Enhancing the Power Grid:

Conservatism, innovation, and technical challenges for the Norwegian DSOs

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Abstract

Society needs to reduce its carbon footprint, and many consider electrification one of the most effective solutions. Buses, airplanes, cars, and industries want to electrify to reduce their emissions. The enormous demand and challenge fall upon the power grid to handle. However, in many countries, the power grid is already struggling to cope with the rapid transition toward zero-emission. Furthermore, constructing a new power grid takes upwards of ten years, whereas society requires more electricity today. Grid-enhancing technology promises a solution, increasing available capacity in the current grid by 25% using sensors clamping onto power lines. The sensors monitor parameters such as angle, voltage, and vibration. Nevertheless, the technology uptake is slow, despite the promised advantages. Several reasons could explain the lack of progress, such as lack of incentives, knowledge, or regulations requiring efficient power grids. In Norway, many industry stakeholders believe company culture is the culprit among Norwegian power grid operators. This report looks at company culture from a multiple-level perspective, uses a mixed-method approach with interviews and surveys, and analyses the data using a QCA-inspired method. The report finds that company culture and technical barriers limit the uptake of grid-enhancing technologies among the Norwegian power grid operators.

Foreword

Completing a master's program is a testing challenge, especially during a pandemic. At times it's felt like the tedious tasks never end; other times, it's been entertaining and enlightening. First of all, then, is a thank you to my friends and fellow students for getting through these years. I've spent too many hours locked up in tiny group rooms with some of you, and it's been a terrible pleasure. I won't do it again. Secondly, and by no means less important, is a thank you to my supervisor, Dr. rer. pol., Thomas Michael Sattich. Thomas, by his first name, no less, as I consider him a friend at this point, has been thoughtful and helpful whenever needed. He has taken time out of a busy schedule to help when required, and for that, I am ever thankful.

I would also like to thank Heimdall Power for suggesting the thesis and guiding me along my way. A thank you goes to James Dittmer and Vivi Mathiesen for taking time out of their schedules and helping me find resources for my thesis. Without them, this thesis would not have been possible.

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1 INTRODUCTION

The world's current energy production is not sustainable and contributes to global warming significantly. Electricity production alone accounted for 26.9% of GHG in 2018 (IEA, 2019). The International Energy Agency (IEA) expects a significant increase in clean and renewable energy resources (IEA, 2021). Furthermore, EIA, the U.S. Energy Information Administration, expects electricity demand to increase by 50% by 2050 (EIA, 2019). Given that much of the world's electricity production comes from fossil fuels, society is dependent on renewable energy resources to cope with the increased electricity demand without further increasing the damages caused by climate change (IEA, 2021c). It is of utmost importance to invest in renewable energy, increase energy efficiency and find solutions for challenges within renewable energy production to achieve SDG 7 (EEA, 2017). These challenges include maintaining the grid's secure and reliable energy supply, producing more renewable energy, and securing the massive investments needed to cope with the increasing electrification of society (Heggen, 2022; Saha et al., 2021).

At the recent COP26 in Scotland, world leaders came together to discuss the progress of the Paris Agreement and agree on further steps to decrease global climate emissions as a part of reaching the UN's Sustainable Development Goals. Close to 200 countries participated in the COP26 conference, resulting in two headline agreements and many minor agreements. The agreements from COP26 build upon the previously established goals from the Paris Climate Agreement of 2015. The Glasgow Climate Pact and the Paris Rulebook set the stage and will create guidelines for future endeavors to cut GHG emissions and reduce the impact of climate change (Carver, 2022). Two minor agreements are especially interesting for the future of the power grid; the phase-out of coal power and 100% zero-emissions vehicles by 2035 in leading markets (DfBEIS & DfT, 2022; Nations, 2021). Swapping coal-fired power plants with clean energy sources, such as solar or wind energy, will, in most cases, significantly change how the power grid functions. Coal plants also create stability in power grids – removing them can cause issues in a grid with intermittent energy resources. Furthermore, zero-emissions vehicles also generate challenges for the power grid, specifically BEVs that need to recharge rapidly (Komarnicki et al., 2017).

However, progress toward reaching the ambitious goals of the Paris Climate Agreement has been slow. Apart from a slight reduction due to the pandemic in 2020, global CO2 emissions have continued to rise since 2015 (IEA, 2021a), dulling hopes of reaching the Paris Climate Agreement goals. Even in well-off countries such as Norway, CO2 emissions have essentially continued to rise, with 2021 emissions only slightly below 2020 emissions in large part due to a fire in a refinery. Had the refinery produced normal levels of CO2, Norway's emissions would have increased in 2021 – levels that have more or less stayed flat since the 1990s (Norum, 2022). Much of the proposed emission cuts in Norway involve significant electrification, demanding more from the power grid. Unfortunately, the power grid is struggling to keep up with the speed of electrification, leading to significant queues for anyone wanting to electrify their operations (Heggen, 2022).

Norway is not alone in struggling to cut emissions – significantly larger countries such as the United States also have similar issues. At the start of June 2022, President Joe Biden invoked the Defence Production Act, or DPA, to increase the manufacturing needed in clean energy and the grid sectors. The Department of Energy plans to bolster the domestic production of heat pumps, insulation, solar panels, hydrogen-related equipment, and electric transformers through the DPA (Howland, 2022b). The move is called a "game-changer" by industry experts and mirrors similar moves done to bolster the production of batteries in the US (Howland, 2022a, 2022b). The power grid is critical for the US to reach its climate goals (Saha et al., 2021). Despite invoking the DPA, constructing a new, more robust power grid will still take several years (Lyse, 2020a). The power grid is crucial to the green shift and reducing CO2 emissions. The longer it takes to improve the power grid, the higher the likelihood it becomes the bottleneck for the green shift.

However, there might be solutions to help the world extract more from the power grid. Smart grid (SG) technologies, such as energy storage systems and advanced metering systems (AMS), allow more insight into and better use of the power grid (Majeed Butt et al., 2021). Similar systems are becoming essential to handle the decentralization of power production, speed up the transition to clean energy and reduce CO2 emissions. The power grid is crucial to the green shift, and technology could be crucial to the power grid.

1.1 INVESTING IN THE POWER GRID

The power grid is both simple and complex, and many point to it as humankind's most giant machine, with roots back to the 19th century (Hughes, 1983). It is relatively simple: Attach a power generator to one end, string out long power lines to wherever the electricity is needed, and the power grid is up and running. Arguably, no technology has had a more significant influence on society than the invention of the power grid (Hughes, 1983). Since then, the grid has, more or less, functioned similarly (NVE, 2022a). As society developed an affinity for electricity and its use became more common, the need for greater control over the power grid grew (Farmanbar et al., 2019). Most of the world's power grid is 'centralized' – meaning that electricity production happens at one specific point in the grid before distributing to the consumers. The familiarity with the regular power grid means that operators know where and how to tackle everyday use in the grid. However, the grid faces significant challenges in meeting the ever-increasing demand for renewable energy. These challenges include the intermittency of renewables (Sattich, 2015) and the decentralization of energy production. Some renewable energy technologies, such as solar panels, allow local energy production in the suburbs and industrial areas (Muench et al., 2014). The decentralization of energy happens at the distributional level of the grid, a blessing and a curse to the grid operators (Kanoria et al., 2011). More consumers are adopting grid-connected technologies, such as electric vehicles, energy management systems, and photovoltaics means greater demand and availability (Muench et al., 2014). Some grid operators have implemented smart grid (SG) technologies to cope with the new challenges by ensuring energy supply, transportation, and reliability. However, the implementation is small-scale and does not necessarily involve grid-enhancing technologies (Kranz et al., 2010).

With the increased need for electrification, the demand for more capacity in the power grid increased. The need for more capacity in the power grid has recently grown faster than the power grid expansion. In Norway, most of the power grid was constructed in the 1950s and 60s, leaving a need for rapid expansion to cope with, amongst others, the extraordinary increase in electric vehicles (Lyse, 2020a; SSB, 2022). The most recent bipartisan infrastructure bill in the US Senate planned to invest $27 billion during the fiscal years of 2022 and 2026 (Saha et al., 2021) (Saha, Cyrs, Neuberger & McLaughlin, 2021). Even in a significantly smaller market like Norway, Energi Norge estimates that the country's power grid needs more than $18 billion in reinvestments to cope with the increasing need for electrification (Heggen, 2022).

The underinvestment and -development of the power grid are not the only obstacles hampering the increased electrification of society. Even without considering the economics of constructing a new power grid, construction takes time. Between planning, applying for a concession, resubmitting with changes, and constructing the power grid, most operators estimate a timeline of 5-10 years, depending on the project size (Kraftnät, 2022; Lyse, 2020a; NVE, 2022a; Swissgrid, 2022). Furthermore, constructing a power grid can also cause significant damage to vulnerable natural resources and contribute to increased greenhouse gas emissions; from the materials and machines used and from releasing CO2 already bound in the ground (Helledal et al., 2020). Alas, using the power grid most efficiently could prove a valuable tool in reducing CO2 emissions and coping with the increasing demand for electrification.

1.2 GRID-ENHANCING TECHNOLOGIES

When referring to smart grid technologies, many often refer to technology that attaches to the power grid and, with various techniques or solutions, helps reduce the load on the grid. These technologies are generally connected to the power grid and, only in certain instances, increase the grid’s capacity but do little to increase its efficiency (some technologies can help stabilize the grid) (Adetokun et al., 2020; Farmanbar et al., 2019; Majeed Butt et al., 2021). Grid-enhancing technologies (GET) are a sub-genre of smart grid technologies. Most grid-enhancing technologies instead clamp their sensors onto the power lines. In theory, attaching GETs allows real-time data to determine whether a power line can transmit more power. As opposed to gas lines or water cables, power lines are not limited to the same extent by circumference, pressure, or flow rate; instead, resistance, vibrations, temperature, and safety limit how much power a line can transmit—called static line rating (SLR) (Energy, 2019).

According to industry actors, most power grid companies run their power lines conservatively to avoid permanently damaging the power lines. Overheating, icing, and wind cause challenges for power grid operators by tearing and stretching the power lines. Keeping the power at or below the SLR reduces the damage risk but limits the power line's capacity. Grid-enhancing technology offers a dynamic line rating (DLR) as a solution (D. o. Energy, 2019; Racz & Nemeth, 2021).

