker-kraftig/.

PricewaterhouseCoopers. 2022. “Kraft nok til det grønne skiftet? | PwC Norge”. PwC. Accessed November 28. https://www.pwc.no/no/pwc-aktuelt/kraft-nok-til-det-groenne-skiftet.html.

Rallo, H., L. Canals Casals, D. De La Torre, R. Reinhardt, C. Marchante, and B. Amante. 2020. “Lithium-Ion Battery 2nd Life Used as a Stationary Energy Storage System: Ageing and Economic Analysis in Two Real Cases.” *Journal of Cleaner Production* 272 (November): 122584. https://doi.org/10.1016/j.jclepro.2020.122584.

Reddy, Mogalahalli V., Alain Mauger, Christian M. Julien, Andrea Paolella, and Karim Zaghib. 2020. “Brief History of Early Lithium-Battery Development.” *Materials* 13 (8): 1884. https://doi.org/10.3390/ma13081884.

Schot, Johan, and Frank W. Geels. 2008. “Strategic Niche Management and Sustainable Innovation Journeys: Theory, Findings, Research Agenda, and Policy.” *Technology Analysis & Strategic Management* 20 (5): 537–54. https://doi.org/10.1080/09537320802292651.

SSB (Statistisk sentralbyrå) ‘Electricity’. 2022. Accessed November 27. https://www.ssb.no/en/energi-og-industri/energi/statistikk/elektrisitet.

Urbano, Eva M., Victor Martinez-Viol, Konstantinos Kampouropoulos, and Luis Romeral. 2021. “Energy Equipment Sizing and Operation Optimisation for Prosumer Industrial SMEs – A Lifetime Approach.” *Applied Energy* 299 (October): 117329. https://doi.org/10.1016/j.apenergy.2021.117329.

Violi, Antonio, Patrizia Beraldi, and Gianluca Carrozzino. 2022. “Dealing with the Stochastic Prosumager Problem with Controllable Loads.” *Soft Computing*, February. https://doi.org/10.1007/s00500-022-06809-2.

Weigelt, Carmen, Shaohua Lu, and J. Cameron Verhaal. 2021. “Blinded by the Sun: The Role of Prosumers as Niche Actors in Incumbent Firms’ Adoption of Solar Power during Sustainability Transitions.” *Research Policy* 50 (9): 104253. https://doi.org/10.1016/j.respol.2021.104253.