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A study of microgrids in Norway

Mapping the motivations, benefits, challenges and prerequisites required for extensive use of microgrids in Norway

Bachelor thesis in Renewable Energy Engineering
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Abstract

The demand for electrical energy in Norway is expected to increase significantly. This will likely cause challenges related to power quality, reliability and resiliency, especially in remote societies. Microgrids could be a part of the solution to such challenges. Currently, there are very few microgrid projects in Norway, and even fewer microgrids in operation. The Centre for INtelligent ELectricity DIstribution (FME CINELDI), is exploring microgrid applications and is involved in some of the Norwegian microgrid projects. The FME abbreviation means that FME CINELDI is one of the national centres for environmental-friendly energy research in Norway, "*Forskningssentre for Miljøvennlige Energi*" in Norwegian.

The objective of this thesis is to give an overview of motivations, benefits, challenges and prerequisites necessary for extensive microgrid deployment in Norway. This overview is achieved through a combination of six different case studies and a literature study. Four Norwegian cases, an American and a Swedish case were explored. This was done through interviews with people working on the projects and studying reports directly related to the projects. The literature study was conduced to address general motivations, the extent of microgrid development and the state of the Norwegian power grid. As a supplement to the literature study, access to FME CINELDI's work and conversations with their scientists were valuable contributions.

Globally, microgrids supply only a very small fraction of power consumers. Motivations for deploying microgrids include improving resiliency and reliability, facilitating for distributed renewable generation and avoiding grid expansion. The latter reduces grid investments and avoids encroachment on nature. The motivations of the few operating microgrids in Norway are usually linked to research and testing. Currently, the technology needed to deploy microgrids is both applicable and available. However, there is a lack of sufficient motivation and the legal system is not adapted for microgrid deployment.

The two foreign cases are located in an American jail and a Swedish village. The microgrid at Santa Rita Jail was established to test microgrid technology, improve reliability of the power supply and for cost optimization purposes. In the village Simris, there was initially no motivation for deploying a microgrid. The initiator's objective was simply to test and develop new solutions for deployment in commercial environments.

The Norwegian microgrids considered in this thesis are situated at the university campus Evenstad, the port Risavika, the two farms at Rye and the remote island Utsira. The primary motivations of the projects at Evenstad and Risavika are climate goals and the expected challenges related to the energy transition. The microgrid at Rye was initially planned for a group of remote islands and has similar motivations as the microgrid at Utsira. These island societies require a grid upgrade within the overseeable future. Therefore, the projects' objectives are to test alternative ways to supply power to such islands. In all the Norwegian microgrid projects, the initiators state that the projects provide valuable experiences.

Although there are few cases where microgrids are economically viable options, some areas and challenges in Norway can benefit from microgrid deployment. Experiences from microgrid actors indicate that testing and further development of microgrids should be prioritized. This is due to the lack of experience, both regarding technical solutions and cost efficiency. With further developed solutions and more experience, microgrids could become more common in the future.

Sammendrag

Kraftbehovet i Norge øker. Dette vil sannsynligvis føre til utfordringer knyttet til strømnettets leveringskvalitet og stabilitet, spesielt i avsidesliggende områder. Mikronett kan være en del av løsningen på disse utfordringene. Det er i dag svært få mikronettprosjekter i Norge, og enda færre mikronett som er i drift. Forskningssenteret for intelligent elektrisitetsdistribusjon (FME CINELDI) jobber med forskning relatert til mikronett og er involvert i noen av de norske mikronettprosjektene. Forkortelsen FME forteller at CINELDI er et av de nasjonale Forskningssentrene for Miljøvennlig Energi.

Hensikten med denne oppgaven er å gi en oversikt over motivasjoner, utfordringer, fordeler og forutsetninger som kreves for omfattende bruk av mikronett i Norge. Dette er oppnådd gjennom en kombinasjon av seks casestudier og et litteraturstudie. Fire norske caser, en amerikansk case og en svensk case ble utforsket. Disse ble utforsket gjennom intervjuer av aktører som jobber med prosjektene og rapporter som er direkte knyttet til prosjektene. Litteraturstudiet ble utført for å beskrive generelle motivasjoner, utbredelsen av mikronett og tilstanden til det norske strømnettet. Tilgang til FME CINELDI sitt arbeid og samtaler med deres forskere var et viktig supplement til litteraturstudiet.