Heimdall Power, a company based in Stavanger, Norway, producing grid-enhancing technology, recently issued a report outlining the potential benefits of a large-scale implementation of GETs (Power, 2021). The company claims that, on average, their technology will increase the capacity of the existing power grid by 25 % by using the grid more efficiently. The increased capacity would also significantly reduce Northern European emissions and increase the revenue of power producers. Furthermore, the report outlines how GETs could increase the availability of intermittent renewable energy resources, thereby increasing the value generation of renewable energy resources (Paredes et al., 2021). DLR, and by extension GETs, also offer increased security by monitoring aspects that provide a risk to humans, wildlife, and nature (Racz & Nemeth, 2021)

Despite the potentially significant improvement offered by GETs, there are no large-scale installations today. Representatives from GET companies offer varying explanations as to why implementation is slow, many pointing to the culture of power grid operators. Power grid operators (TSOs or DSOs) culture is often perceived as conservative, valuing tried and tested methods instead of new and innovative ones (Muench et al., 2014). Many researchers, industry experts, and employees mirror the same message when questioned about innovation in the power grid industry. However, few documents show such an effect in the power grid industry, which is the reasoning behind this research.

1.3 THESIS STRUCTURE

The structure of this research resembles how one would explain a complicated topic. First, it establishes “the groundwork” for this research; who is involved, why, and why this research is relevant – which is the part you have read. Second, as this is a complicated issue with socio-technical, cultural, and technical challenges, this research explains the larger picture surrounding the research in a literature review. It provides a background for the importance of the power grid and explains how a power grid system might work. With a deeper understanding of the power grid established, this research explores the technical and societal challenges of expanding it: How it can be a bottleneck or an enabler to the green shift. Included is a more thorough explanation of the technology in use and how it could be advantageous.

With the basics out of the way, this research follows a more traditional structure. The problem statement and research questions follow the literature review. After stating and explaining the problem, this research provides reasoning and explanation as to why Norway is an excellent case for this research. Then comes a deep dive into the theory structuring this research and the research strategy used to extract as much correct information as possible. The method chapter explains the techniques behind the data collection and analysis before the data chapter presents the analyzed data. The data is then discussed in the following chapter, followed by a conclusion and reference list.

2 BACKGROUND: HOW POWER GRIDS FUNCTION

In general, a power grid consists of three layers: the transmission (often referred to as highways), the regional (county roads), and the distributional (local roads) grid. Each level transports different amounts of energy, with the Norwegian transmission grid often surpassing 132 kV and, in some cases, above 420 kV of power (NVE, 2022a). The amount of power transmitted in each grid level differs between countries, with some requiring more than 420 kV. Another essential factor is the frequency of the power grid. The frequency determines the stability of the power grid. Typically, the North American power grid runs at 60 Hertz (Hz), meaning that the electrons change direction 60 times each second (Wald, 2011). Meanwhile, most countries in Europe operate on 50 Hz (Swissgrid, 2022). Whether a country uses 50 or 60 Hz is in itself insignificant. However, it is significant that the entirety of one power grid runs on the same frequency to avoid damage to anything attached to the grid. Suppose the frequency strays too far from its ideal rate: In that case, users of the power grid will experience brownouts (unstable electricity current forcing light bulbs to flicker, for example), blackouts, and/or damages to any equipment attached to the power grid (Wald, 2011). The frequency is affected by the load on the power grid. Sudden changes in load, such as unexpected power peaks, can slow the frequency down to a halt, thereby cutting all power (Wald, 2011).

The increase in renewable energy resources, especially solar PV, offers other technical challenges such as voltage instability. Voltage instability is a dramatic drop in transmission system voltage which can lead to system disruption; in other words, blackouts (Van Cutsem, 2000). With its projection to become the dominant energy source in 2050, the power grid must cope with it (IEA, 2021b). Normally, the voltage in the power grid drops from generation to consumption by a couple of percent and is not much of a problem. System planners and operators handle heavy stress situations for the grid and check that all bus voltages remain within bounds (Van Cutsem, 2000). This is generally not a problem for power grid operators, especially at higher grid levels. However, more solar PV production at the lower levels of the power grid, such as on house roofs, can create voltage instability at a level the operators cannot control (Bukola Babatunde Adetokun et al., 2020).

As the decentralization of power production continues, power grid operators must learn to cope with more voltage instabilities (IEA, 2020, 2021b).

In Norway, the size of a distributional systems operator (DSO) is determined by the number of customers, not by the amount of delivered energy. According to the NVE, there are three different sizes of DSOs: small, medium, and large. Small DSOs (operators) serve less than 7000 end-users, and large operators serve more than 45 000 end-users. That leaves medium-sized operators with between 7000 and 45 000 end-users (NVE, 2022b). Since the operators follow the same regulations, they are also measured against a similar efficiency model. In this research, the only differences between the Norwegian DSOs are the company size and how many kilometers of lines they operate. Furthermore, this summer, Norway implements a new power tariff to incentivize lower power peaks in the power grids and alleviate some pressure from the power grid. The power tariff increases the cost of using power at peak hours and using large amounts of electricity simultaneously, charging an EV, showering, and cooking, for instance (Norge, 2022b).

3 LITERATURE REVIEW ON POWER GRID CHALLENGES

With the previous chapters focusing on the theme and how the power grid works, this chapter will explain briefly how the power grid is essential to the green shift. This chapter will then introduce and briefly explain how smart grid technology could improve how the grid is run and why grid-enhancing technologies can solve some of the grid's problems.

3.1 ENABLER AND BOTTLENECK

As briefly mentioned in previous chapters, the power grid is critical to succeeding in shifting towards greener energy sources. Today, electricity production is the single largest emitter of GHG gasses; less than a third of it is renewable (IEA, 2021a). According to the IEA, achieving zero emissions by 2050 requires a complete transformation of the global energy system (IEA, 2021b). In the IEA scenario, by 2050, almost 90% of all electricity production will come from renewable energy resources, with wind and solar PV accounting for nearly 70%. Furthermore, this scenario requires significant electrification: Multiplying today's heat pumps tenfold, reducing the number of people without electricity from 760 million to zero, electrifying industries and steel production, and electric vehicles in all sectors (IEA, 2021b). However, this IEA report does not consider the infrastructure needed to cope with such significant changes. In another report, IEA reckons the world needs to extend its power grid by 16 million kilometers in the next decade, 80% more than the world managed in the previous decade (IEA, 2020). Not only does the world need significantly more power grid, but the grid also needs to handle massive amounts of renewable energy resources, flexibility, and voltage instability (Economist, 2022; IEA, 2020).

Technical issues are not the only challenges the power grid must face. It is commonly known among industry experts, stakeholders, and insiders that the industry is conservative. In 2011, Grist, a non-profit media organization focusing on telling stories of climate solutions, wrote an interesting article on the perceived culture in the power grid industry (Roberts, 2011). Based on a survey from Black & Veatch, the author paints a picture of an industry solely focusing on regulatory requirements, with industry R&D the least important aspect to the CEOs. From the data, the author explains how companies in deregulated areas seem eager to implement new technology, whereas companies in regulated areas remain steadfast in their tracks. The article also draws upon an example from Germany: From 2000 to 2011, renewable energy production increased from 4% to 17%, but most came from private citizens and co-ops, not the utilities (Roberts, 2011).

The power grid is the bedrock of clean and secure electricity, as the IEA states in their report from 2020 (IEA, 2020). That bedrock is not strong enough to handle the future, and strengthening it seems to demand more than just technical solutions (IEA, 2020; Roberts, 2011; Wald, 2011).

3.2 SMARTER POWER GRIDS

It is difficult to determine the exact origins of the term ‘smart grid.’ Some sources credit the start of smart grids to the invention of the smart meter in the 1970s (Majeed Butt et al., 2021; Paraskevakos, 1972). The smart meter allowed power grid companies to monitor the power consumption of their customers. However, despite the early invention, large-scale implementation did not happen before the 2000s, with Norway one of the early adopters of mass implementation of AMS (Norway, 2019a). Nevertheless, smart meters are only a minor part of smart grids. The term smart grid encompasses and connects many technologies: energy storage systems, cities, buildings, power plants, smart homes, sensors, information technology, micro-grids, decentralized power production, communication, and provides increased sustainability. Higher user demand, increased reliance on stable power, and more electrification forced tighter regulations and increased order for safety, causing the need for technology to monitor the grid to become apparent (Majeed Butt et al., 2021; Pöyry, 2008).

By implementing sensors and improving the information flow, smart grids increase their efficiency, output, and potential capacity (Farmanbar et al., 2019; Majeed Butt et al., 2021). The term 'smart grid' does not define one specific technology. Instead, it helps us determine some of the technology in the power grid. In 2009, Yu et al. made a table illustrating the differences in how a conventional grid stacks up to the smart grid (see table 1). Whereas a conventional grid uses a small number of basic sensors, one-way communication, mechanical operation, centralized power generation, and limited control, a smart grid offers a wide range of control thanks to a large number of sensors, two-way real-time communication, and distributed power generation (Yu & Luan, 2009).

Table 1 is a comparison of smart and conventional grids.

Smart Grid	**Conventional Grid**
Two-way real-time communication	One-way communication
Distributed system of power generation	Centralized for power generation
Interconnected Network	Radial Network
A large number of sensors are involved	A small quantity of basic sensors are used
Digital Operation	Mechanical Operation
Automatic Control and Monitor	Manual Control and Monitor
Wide range of control	Limited control
Security and privacy concerns	No security of privacy concerns

Most power grid operators aim to maintain the highest possible uptime for the power grid (Drax, 2019; NVE, 2022a). A smart grid can offer many advantages, such as improved transparency, efficiency, and control (Yu & Luan, 2009). However, this does not determine whether a smart power grid is 'better' than a conventional grid, especially for power grid customers. Determining what 'better' means in this context is difficult. One way of measuring 'better' could be to measure the downtime of a power grid, meaning how often and for how long power grid customers experience blackouts – lack of electricity. Less downtime generally equals a more robust power grid.

In Norway, the Norwegian Energy Regulatory Authority measures this based on how much energy a power grid operator *did not* deliver through the KILE (Kostnader ved Ikke Levert Energi) system. Whereas the economic regulation of Norwegian DSOs encourages low-cost operations, the KILE system exists to incentivize "socio-economic optimal delivery reliability." The system reduces the income of the power grid operator equal to the socio-economic cost of the power outage. This means that the more customers affected by the blackout, the higher the socio-economic cost is, thereby reducing the income for the power grid operator. When the system was introduced in 2001, it only measured power outages longer than three minutes but has since been revised to incorporate shorter outages to encourage satisfactory delivery reliability (NVE, 2016a). The question for many power grid operators is whether smart grids improve or decrease the delivery reliability of their power grid, as there is no way to avoid power outages altogether (National Academies of Sciences & Medicine, 2017).

Resilience, robustness, and reliability are sometimes used interchangeably but are not the same. In 2020, Das et al. introduced a model to measure the resilience of smart grids. Resilience describes a system's ability to respond, and recover from, extreme events such as blackouts caused by severe weather. In contrast, reliability refers to the ability of the system to function under normal circumstances. Robustness refers to the system's ability to maintain functionality while withstanding fluctuations in adverse situations and operating conditions (Das et al., 2020). Generally, the power grid is designed to operate reliably under prescribed conditions and be robust to random fluctuations. However, the power grid also faces several extreme events that can inevitably result in significant deterioration and even loss of service. Typically, these events are severe weather such as hurricanes and storms or attacks from human agents – a class of events to which "no person or place is immune" (Academies et al., 2012; Das et al., 2020). A reliable grid functions well under normal circumstances. A robust grid withstands significant pressure during irregular circumstances. A resilient grid recovers quickly from adverse/unstable circumstances that have caused a failure (Das et al., 2020).

Studying power grids' resilience, especially smart grids, has become increasingly popular and important to several countries. The US DoE has announced funds of up $7.5 million to support "research and development of innovative designs that strengthen the resilience of the US power grid" (U. S. D. Energy, 2019). In India, the national transmission systems operator (TSO) published a report on enhancing the reliance of electricity infrastructure against climate change and extreme climatic events (PGCIL, 2015), pointing to the expansive geographical nature of the power grid and must withstand continuous and extraordinary challenges, such as severe weather. The rapid development and adaptation of smart grid technologies such as microgrids and dynamic pricing increase the randomness in the grid's operation, making it more prone to instabilities and failures (Das et al., 2020). In general, the power grid's vulnerability stems from the exposure to the external environment, allowing for tampering or damage. However, the introduction of a communication infrastructure connected to the cyber-space intertwined with the physical grid makes the power grid susceptible of cyber-attacks (An & Yang, 2018; Das et al., 2020; Teixeira et al., 2015).

Grid-enhancing technology generally separates itself from other smart grid technologies by attempting to increase the efficiency of the power grid itself (Dupin et al., 2019; Racz & Nemeth, 2021). Furthermore, GET often attaches itself to the power lines instead of being implemented into the power grid (D. o. Energy, 2019). The devices connect to the power lines and measure temperature, angle, and voltage parameters. The data allows operators better insight into the grid and a dynamic line rating. Dynamic line rating (DLR) is perhaps the most significant advantage of GETs, and in studies, it has proven to offer more than capacity increases. Using the available data, Racz and Nemeth showed that DLR can increase safety by allowing better control of the electric fields generated by power lines (Racz & Nemeth, 2021). The technology is still young, and stakeholders believe there is still more to learn from GETs and their data.

4 PROBLEM STATEMENT

The power grid is potentially both an enabler and a bottleneck for the transition towards a more sustainable energy future (IEA, 2020, 2021b). Unfortunately, expanding the power grid is a tedious and slow process, taking anywhere from 3 to 7 years (Lyse, 2020a), depending on size, cost, capacity, et cetera. It is, however, possible to deter the urgent need for a new power grid with grid-enhancing technologies, according to the manufacturers (Power, 2021). Despite the apparent possibilities GETs offer, implementation of the technology is slow. It is uncertain why progress is slow, which is the background for this research.

4.1 KNOWLEDGE GAP

Three main aspects affect the speed of implementation of SG technology, and thereby GETs, into the power grid: Regulation, economics, and cultural differences (Muench et al., 2014). The companies in this research all operate under the same regulations, and the economies are also regulated similarly, which this research returns to in a later section. Cultural difference is more of an all-encompassing category, including aspects such as risk aversion, willingness to change, and innovation. Therefore, the research proposed in this report focuses on the cultural differences between the companies.

The culture of power grid operators is not widely documented in currently available academic literature. Some have looked at the drivers for transformation in power grid companies (Reegård et al., 2019), which could include culture, whereas others have looked at the energy consumption culture (Stephenson et al., 2015). However, in a report from 2014, Muench et al. documented reluctance or ignorance toward smart grids within DSOs as a management issue, pointing to poor adaptation of the organizational structure (Muench et al., 2014). The technological aspect is certainly a lot more popular with an abundance of research on various challenges such as renewable energy (Bukola B. Adetokun et al., 2020; Foley et al., 2013; Luthander et al., 2019), extreme weather (Das et al., 2020; Jufri et al., 2019; Pörtner et al., 2022), and bottlenecks (Bauknecht et al., 2020; Malhotra & Schmidt, 2020; Winter et al., 2015). Interestingly, dynamic line rating, one of the main benefits of grid-enhancing technologies, is not as widely covered (Dupin et al., 2019; McCall & Servatius, 2016; Racz & Nemeth, 2021), perhaps due to it being a developing field of research. However, several sources within the Norwegian DSOs view the culture as conservative and somewhat reluctant to change. The reasoning is often based upon the significance of their social mission of delivering electricity to all customers at all times (NVE, 2015). Furthermore, one can also look at how the power grid operators often base their decisions on a 40-80 year view instead of a typical 5-10 year horizon (Lyse, 2020a; Zellweger, 2007), likely leading to more risk-aversion. New technology, especially technology dependent on connectivity, is potentially a new vulnerability for grid operators (Das et al., 2020). This can lead companies to choose repeatedly tried and tested technology instead of new and unproven technology to avoid expensive investments in seemingly unreliable technology, thus hampering innovation. There have been several examples of risk-aversion crippling companies; most famous perhaps is the bankruptcy of Kodak, a world-renowned producer of analog photographic equipment, exemplifying that some risk is needed to evolve (Cuthbertson et al., 2015). Nonetheless, municipalities own most of the Norwegian DSOs, which all serve under NVE's economic regulation, making bankruptcies unlikely (Norway, 2019b; NVE, 2016b).

Contrary to the conceived conservatism ingrained in the industry, some actors have publicly stated an interest in being innovative and forward-leaning (Lyse, 2020b). Therefore, there seems to be a gap between what industry actors observe, what the companies convey, and what evaluations the decision-makers in the power grid industry determine as crucial. This report attempts to narrow that knowledge gap by finding differences in how the companies determine whether or how to explore new technological opportunities.

4.2 RESEARCH QUESTIONS

This research attempts to answer one fundamental question:

- Is the company culture within the power grid industry limiting the uptake of grid-enhancing technologies?

Answering this question is not straightforward, nor will it necessarily give the full insight into what limits the implementation of GETs. Therefore, this research will answer a sub-set of questions to understand the power grid's challenges and culture. The answers to these more focused questions will help this research offer a better answer to the main research question:

1. Are the grid companies aware of grid-enhancing technologies?
2. What do the grid companies view as challenges for new technology in the power grid?
3. Are there cultural differences between power grid companies?

5 THE CASE OF NORWAY

This chapter will focus on the differences in how countries operate their power grids. By doing so, this chapter explains why Norway is a viable and reasonable study. The power grid is more or less standardized. Some power grids stretch across continents, and others connect villages, yet the functionality is similar (Swissgrid, 2022). However, almost every continent or country operates, maintains, and finances its power grid differently (Kraftnät, 2022; Pöyry, 2008), which means finding differences in culture and perception of risk/risk aversion across countries could prove problematic.

Furthermore, how governments incentivize technology that improves the power grid operation also differs. Sweden, for instance, strongly incentivizes constructing a new power grid (Kraftnät, 2022) without necessarily increasing the efficiency of the existing grid, according to sources within the industry. In contrast, Ireland requires all power grid operators to ‘observe the true real-time grid capacity’ from 2023 (Jones, 2021). Both scenarios make discovering risk aversion in meeting innovation in the power grid difficult. So far, this report has mentioned the Norwegian power grid several times – from explaining its new power tariff to providing a better understanding of the size categories of each company – but it has yet to explain why the Norwegian power grid is relevant.

Norway differs from Sweden and Ireland in that in most of Norway’s power grid was constructed with significant overhead capacity in the 50s and 60s. The considerable overhead led most DSOs to not worry about their ability to deal with increased electrification for many years. It also allowed many households to use electric heating as standard, with most houses using main fuses with 230 volts and 63-ampere capacity (Svendsby & Buggeland, 2015). At the same time, most houses in the US used 120 volts and 60-ampere main fuses, equating to roughly half the output (Wallender, 2022). Modern houses in Ireland use 52 amperes in a three-phase grid (ESB, 2021), still 2500 watts behind the old Norwegian standard. However, such strong fuses allow private homes to install high-capacity EV chargers or solar panels without stressing their fuse boxes. The significant overhead meant that the infrastructure withstood some electrification. Still, the recent and quick push toward solar PVs and EVs has left the DSOs scrambling to modernize large grid parts to cope with increased demand (Heggen, 2022).

How each DSO handles its modernization is of interest as all DSOs in Norway operate under the same regulation managed by the Norwegian Water Resources and Energy Directorate (NVE). The regulation measures and compares the DSOs' efficiency in operating, maintaining, improving, and constructing the power grid. The more efficient a DSO is, the more money it receives from the government. The evaluation also considers employee spending and other business-related costs (Pöyry, 2008).

Recently, Norwegian officials opened for technology attaching onto power lines, opening the door for more innovation in the Norwegian power grid (NVE, 2016b). Despite the new regulation, DSOs have been reluctant to incorporate GETs on a large scale. Increased efficiency and lower construction costs should, in theory, incentivize DSOs to implement similar technology. However, this is an interesting area to research as all participants operate under the same regulation. Additionally, with all else being relatively equal, finding differences and potential factors influencing the differences between each DSO will be easier.

Norway poses an interesting case because of more than its rules and regulations. The electricity production consists of more than 90% hydropower, providing the country with renewable, cheap, and clean energy (Statkraft, 2022). However, since the fall of 2021, Norway has experienced skyrocketing electricity prices (Lydersen & Holm-Nilsen, 2021; Skifjeld et al., 2022). There is no one answer to why the prices are rising, but some blame the power export through newer power cables (Årseth, 2022). The claim has since received criticism as incorrect (Molnes, 2022). However, no matter the cause, the prices only affect the southern parts of the country, while the northern parts continue to have some of Europe's cheapest electricity prices (Norge, 2022a). A large part of this price discrepancy is the lack of transmission capacity between the north, mid, and south parts of Norway's power grid (Norge, 2022a; Statnett, 2022). The price difference between the north and south can sometimes exceed 8 NOK per kWh – more than 20 times higher (Norge, 2022a; Skifjeld et al., 2022). The sudden extreme prices and internal price differences in Norway show how vulnerable countries can become due to low capacity in the power grid.

Furthermore, with the increasing penetration of renewable energy resources in the power grid, it becomes more likely that areas of the grid experience more available power than other areas (Howland, 2022b; IEA, 2021b; Saha et al., 2021). Understanding challenges in integrating technology that could reduce such instances could become vital to policymakers and businesses.

6 THEORY

This study requires a framework to understand better the inner workings of culture, innovation, and transition and how that changes society as it is today. The multi-level perspective (MLP) is a valuable tool to structure the systems around innovation and transition and the resistance against it from a societal perspective. Furthermore, it is also helpful in defining and separating the different transition levels, from a niche involving few to part of an established regime that many follow. Innovation and culture also play a vital part in breaching a regime. Innovation drives progress, and a culture supporting innovation is essential for innovation to thrive. The multiple-level perspective can house both aspects, depending on the understanding of the model. This study understands the power grid industry as the landscape we experience today, incorporating and pressuring the regime that holds the rules and regulations that run it. In contrast, the development of grid-enhancing technology is a niche trying to break through into the regime.

6.1 A MULTI-LEVEL PERSPECTIVE

Geels explains the MLP as “a middle-range theory that conceptualizes overall dynamic patterns in socio-technical transitions” (Geels, 2011). The theory aims to combine various disciplines and findings from different works of literature. Transitions are considered non-linear processes within the MLP, with transitions resulting from “the interplay of developments” inside the levels (Geels, 2011). The framework establishes three different heuristic and analytical levels; the socio-technical landscape, the socio-technical regime, and niches (Geels, 2002). The socio-technical landscape is the most stable level and incorporates both the regimes and the niches. It is both physical and metaphorical, including the broader contextual developments that influence the socio-technical regime. Actors within the regime have little or no influence on the landscape (Geels, 2012; Geels et al., 2017). In this setting, increased stability equals a longer time for the level to succumb to changes. Each level is influenced and pressured by the landscape, with each level having decreased stability, niches being the most unstable, most likely to change, and having the least structure (Geels, 2011; Grin et al., 2010). Transitions occur when a disruptive force at the landscape level puts pressure on the incumbent regimes, allowing innovative technologies to penetrate the regime level and eventually become the new regime (Geels, 2002; Grin et al., 2010).

The socio-technical regime consists of, among other components, regulations, infrastructure, technology, science, and culture. Central to them is providing a societal function such as transport, heat provision, or housing (Kern, 2012). It is also possible to define them as “the linkages between elements necessary to fulfill societal functions” (Geels, 2004). We can conceptualize socio-technical systems as aggregates of similar segments, such as cultural meaning, infrastructure, rules, regulation, markets, knowledge, and technical artifacts. Changes in such systems are often based on mechanisms of co-development of technology and society (Kern, 2012). Several studies suggest that the MLP can be usefully adapted to understand the process of changes in a socio-technical system (Geels, 2004; Rip & Kemp, 1998). To understand better how the transitions occur, we can use the power grid system as a concept. The landscape level consists of slowly changing factors such as climate change, which influences how the power grid is developed and used, but the effects climate change has on the power grid are beyond the control of individual actors. We can characterize the current regime system by a figuration of institutions, networks, user practices, regulatory frameworks, scientific knowledge, cultural meanings, and technological artifacts. Regimes are thought to have relatively stable configurations (Kern, 2012; Rip & Kemp, 1998). In general, we consider stable configurations a positive thing; it creates and provides stability for technology development. However, stability can also cause a feeling of ‘entrapment’ or a ‘lock-in’ feeling (Unruh, 2000; Walker, 2000). The literature on technological regime change usually emphasizes these incremental changes in the existing trajectories instead of abrupt changes at a niche level (Berkhout, 2002). New energy practices and technological innovations such as renewable energy technologies emerge at the niche level. These places or markets are protected, allowing the technology to evolve and potentially start competing with the dominant regime before eventually ‘overturning’ it (Smith et al., 2010). However, Smith et al. also question what makes niches a “protective space” and how far it extends – alas, what protection the niche offers (Smith et al., 2010).

Niche innovations are innovations, social or technical, that are radically different from the prevailing socio-technical system and regime. The innovations are able to gain a foothold in specific applications, markets, geographical areas, or through targeted policy support (Geels et al., 2017). Niche development, however, is dependent on gaining valuable knowledge and generating more beneficially articulated supportive institutional requirements. Furthermore, the development needs commitments from a more extensive network such as potential investors and mainstream users (Raven, 2006; Smith et al., 2010). Niche actors must be persuasive on different terms to various constituencies, performing considerable economic, political, and institutional work. Niches compete with incumbent regimes, outperforming them to take over (Hendriks & Grin, 2007; Smith, 2007; Smith et al., 2010), which means that niches are not for blueprints but a source for transformative ideas and capabilities. Their potential is constrained, enabled, and interpreted through the more robust structures of the regime (Bos & Grin, 2008; Grin et al., 2004; Roep et al., 2003; Smith et al., 2010).

We can distinguish four phases in these decades-long transition processes through the MLP. Radical innovations emerge on the fringes of the existing regimes in the first phase. The innovation networks are unstable, experimental, fragile, and often uncertain, leading to the generation of different design options – many of which fail (Geels et al., 2017). The innovation then enters the second phase, permeating small market niches, and providing further development and specialization resources. Here, the innovation develops its trajectory, and with a dominant design, the expectations and rules emerge and begin to stabilize (Geels et al., 2017). For the third phase, the innovation starts breaking through more widely and competing with the established regime. However, this is dependent on a couple of factors: Internal factors such as price and performance improvement and external factors such as the development of complementary technology, infrastructure, cultural acceptance, and support from significant actors. Persistent internal problems such as urban air quality or rising energy prices causing landscape pressures also create instability and open up "windows of opportunity" for niche innovations (Geels et al., 2017). The fourth and final phase is distinguished by a significant change in the regime, with widespread implementation of innovations combined with broadscale changes in policies, infrastructure, industrial and market structures, lifestyles, and acceptance of normality. "The new regime becomes institutionalized and increasingly taken for granted" (Geels et al., 2017).

In 2010, Smith et al. argued that the change in sustainable development emphasizes the specific interest in the normative direction of innovation. This means that the challenge for innovation no longer rests solely on the economic potential; it also relies on the societal changes introduced by innovation. Furthermore, it also depends on environmental consequences and social sustainability (Smith et al., 2010). Studying sustainable transitions using the multiple-level perspective could fit well, but while Smith et al. argue for its potential, they also explore its pitfalls. So far, there has not been a 'standard' for using the MLP in research – no specific set of indicators, metrics, or measures. Furthermore, sustainability transition studies combine evolutionary theories of socio-technical change with agency and decision-making theories (Smith et al., 2010).

6.2 ENERGY AND INNOVATION CULTURE

Innovation can be a company's most potent weapon to create profits (Kuczmarski, 2003). Innovation is essential for the competitiveness of the whole economy. Combined with innovation strategy, many consider innovation as one of the ways to build up competitive advantage advantages and achieve a successful strategy (Christensen, 1997; Drucker, 2014; Grant, 2013; Johnson et al., 2011, 2012; Jones, 2012; Krause, 2016). In a Kuczmarski & Associates Inc. (K&A) study, statements made by managers of Fortune 500 companies show an increasing reliance on cost-cutting to achieve growth (Kuczmarski, 2003). While striving to stay cost-competitive is a sound and prudent business practice, innovation is the single best way to leapfrog the competition, move ahead of the industry pack, and, most important, create new ways to bolster profit margins and fuel future earnings streams (Kuczmarski, 2003). This also applies to the power grid industry, albeit with a greater focus on regulation – innovation can be highly effective in increasing the usability of the power grid. However, innovation comes from within the company and whether or not there is a culture for innovation within it (Muench et al., 2014; Sataøen et al., 2015; Winter et al., 2015).

Culture generally refers to a shared set of meanings, traditions, ideals, norms, materials, and practices that come together to form a distinct assemblage with subjective and objective features. Culture can refer to the characteristics of an indigenous group ('ethnic culture'), a workplace ('organizational culture'), a generation ('millennials'), a country ('American culture'), or a pan-national epoch ('Western culture') (Stephenson, 2018). Cultural assemblages contain common meanings from the past and cast these meanings into the future, as reflected in people's and institutions' daily activities; hence cultural patterns are frequently regarded as a force of habituation (Dew et al., 2017; Stephenson, 2018; Stephenson et al., 2021). Culture is not an afterthought when it comes to sustainability-related concerns and outcomes. Cultures rarely remain static; they adapt and morph in response to changing circumstances. While many cultures are well-established and reasonably consistent, their ability to adapt to changing circumstances as an adaptive mechanism is also essential, especially in this era of climate change. Some studies of families and enterprises in various nations have found causal relationships between cultural traits of these actors and results, such as relative levels of energy use (Dew et al., 2017; Stephenson, 2018; Stephenson et al., 2021).

Two terms from culture studies are especially relevant for the power grid industry: Energy culture and company culture. Janet Stephenson uses an energy culture framework to showcase and model what drives household energy usage (Stephenson, 2018). Energy culture is relevant to understanding why, how, and when consumers increase their energy use, which in this case means the increased load on the power grid (Stephenson, 2018; Stephenson et al., 2015). However, for this research, we already know why, how, and when consumers increase their electricity consumption (Economist, 2022; Heggen, 2022; IEA, 2021a, 2021b). The question then is the company culture of power grid companies.

In 2014, Muench et al. looked at what hampers energy system transformation, specifically change in the power grid systems. The report found several interesting limitations through a series of qualitative interviews – a similar method to this research. One of the issues for SG in Germany was a poor adaptation of the organizational structure (Muench et al., 2014). While most DSOs accepted that the electricity industry is changing fundamentally, some companies chose to ignore it. To cope with the changes, Muench et al. found that the companies must shift their priority from cost-effectiveness to innovation capacity – a culture that contradicts how they have done until now. They also found that top management and employees were reluctant to adapt, particularly for the traditionally blue-collar workforce in DSOs (Muench et al., 2014). In a report from 2011, Roberts found similar results from the top management in U.S. DSOs (Roberts, 2011). The same report from Roberts also noted what he called “small-c conservatism” in power grid companies. The phrase stems from the companies’ reluctance to innovate, change their operations, and avoid risk. However, he also states the companies had well-founded arguments for it: Regulation not demanding it, constructions that have to last long, and uncertainty of use/longevity (Roberts, 2011).

Risk-aversion towards innovation is not uncommon in the public sector and institutions with significant social responsibility (Dew et al., 2017; Torugsa & Arundel, 2017). A clear example of this is the simple case of switching to LED lights on U.S. Navy ships. LED lights offer technical, safety, and efficiency advantages over incandescent and fluorescent lighting systems. The Navy started researching LEDs in 2002, yet, in 2015, 90% of total fleet lighting needs were still from other sources (Closson, 2013; Dew et al., 2017). Part of the reason for this slow implementation is the apparent benefits of LEDs; organizations do not adopt energy innovations using analyses focused just on costs and benefits. The Navy views energy as an abundant resource and sees no interest in changing its view (Dew et al., 2017). Muench observed similar behavior with SG and DSOs as several companies saw no need for technology to optimize their grids – they had no issues to fix. Furthermore, they had little experience with smart grid technologies, and the perceived threat of data security worsened the situation (Muench et al., 2014).

However, this only gives us a general overview of the culture in the power grid industry but not a detailed insight into the Norwegian power grid industry. In 2019, Reegård et al. presented findings from researching drivers for transforming the power grid company. Instead of claiming an innovative culture inside the company, the interviewees explained that most innovation came from a handful of individuals (Reegård et al., 2019). The finding could indicate that Norwegian power grid operators resemble their colleagues abroad despite different regulations.

7 RESEARCH STRATEGY

This chapter explains how the methods combine and how inductive and abductive logic understands different aspects of the research. The increasingly popular QCA model inspires this research. Since the data available on this subject is limited, it is not possible yet to do a complete QCA evaluation of culture in the power grid industry. Therefore, this research takes some of the strengths of QCA and combines them with a more common mixed-method approach.

7.1 INDUCTIVE AND ABDUCTIVE LOGIC

Inductive logic is based on learning from patterns and experiences to formulate a hypothesis, proposition, or conclusion. Inductive research starts with a case, makes observations, and then generalizes and establishes regularities (Blaikie & Priest, 2019; Dey, 2004). Blaikie and Priest define inductive logic as a generator of limited generalizations from observed or measured physiognomies of individuals and social phenomena. Part of this research will consist of inductive content that requires observations and measurements. That data will expose patterns and regularities that can help explain certain phenomena. Eventually, it could lead to a testable theory through hypotheses. When phrasing the research questions, the inductive logic of inquiry does not disregard previous research and theories. Instead, it tries to generate meaning from the knowledge and data collected. In this research, inductive logic will help better understand the matureness of the technology. Furthermore, it could help make predictions for future development and behavior. Inductive research also allows adjusting the research direction and objectives during the research process.

Abductive research aims to distinguish the construction of reality according to different actors. It considers how these actors conceptualize, understand, and give meaning to their social world

(Blaikie & Priest, 2019). Furthermore, the research strategy enables the concept of recontextualization, which entails observing, describing, interpreting, and explaining a phenomenon, pattern, or other within the frame of a new context (Danermark et al., 2019). By recontextualizing a known phenomenon, it can be seen through new lenses, resulting in original meaning and interpretation. Abductive research aims not to the accuracy or truth of a theory. Instead, it seeks to use theory and observation to arrive at a novel understanding of specific events, phenomena, or concepts (Danermark et al., 2019; Dey, 2004). Abductive logic does not produce generalizable results. Instead, it considers the uniqueness of certain phenomena, concepts, and events (Dey, 2004).

This research uses the abductive logic of inquiry to recontextualize relevant transition approaches to explain how implementation barriers to technology, such as grid-enhancing technologies, are addressable. Abductive logic is also helpful for understanding grid operators' motivations for implementing GETs into their systems and interpreting the results within a conceptual framework. The logic enables an interpretive process that ascribes meanings to events in a broader context. However, it lacks a fixed criterion, making it difficult to assess the validity of a conclusion derived from abductive research (Danermark et al., 2019; Dey, 2004).

This research uses inductive logic to find patterns and formulate a conclusion. Combining inductive logic with a QCA-inspired mixed-method approach allows the researcher to find patterns and experiences. This becomes part of the data reanalyzed based on a hypothesis before coming to a conclusion and presenting regularities that conform with the data. The research then combines this inductive understanding with an abductive interpretation of the theory and framework. The abductive logic allows the researcher to view the data and the results in a framework to understand the effects of the conclusion.

7.2 INSPIRED BY QCA

In recent years there has been an increase in interest in a methodological family known by its abbreviation, 'QCA.' The acronym stands for 'Qualitative Comparative Analysis,' popularized in 1987 by American social scientist Charles Ragin (Schneider & Wagemann, 2010a). A QCA analysis's overall purpose is to assist the researcher in arriving at a meaningful interpretation of the patterns shown by the investigated instances. Analyzing set-theoretic links between causally relevant conditions and a characterized outcome is the crucial premise guiding the technical element of QCA. The necessity and/or sufficiency of these set-theoretic links is then determined.

In a broader sense, QCA is regarded as a research strategy, and in a more specific sense, as an analytical tool. In other words, the interpretation of QCA as a research approach relates to the iterative process of data collection, model specification, case selection, and re-conceptualization of the conditions and outcomes, all of which are critical for any QCA-based study design. This component of QCA is quite similar to quantitative, variable-oriented data analysis approaches like regression analysis in its different versions, for example (Schneider & Wagemann, 2010a). This feature of QCA comes from its 'qualitative roots,' as it is a frequent technique in conventional qualitative comparative research to exclude and/or add cases from the analysis during the study, re-code values for specific instances, or re-conceptualize entire variables. However, most of these techniques are usually prohibited in quantitative, statistically oriented research (Schneider & Wagemann, 2010b). The third facet of QCA can be used as an analytical tool. This is the so-called 'analytical moment,' which occurs after all the cases have been identified and all conditions and outcomes have been measured. The primary purpose of this stage of the QCA-based research method is to uncover empirical patterns in the data (Schneider & Wagemann, 2010a, 2010b).

The QCA inspired a model, which in this case is a table, to help us better understand the results of the methods in this research: Surveys and interviews. It is important to note that this is not a full QCA – this research uses only parts of the QCA and takes inspiration from its strengths, such as the analytical tool, to improve the study's validity.

8 METHOD

This forthcoming chapter outlines the methods used in collecting and analyzing the data. Each subsection explains the chosen method and argues why it is the most effective given its use. The method is how this reporting conducted the research.

8.1 MIXED METHODS

Deciding whether to do qualitative or quantitative research is one of the first challenges of writing a master's thesis, as each method has its benefits and negatives. Generally, quantitative methods concern themselves with measuring and counting aspects of social life, whereas qualitative methods concern themselves with exploring social actors' interpretations and meanings and discursive descriptions of them (Blaikie & Priest, 2019). Another solution to the indecisive, or where neither research fits well enough, is to do both, which is what this thesis does. This research practices a mixed-method approach to answer the research questions in this thesis.

Sequencing is an essential part of mixed methods. Sequencing refers to the logical and chronological combination of methods in a design (Mele & Belardinelli, 2019). Two designs are prominent: A parallel design and a sequential design. This research uses a sequential design where one method comes before the other (Mele & Belardinelli, 2019). In this case, a quanti-qualitative design that emphasizes an explanatory approach. This is useful when the data collected in the first round, in this case, a survey, is puzzling or if the researchers feel that the data is not revealing enough. The researchers can then use qualitative methods such as interviews to understand casual mechanisms assumed to underlie correlation or causal quantitative findings. The qualitative phase can also shed light on actors' inner views, thereby contributing to a "refinement of the findings" (Mele & Belardinelli, 2019).

Andrews, Nonnecke & Preece writes that a web-based survey efficiently distributes and collects easily stored data in online databases (Andrews et al., 2003). This research uses a quantitative survey to collect representative and generalizable data effectively. Blaikie and Priest write that a mixed method "involves the collection, analysis, and mixing of both quantitative and qualitative data in a single study or a series of studies" (Blaikie and Priest 2019). According to Sharlene Nagy Hesse-Biber, the author of the book "Mixed Methods Research, merging theory with practice," mixed methods can be suitable if done correctly (Hesse-Biber, 2010). Hesse-Biber argues that using qualitative methods in mixed methods can be very useful, giving the researcher a better understanding of the issue. Hesse-Biber writes about different reasons to perform mixed-method research, one of which is "initiation." She emphasizes that some findings will need clarification which initiates further research. Including interviews after a qualitative survey could add new insight into the issue (Hesse-Biber, 2010).

Hesse-Biber interviewed David Karp about what he thought about using mixed-method. He expressed that these methods should be used to theoretically forward our understanding of something. He also states that using this method when it does not forward our understanding is highly problematic and could weaken the research (Hesse-Biber, 2010). It is crucial to consider whether adding another method will strengthen or weaken any research. Due to the different angles of the research questions, a mixed method was thought to strengthen the research. However, as Hesse Biber points out, there can be potential unintended negative consequences of including different research methods during the research. One problem is that a researcher uses two different methods but is not necessarily skilled in both. According to Hesse-Biber, using mixed methods is an explanatory sequential design. This research first collects the data through a quantitative approach and then follows up with a qualitative methodology. Using mixed methods "gives priority" to the quantitative method (Hesse-Biber 2010).

In 2013, Neuman wrote that a close-ended survey could be problematic because it forces the respondents to answer one of the provided alternatives. Studies have shown that not offering an "other" or a neutral answer such as "not certain" forces people to answer, despite not knowing the answer or their opinion about the issue (Neuman, 2013). Neuman suggests the possibility of using a partially open format, where the researcher adds alternatives such as "other." However, doing an open-ended survey is time-consuming to code and analyze. A danger while doing an online survey is not receiving many answers, and the respondents become tired of answering surveys (Neuman, 2013). Neuman states that reflecting on what the researchers want to learn from each question is crucial. Before settling questions, the researcher should consider how the results will be used (Neuman, 2013).

This research uses a mixed-method approach inspired by QCA to find and determine differences in culture among power grid operates. This research is based upon informal interviews with sources within the power grid industry and academia. A couple of things are evident from these interviews:

1. Power grid companies are run conservatively due to their significant responsibility.
2. The conservatism is reflected in some aspects of their operations, such as their reluctance to change operational methods despite potential gains.

By talking to researchers inside the industry, it became clear that some companies would not change how they run their power grid even if newer methods could increase their efficiency, often due to the perceived significant change in operations. Furthermore, some companies seemed uninterested in broadening their understanding of new technology due to the same perceived challenge.

Companies that show knowledge of newer technology available to improve the power grid are more likely to have evaluated the use-case of the technology and thereby more interested in implementing new technology into their grid. Furthermore, this could indicate that the company is willing to endure the perceived higher level of risk that comes with innovation. This, in turn, opens the door for technology, such as GETs, to be installed in the power grid.

However, that would only showcase a difference in how the power grid companies evaluate technology and its use-case. Therefore, this research includes a more profound in-depth interview with the survey's outliers to understand better where this potential difference comes from. Interviews are one of the core data collection methods in qualitative research (Belk et al., 2012). The researcher can gain in-depth knowledge about something using interviews that most likely are important in the informant´s life, something only the informant has much information about. The in-depth interviews are often long (up to and over an hour) and have a somewhat formal structure (Belk et al., 2012).

8.2 DATA COLLECTION

Data in this research comes from three primary sources: A literature review, a survey, and in-depth interviews with actors inside and experts surrounding the industries. The research requested a response to a study from 25 different Norwegian DSOs of varying sizes: five large, eight medium, and 12 small. After the survey, four companies of differing sizes were interviewed to understand the motivations and thought processes behind the answers. Other experts were consulted and interviewed before, during, and after surveying the DSOs. This chapter focuses on the data gathered from surveys and interviews, based on the previous chapter's logic.

The survey attempts to differentiate how each power grid operator views new technology and innovation within the industry. The research tackles this by questioning the company's motive for innovating and whether the companies are aware of any viable alternatives to physical grid expansion. The participants represent companies of different sizes and budgets, from several thousand to a couple of hundreds of customers. The survey suggested the types of personnel with knowledge of the theme but left it to the company to decide who and how many would answer. It is, therefore, improbable that personnel of similar positions in all companies answered the questions. Furthermore, some companies, mainly the large ones, have specific departments looking at research and development. That is an obvious advantage and challenge in a survey looking at culture as an inhibitor of innovation, which will be deliberated later.

The survey posed five required questions and one optional. One of the questions included ranking how the companies consider different attributes when upgrading or constructing a power grid. The survey tasked the companies to answer these questions:

1. What significant challenges does the company see in the power grid today?
2. Follow-up: Do the challenges require changes in the company/in the company's daily operations (such as limiting new connections due to the lack of available capacity)?
3. Ranking: Where would an improvement be most valuable to the company?
    a. Increased delivery security
    b. Increased capacity
    c. Increased safety
    d. Reduced maintenance costs
    e. Other
    f. Real-time data from the power grid
4. Follow-up on ranking (optional): If you rated "other" highly in the ranking, what would your company prioritize?
5. Does the company see any alternatives to constructing a new power grid?
6. Are there new technologies that the company considers interesting in the daily operations and planning of a new power grid?

There is a plan behind the order and the wording of each question. By positioning the more "locked-in" questions closer to the end of the survey, the participant's answers are less likely to be influenced by a more leading question. It also allows the participants to answer more freely, perhaps more likely to touch on other subjects and themes than if asked a stricter worded question. The questions are open to interpretations and short and long answers. Some respondents wrote responses over 100 words, and others kept them short at ten words or less. The results are presented in the next chapter.

Interviews:

A significant part of this research comes from qualitative interviews with actors, experts, and stakeholders in and from the power grid industry. The interviews were conducted before, during, and after the surveys to gather as much context and knowledge as possible. Some unscripted interviews had no goal other than gathering viewpoints and context, whereas others had specific goals. Following is a table of interviewees, listed in no particular order:

Table 2 is an overview of participating interviewees and their expertise and relevance to this research.

Interviewee number	Tittle/expertise	Relevance
1	Regulation expert	In-depth knowledge of the Norwegian power grid regulatory affairs and understanding of DSO culture
2	Sales, GET	Operating in a market of interest to this report
3	CEO, GET	In charge of one of the leading GET-companies
4	CEO, DSO	Large DSO
5	Head of communication, interest organization	In-depth knowledge of Norwegian DSOs and their culture
6	Head of communication, DSO	Large DSO, extensive knowledge of industry culture
7	Regulation expert	Extensive knowledge of EU and US regulations
8	Engineer, DSO	Small DSO, knowledge of technological challenges
9	Engineer, GET	Extensive knowledge of GETs
10	CEO, DSO	Small DSO
11	CEO, DSO	Mid-size DSO

12	Industry expert	Researcher with expertise in the energy industry
13	Industry expert, DSO	Large DSO; research and development
14	CTO, DSO	Mid-size DSO; technology

The data from the interviews and surveys are presented in the next section.

8.3 DATA ANALYSIS

This research uses the inspiration from QCA and data from the mixed-method approach to create a table for identifying if culture limits GETs. The table is presented and explained in this chapter and put to use in the discussion chapter.

QCA-inspired table:

Table 3 shows what the QCA-inspired table contains. The table does not provide any results.

Size/factor:	Grid alternatives	Prioritizes innovation	Resource issues	Prioritizes regulation	Attention to culture
Small					
Medium					
Large					

Nailing down differences in culture is inherently complex. This table is an attempt to represent different aspects to show the differences between the companies better. The table has five categories: Grid alternatives, prioritizes innovation, resource issues, prioritizes regulation, and attention to culture. Each category indicates whether the DSOs fulfill the criteria or not. This table has three size brackets representing the three sizes that NVE operates with. That allows for a simplified comparison of the companies in the same way NVE evaluates and compares the companies.

The first category, “grid alternatives,” is a valuation of whether or not the companies see any alternatives to constructing more grids. Viewing grid alternatives as solutions to the increased demands of the power grid could indicate a greater interest in R&D. The next category evaluates if the companies prioritize innovation in their tenders. The third category is the resources. Some companies point to resources as a hindrance to R&D, and the category evaluates the company's claim. “Prioritizes regulation,” the fourth category, evaluates if the company views regulation as a hinder or the most important thing to operate after. The fifth and last category, “attention to culture,” evaluates if the respondents viewed culture as a challenge.

The table allows this research to use QCA-inspired logic to determine the similarities and differences between the companies. Establishing the differences makes it easier to determine if culture is indeed a factor or if it has no causality. It potentially increases the validity of the research.

This report presents the data as raw as practically possible to allow the reader to understand how this research concludes. The data gathered from surveys and interviews are presented in the next section. The section includes as much data as possible; any data left out was irrelevant to the research. Irrelevant data is any data unrelated to culture, the power grid, innovation, and other topics of interest to this research.

8.4 LIMITATIONS

This chapter will explain the different limitations of this research, such as method, data, time, and other aspects.

First, this research is limited in two aspects: time and resources. Designing and conducting research in a short timeframe is difficult. Furthermore, doing this research single-handedly only makes the challenge more remarkable. Secondly, discovering and attempting to verify a cultural difference is inherently tricky. In a previous chapter on energy culture we saw that despite different methods and lots of research, few managed to pin-point culture as the deciding factor, but rather as a limiting factor (Dew et al., 2017; Muench et al., 2014; Reegård et al., 2019). Culture is ingrained in how we act, decide, and handle the world – a significant part of our understanding (Stephenson et al., 2015). To best measure the influence of culture in Norwegian DSOs, this research proposes a survey conducted by companies of varying sizes and locations. The survey attempts to measure which challenge related to the current use of the power grid the companies prioritize highest and then explore how each company tackles the challenge. This research can decipher where culture impacts decision-making by identifying challenges and solutions (Blaikie & Priest, 2019). By doing so, the survey also allows for a quantitative measure of company culture instead of relying solely on qualitative interviews – one of the most significant benefits of a mixed-method approach (Hesse-Biber, 2010).

Thirdly, it is complicated to decipher where to draw the line between personal experience and a company phenomenon. Using a mixed method gives the researcher, and the respondents, the opportunity to dive deeper into the decisions and understanding behind the answer (Blaikie & Priest, 2019; Hesse-Biber, 2010). Going into greater detail in each question gives the research a higher chance of identifying whether the answer stems from personal experience or perceived company culture. It also offers a better understanding of the outliers in the survey – the answers significantly different from the most repeated answer – by questioning what motivated the respondents to their answers.

Fourth and final, choosing only one method would be a worse compromise for this research than using a mixed approach. Each technique has similar disadvantages: Recruiting enough participants for a significant quantitative measure of culture and decision-making within a small timeframe is difficult. The same is true for qualitative interviews. Even if we ignore the time aspect, basing the research on a solely quantitative measure could leave out a vital part of information: The motivation and thought process behind the decisions. Using exclusively qualitative measures risks having a not significant enough representation of the industry for the results to be applicable in a broader context (Neuman, 2013). However, by combining the methods, this research provides an insight into the results of each technique, culminating in a viable understanding of how culture influences the Norwegian DSOs.

9 PRESENTATION OF DATA

This chapter presents the data gathered from surveys and interviews, starting with the survey. Data from the interviews are not as structured and are therefore presented as more of a commentary on relevant aspects and subjects. The data from the survey is presented in the corresponding order to how each question was posed. See the previous chapter for exact questions.

9.1 SURVEY

Question 1:

On the whole, there are several significant challenges for the DSOs. Historically, Norway's power grid construction happened in the mid-20th century with what industry experts and companies have called "a significant overhead." Therefore, DSOs have had little reason to expand, strengthen, or improve the power grid. However, there has been a massive increase in interest and need for electrification in recent years, suddenly demanding a lot more from the power grid. As one participant illustrated, "It feels like there are fires everywhere … there are no calm days at the office." This is reflected in the responses from most of the companies; unprecedented amounts of connection requests and a lack of capacity are common traits. However, increasing the capacity does not solve all of the problems for the DSOs. Many respondents, specifically large companies, struggle with frequency issues in their distributional grid. An increasing amount of electric vehicles (EV) and solar panel installations are causing disturbances to the grid frequency by demanding and producing significant amounts of power at a "lower level" in the power grid. The large DSOs struggle to cope with the quick changes in load due to the construction of the grid, leaving little flexibility in the outer reaches of the power grid; furthermore, with more production and higher power peaks, the complexity of the power grid increases. Interestingly, while the medium-sized DSOs also want more capacity, one of the respondents pointed to the increased power losses from transporting more energy over longer stretches. Small DSOs also want more capacity. One of the companies points to the central power grid, operated by the national TSO Statnett, as a potential limiter for access to enough power.

Question 2:

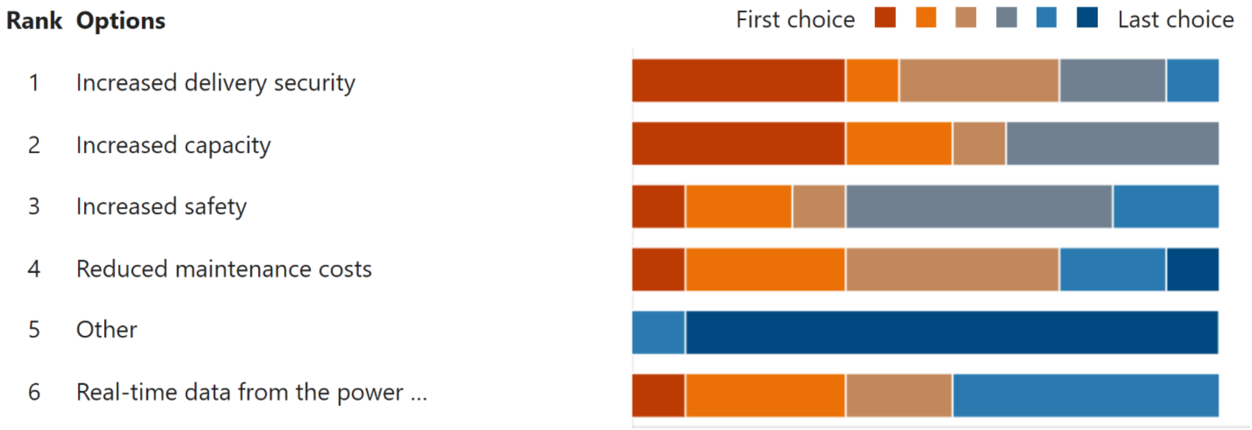
Here the differences between the companies become more apparent: The challenges discussed in Q1 have not significantly affected daily operations for small DSOs. However, the companies consider strengthening their power grid "in some years' time." Medium-sized companies are starting to feel the pressure, with several companies having to use more time calculating new connections. Furthermore, the programs the DSOs use to calculate new connections are not good enough, leading to longer case processing times and long queues. Meanwhile, large DSOs also struggle with longer case processing times, new connections, and increased costs. Unlike small and mid-sized DSOs, large DSOs have already had to implement strict measures to cope with higher demand. For some, that means stopping new connections in certain areas and changing operating limits and service intervals. Others are looking at increasing their efficiency with the help of technology by automating processes, improving monitoring, and more risk- and state-based power grid maintenance.

Furthermore, some large DSOs are looking to digitize more operations and reduce the number of tasks for caseworkers, thereby reducing wait times. Large DSOs want more technology to monitor their power grid, but no company seems confident in the available technology, regulation, or both. Some feel like the industry for technology is not mature enough or that the current planning of power grids needs changing to implement the technology. Others feel that the power grid operators do not dare to take the risk associated with new technology. “We have to make better use of today’s power grid, know the actual margins, and exploit flexible consumption,” explains one of the large DSOs.

Question 3:

In table 4, we can see how the different respondents ranked the most important metrics they needed to upgrade in their power grid. Here are some interesting things: first, most large DSOs want increased capacity, whereas mid-size and small DSOs want to improve their delivery security. Second, half of all surveyed put real-time data as their second to last priority, perhaps despite one of the large DSOs maintaining it as their top priority. Third and final, there seems to be little agreement on the importance of reducing maintenance costs; some rate it highly while others put it last. These priorities could indicate how far ahead each company is currently planning with maintenance costs and data collection looking like long-term issues versus capacity and delivery security as more “deal with now”-matters.

Table 4 shows how respondents ranked six potential upgrades to their power grid. Interestingly, all companies differed in their priorities – some more than others.



Question 4:

As no company rated “other” highly, there were no responses of relevance to question four. However, on a more general note, some companies did note the importance of constructing and maintaining a robust power grid while also digitizing with extensive use of technology. All Norwegian companies are mandated to run the power grid in the most robust and socio-economic way possible. Furthermore, power grid companies have to prioritize testing other solutions in combination with the expansion of the grid, such as batteries, hydrogen production, and increased flexibility from end-users. Several companies fear the power grid could become a bottleneck to the green shift without such measures.

Question 5:

Alternatives to constructing a new power grid are wide-open categories and provide varying answers. There are some separations between the three types of companies, but the lines are blurred. In general, all companies are interested in solutions that alleviate some pressure from constructing a new power grid. However, which solutions they believe in are vastly different. Generally, large DSOs view technology, specifically sensors and energy storage, as a potential solution. Some are already testing the technologies on an R&D level, but the technology is not relevant to daily operations as of now. The mid-size DSOs show less interest in technology, citing the lack of significant reference projects and information about its usefulness. “We have had bad experiences with a pile-up of data systems that we never use,” explains one of the mid-size companies. Those experiences have put some mid-size and small companies “on hold” when testing new technology; instead, they let the large DSOs be the guinea pigs. Both mid-size and small DSOs want more emphasis on power control and flexibility for end-users. They also hope, especially the small DSOs, that the new power tariff will incentivize a reduction in peak power demands. Such incentives would also help avoid situations with too high power peaks due to low power prices and existing high power demand.

Question 6:

One thing is common for all DSOs: They want more data from the power grid, especially real-time data and analysis. Instead, the difference shines through in how much data they want. Small DSOs want more real-time data on power peaks and transformer stations. In contrast, mid-size DSOs wish to access more real-time data from the grid and increase industry-user flexibility combined with upgrading physical components. The lists from the large DSOs are more detailed, perhaps illustrating that some companies are already testing technology. Large DSOs want to use data to automate processes and decisions to reduce costs and use “the actual capacity of the grid.” However, using the grid closer to its capacity could increase wear and tear, increasing maintenance requirements. How significant the wear and tear increase is is still unclear. Furthermore, the large DSOs want to use Norway's extensive implementation of AMS to measure and stabilize the voltage at lower grid levels, implementing batteries to stabilize and absorb power peaks. Some companies are also considering using drones for line inspection to decrease costs and GHG emissions by reducing the need for helicopters. Other technologies to detect faults or wear and tear are also highly sought.

9.2 INTERVIEWS:

More than 20 hours have been spent interviewing people of interest during the course of this research. Therefore, it is challenging to summarize essential findings from such a tremendous amount of data. Instead, each theme showcases relevant commentary or acknowledgments from interviewees. Furthermore, without looking at the larger picture, some of the data about to be presented might seem unnecessary. However, it paints a larger image of how the Norwegian power grid is doing and thus becomes valuable to understand where the culture comes from. The importance of interviews becomes evident in the discussion chapter.

The current state of affairs in the Norwegian power grid:

Production and higher power peaks at the distributional level of the grid cause significant worry for most DSOs. Increased demand for electrification has led several companies to stop new connections and look at other solutions while planning and constructing a new power grid. “We cannot adapt quickly enough … it feels like there are fires everywhere,” explains interviewee 13. Similar excerpts are echoed from all mid-size DSOs. “We are starting to struggle with voltage instability due to evermore private households installing solar PVs and home chargers for their EVs. Such installations happen at a grid level that we have little opportunity to control effectively, and our systems for monitoring for faults are not good enough at that level,” explains interviewee 10. There are fewer worries at the higher levels of the power grid, but all is not well still. “We have enough capacity at the regional level for the foreseeable future, but we are worried that the national power grid cannot deliver enough energy to our regional level,” explains interviewee 11. Mid-size companies are also considering strengthening specific parts of their grids. At the same time, mid-size also want to “dip their toe” into more real-time data. “We want more data, but we do not want more data screens surrounding us with useless information,” explains interviewee 11.

Such is not the case for larger DSOs; “We have enough energy available, but we cannot deliver all of it. We have to construct a stronger grid to cope with more electrification of industry and transportation. Otherwise, we could risk becoming a bottleneck to the green shift,” says interviewee 4. Interviewee 4 continues, “We are already planning and constructing for several billion NOK in the coming years, construction work we want to do with as little pollution as possible. That means electrifying the construction site, which demands even more from the power grid that we are the ones building.” The increasing demand for electricity at all times is seemingly causing more work than expected. However, constructing a sturdier power grid will not solve all problems; “We are in dire need of more real-time data from our grid, especially from lower levels. We need to know what is happening, where, and what to do about it. Nevertheless, even if we know some or all of that now, we still need to construct a grid capable of using that information,” explains interviewee 13.

Small DSOs face many of the same challenges associated with solar PVs and EVs, but not one operator cited a need for more capacity in the foreseeable future. “We have some areas affected by voltage instability that could cause issues, but we have enough capacity in the grid. However, we are considering building more substantial transformers to cope with peak demands,” explains interviewee 8. Instead, small DSOs worry that they have too few resources. “We are less than 20 people in this company, mostly field engineers. Planning, building, and maintaining the grid will take a lot from all of us. I am worried we cannot do it all," says interviewee 8.

Recently, small hydropower dams have become increasingly popular among investors, causing an interesting issue for certain small DSOs. "I think we have more than 30 small hydropower plants now, with 100-200 MWh more power into our grid. Many plants are at the end of rivers deep in the valleys where we do not have enough capacity to cope with their production. They may want to produce at peak hours because the price is good, but we cannot cope with all of it right now," explains interviewee 10. "Any voltage challenge we might have pale compared to the small hydropower plants we have to cope with," according to interviewee 10. Asked about how to handle it, interviewee 10 responded, "We are planning for a new grid as we needed to do it anyway. There are no viable alternatives as far as we can see."

"I do not believe the regulation limits technology in the Norwegian power grid. However, I do feel like some DSOs interpret the regulation too conservatively. They have to maintain stable power to all end-users, but they can give deals based on flexibility and availability. Often, it seems, DSOs do not want to use flexibility. Instead, they insist on taking their time and constructing a new grid," explains interviewee 1. "Not using the grid and the regulation to its fullest could hamper the green shift," interviewee 1 describes.

Smart grid technologies:

"We do not want to be guinea pigs, but we also do not want to be left behind by other companies. It is difficult managing both," explains interviewee 11. Mid-size and large DSOs focus heavily on technology as a part of their daily operations. Whereas small DSOs focus on better control of power peaks (controlling charging of EVs, for example), mid-size and large DSOs want more insight into how their power grid is doing. "We need to know more about the condition of the power grid, especially in the lower levels, to detect faults. Before AMS, we literally could not tell if someone had lost power before they rang us up and told us. We then checked the power lines meter by meter to find the fault. We still do that today; only we now know if someone has had their power cut. Having the technology to find faults would benefit us greatly," explains interviewee 13. On the regional grid level, finding faults is less complicated with more systems and switches informing of defects.

One goal of smart grid technologies, especially grid-enhancing technologies, is extracting more from the current power grid. By running the power grid closer to its limits (temperature, vibration, et cetera), GETs hope to increase the power grid's capacity by somewhere around 25 percent. However, doing so could also increase the wear and tear on the power grid, leading to increased maintenance costs and reduced durability. "The grid can probably withstand more power, but we have to change our maintenance to handle it. We have to predict faults. The only problem is that no one can say for sure when a transformer breaks and fixing it could take time. We need actual and accurate data from the grid to handle such instances," according to interviewee 13. "We already know a lot about our power lines, such as the temperature, so we do not see how other parameters from more technology will help us," states interviewee 4. Interviewee 13 also concedes that using more data, specifically from GETs, is more of an R&D question and not one that the engineers consider.

Some large DSOs already use technology to increase the flexibility in their grid. Mid-size DSOs are now looking to do the same, using the large DSOs as a template. "Flexibility could significantly increase available power in specific areas with limits today. However, we are still unsure if we can trust the available technology to solve this challenge," explains interviewee 14.

A common worry among DSOs is the potentially increased vulnerability if they digitize the power grid. By increasing access points and information flow, some DSOs worry that the power grid will be vulnerable to data attacks. "Any solution we consider cannot cause risks to the power grid. The grid has to be robust and reliable," explains interviewee 13. However, that is not the view of the GET industry; "Our technology can help power grid operators find the margins they need to allow more power into the grid, and we do not believe that to be a risk for them. We can integrate the information from our sensors into their existing programs, allowing them to make better-informed decisions. From a technical point of view, we would argue that this is a no-brainer," explains interviewee 9. "We have to know that we can trust any data we use. The margin of error is crucial," according to interviewee 13.

Innovation and culture:

"This is a very conservative industry. It takes time for things to change. Take the share of women in this industry as an example; it is very uneven, with almost all CEOs being men," was echoed by several interviewees, especially from the larger DSOs, experts, and stakeholders. It is also possible to see this in numbers; some companies struggle to follow Norwegian laws on gender distribution, whereas others work to increase their ratio (Energi, 2020; Nyman, 2021). Interviewees 1, 5, 6, and 13 all believed that companies not prioritizing equality in their hirings are also less likely to prioritize innovation. “We are supposed to be conservative. We have to be able to maintain operations using pen and paper – we cannot rely solely on any technology. At the same time, we are supposed to run the grid in a digitized way. People expect things to be digital, to just ‘google it’ and know what is up. The power grid is far off that right now,” explains interviewee 13. Similar statements came from several interviewees, underlining how difficult digitizing the grid could be.

“The green shift will be a massive challenge for the entire energy sector, especially the power grid industry. Change has to happen quickly if we are to reduce the effects of climate change. However, the energy industry is inherently conservative, often refusing change unless forced upon it. It will be interesting to see if the sector can cope with the world's demands or if it will push back and refuse to change,” is interviewee 12’s take on the energy sector, referencing several points that other interviewees bring up.

“I believe the power grid companies' reluctance is holding GETs back. We know our technology works, but our industry needs a large installation to truly show what our technology is capable of. Right now, that is not happening because power grid operators are unwilling to try something new. It seems they are not open to innovation,” explains interviewee 3. Despite some DSOs wanting more capacity in their power grid, GET representatives do not feel it is simple to get in touch about their technology. “First, we must wiggle our way through the company until we reach the right people. If we reach the right people, we still have to convince them of our technology. Moreover, when we mention “increased capacity,” it is as if they zone out. It is more difficult to sell than we imagined,” explains interviewee 2. “It is difficult to say what is causing it. However, we often feel there is a lack of interest for innovative solutions,” interviewee 2 continues.

“We do not prioritize R&D in-house to save resources. Instead, we have partners that test technology, develop specification requirements, and base our decisions on their recommendations,” explains interviewee 10. “We are looking towards the large DSOs to do the R&D and then decide based on their knowledge. It saves us resources but leaves us trailing behind the cutting edge of technology. Even if we had the resources, we would not want to be guinea pigs for new technology," explains interviewee 8. "We can implement changes in weeks compared to months or years for larger DSOs. That is a benefit of our size," says interviewee 10.

10 DISCUSSION

This chapter discusses the data gathered during this research. First, this chapter discusses the QCA-inspired table and its logic. It then examines what implication the data and results from the table have on the culture of the power grid industry. Second, the research uses the multiple-level perspective to analyze and understand the transition happening in the Norwegian power grid industry, including a discussion of how culture affects the shift towards innovation in the Norwegian power grid industry.

10.1 A SPLASH OF QCA TO FIND DIFFERENCES:

Table 5 is the QCA-inspired table with results. The crosses in each category mean that the category is fulfilled and provides a method for separating the different grid companies.

Size/factor:	Grid alternatives	Prioritizes innovation	Resource issues	Prioritizes regulation	Attention to culture
Small			**x**	**x**	
Medium	**x**		**x**		
Large	**x**	**x**	**x**		**x**

After analyzing the data, this is what the table looks like. However, there are several interesting things to discuss, starting from the left with grid alternatives. **Grid alternatives:** Small DSOs either showed no interest or need/want for grid alternatives. Most small DSOs felt that their grid was strong enough and that the added complexity would only lead to more work with little to no gain. Furthermore, in situations where grid alternatives could provide a viable alternative, short-term or not, small DSOs instead opted to build a new grid, as they "needed to do it anyway." However, both large and medium DSOs wanted grid alternatives. Some mid-sized DSOs need increased capacity quickly and view alternatives, such as GETs, as a viable solution. Several large DSOs were already testing and implementing grid alternatives, but only on a pilot level for now. Only one company specifically mentioned GETs as a solution, but in the same sentence, listed two significant challenges: They cannot react to the data as they want, and the engineers do not want to change how they work. In both surveys and interviews, representatives from larger DSOs pointed to the conservative culture as limiting the companies' interest/use of grid alternatives.

Prioritizes innovation: Only the large DSOs viewed innovation as a priority and a need for the future. Neither small nor medium DSOs felt the need to innovate; instead, they pointed to the large DSOs for innovation and R&D projects. R&D departments in large DSOs wanted to test new smart grid solutions but received pushback from other departments. On the technical side, however, things remain challenging. A smart grid needs more than monitoring, and it becomes evident that the DSOs have not yet prepared their grid to handle new operational methods (Das et al., 2020; Farmanbar et al., 2019). Many Norwegian grid operators know of technologies such as GETs, but few view them as a solution or necessity for the modern power grid, similar to findings from research (Bauknecht et al., 2020; Dew et al., 2017; Høiem et al., 2021). Furthermore, even if some operators implemented technology such as GETs, they would not have a grid capable of responding to the data.

Resource issues: Small DSOs pointed to a lack of resources as the main problem for innovation, whereas mid-size DSOs were more worried about unnecessary data costing efficiency, thereby stressing the available resources. Large DSOs did not cite monetary resources as an issue. Instead, the companies point to the need for more personnel to cope with the increasing workload. **Prioritizes regulation:** Only the small DSOs indicated the regulations as a limit for innovation, whereas large and medium DSOs did not see the regulation as a challenge. However, some of the large DSOs wanted a stricter regulation to require more technology in the power grid, legitimizing the spending on technology solutions.

Attention to culture: Several representatives from the large DSOs pointed to the company culture as a limiter for innovation, whereas both small and medium DSOs did not mention it. However, representatives from interest organizations of smaller grid operators did view the company culture as challenging. Many respondents also pointed to the uneven balance of women and men in the workspace as an indicator of the culture: Conservative and unwilling to change. Their viewpoints reflect what others have also found (Muench et al., 2014; Reegård et al., 2019; Roberts, 2011); the power grid industry is conservative, and innovation comes from individuals, not the company culture. The interviews show differences in the company cultures of Norwegian DSOs. Large

DSOs are more interested and willing to change to innovate, whereas medium DSOs are just starting to follow the large DSOs. Small DSOs have yet to show evidence of change in company culture and remain conservative. However, as interviewee 10 points out, “we can implement changes in weeks compared to months or years for larger DSOs – that is a benefit of our size.” Small DSOs still can catch up – if they want to.

This research set out to answer three minor questions on its way to answering one significant question. Three things become evident from the data and results in this research: First, some power grid companies, specifically the large ones, are aware of grid-enhancing technologies – some are already piloting the technology. However, despite knowing of the technology, several companies report being unsure of what the technology can do. This also points to a communication challenge for the GET industry and the technical difficulties of thoroughly exploiting GETs. Some large DSOs want to convert into data-driven companies but are uncertain of how and suffer from pushback internally. Second, there are many challenges for new technology in the power grid. The biggest hurdle seems to be a reluctance to test new techniques and equipment when the old methods already provide what they want. There is also the perceived increased risk with new technology and pilots that hinder innovation. Third, there are significant differences in the company cultures of the DSOs. Whereas large DSOs have specific departments working on R&D and encouraging innovation, other companies have to rely on innovation from individuals to keep up with modern-day challenges. We can also see that many representatives point to conservative company culture as a challenge in changing how the companies conduct their business.

10.2 TRANSITION IN A MULTIPLE-LEVEL PERSPECTIVE

As previously explained, the MLP remains a helpful tool for understanding transition. This research sees the power grid industry as the regime. The technologies, such as GETs, are niches, and the landscape consists of regulation, politics, and the public. It is already well established how vital a robust power grid is to society and the green shift (IEA, 2020, 2021a, 2021b). Furthermore, from the surveys, interviews, and previous research (Bauknecht et al., 2020; Høiem et al., 2021; Reegård et al., 2019; Roberts, 2011), we can see that the company culture affects innovation, technology, and by extension, potential advancements in the power grid industry. Industry, business, politicians, and society demand more from the power grid. The landscape is shifting, and niches want in (Geels, 2012; Geels et al., 2017). Therefore, it is also relevant to see how it could be slowing any transition from a multi-level perspective.

According to Geels, transition happens in four stages (Geels et al., 2017). Currently, GETs are in stage two, vying for stage three: The technology has permeated some markets and established a design, with expectations and rules beginning to stabilize. However, GETs have established themselves in some markets, competing with the regime and receiving backing from a landscape that is in dire need of more capacity in the power grid for the future (Heggen, 2022; IEA, 2020, 2021b; Lyse, 2020a; Saha et al., 2021). According to Geels' explanation of the MLP, the external pressure from the landscape creates instability and opens up "windows of opportunity" for niche innovations (Geels et al., 2017). However, the GET industry as a niche requires more than an opportunity to establish itself. Internal factors such as price and performance and external factors such as complementary technology and cultural acceptance are also critical (Geels et al., 2017). Currently, solutions are available that increase the capability of GETs (D. o. Energy, 2019; Racz & Nemeth, 2021), but some DSOs in this research responded that they do not have such equipment yet. Studies have also shown the economic benefits of large-scale implementation of GETs (Paredes et al., 2021), potentially fulfilling the price and performance factors.

Nevertheless, the culture, specifically the company culture of power grid operators, remains a challenge. Many DSOs reported little interest in grid-enhancing technologies, and several said the company culture hampered changes. The finding would mean that even if companies could fully exploit what GETs offer, the company culture could slow the implementation of the technology despite its advantages. This finding also corresponds with similar research, such as the slow implementation of LEDs in the U.S. Navy (Dew et al., 2017) and several reports on a conservative company culture hampering innovation in the power grid sector (Høiem et al., 2021; Muench et al., 2014; Reegård et al., 2019; Roberts, 2011).

11 CONCLUSION

This research set out to discover if company culture affects the implementation of grid-enhancing technology in the power grid. This research shows, through analyzing existing research and using the data collected through surveys and interviews, that company culture affects it. However, concluding that company culture is the only factor limiting implementation would be incorrect.

Several technical challenges need sorting out first. Many grid operators want more data from their power grid, but the same companies report not having the equipment necessary to use the data to exploit the benefits. The power grid is in the middle of a fundamental change, with power production moving to the lower level of the grid, increased demand for flexibility, and higher peak loads. In Norway, many DSOs point to the larger companies taking responsibility and leading the way in large parts due to the differences in available resources. There is also a clear difference between how the DSOs handle technology, with the largest DSOs most interested in innovating and the ones most aware of the cultural hurdle inside the companies. There is a dire need for company culture and technical fixes to the grid for the power grid and grid-enhancing technologies to succeed.

Further research: The power grid needs technical changes to use the data from grid-enhancing technologies and, possibly, other smart grid technologies. However, with increased reliance on the power grid, these changes cannot come fast enough. The implications could mean we cannot cope with the current climate goals. This research recommends further research into the technical challenges of the power grid and whether these challenges are significant enough to limit the power grid's ability to enable the green shift.

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