Globalt forsyner mikronett en veldig liten andel av strømforbrukerne. Motivasjoner for å installere mikronett omfatter forbedring av leveringskvaliteten og implementering av distribuerte fornybar energiproduksjon, samt å unngå nettutbygning og -oppgraderinger. Sistnevnte reduserer investeringskostnader og hindrer naturinngrep. Motivasjonen bak de få operative mikronettene i Norge er vanligvis knyttet til forskning og testing. Teknologien som trengs for etablering av mikronett er både tilgjengelig og anvendelig. Likevel mangler det tilstrekkelig motivasjon og et tilpasset lovverk for økt bruk av mikronett.

De to utenlandske casene omhandler mikronettene i et amerikansk fengsel og en svensk landsby. Mikronettet til fengselet Santa Rita Jail ble etablert for å teste teknologiske løsninger for mikronett, for å forbedre strømforsyningens pålitelighet og for kostnadsoptimalisering. I landsbyen Simris var det opprinnelig ingen motivasjon for etableringen av et mikronett. Intensjonen til initiativtakeren var å teste og utvikle nye løsninger for kommersiell bruk.

De norske mikronettene som ble utforsket er plassert på universitetscampuset Evenstad, havnen Risavika, gårdstunet på Rye og den avsidesliggende øya Utsira. Bakgrunnen for mikronettprosjektene på Evenstad og Risavika er klimamålene og forventede utfordringer knyttet til energiomstilling. Mikronettet som er installert på Rye var opprinnelig planlagt for en avsidesliggende øygruppe og har lignende motivasjoner som mikronettet som er installert på Utsira. Felles for disse øysamfunnene er behovet for en nettoppgradering innen overskuelig fremtid. Derfor er prosjektenes mål å teste alternative måter å levere strøm til slike øysamfunn på. I alle de norske mikronettprosjektene opplever initiativtakerne at prosjektene gir verdifulle erfaringer.

Selv om det er få steder hvor mikronett er økonomiske lønnsomme, finnes det områder og utfordringer i Norge hvor etablering av mikronett kan være fordelaktig. Erfaringene til aktørene som jobber med mikronett tilsier at testing og videreutvikling av teknologi bør prioriteres. Dette skyldes mangel på erfaring, både knyttet til kostnadseffektivitet og tekniske løsninger. Med bedre utviklede løsninger og mer erfaring, kan mikronett bli mer vanlig i fremtiden.

Preface

This thesis is written to conclude our bachelor degrees in Renewable Energy Engineering at the Norwegian University of Science and Technology (NTNU). The project is a collaboration between Clemens Martin Müller and Sigrid Eliassen Sand. For each student the thesis amounts to 20 ECTS credits.

The problem statement was developed in collaboration with a supervisor from FME CINELDI. We chose this topic because we find the concept of microgrids to be very interesting. This project has provided us with experience and knowledge that we greatly appreciate.

Our supervisors Olav Bjarte Fosso and Kristian Myklebust Lien have been of tremendous help in the work of this thesis. We would like to thank them for the guidance and support that they have provided. Furthermore, Maren Kristine Istad and Kjersti Berg from FME CINELDI deserve thanks for their input to this thesis.

Throughout the work of this thesis, multiple industry professionals have been involved. Thanks to Luis Arturo Hernandez Salmeron, Marius Aleksander Kolby, Åsta Vaaland Veen, Bernhard Kvaal and Asbjørn Tverdal. These have been essential in the work with the case studies conducted in this thesis. We are very grateful for the interesting, enlightening and pleasant conversations they have offered.

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Contents

Terms and acronyms

BESS	Battery Energy Storage System
CENS	Cost of Energy Not Supplied
CERTS	The Consortium for Electric Reliability Technology Solutions
CHP	Combined Heat and Power
COP	Conference Of the Parties
DER	Distributed Energy Resources
DSO	Distribution System Operator
FME	Center for environmental-friendly energy research
FME CINELDI	The Centre for INtelligent ELectricity DIstribution
FME ZEN	The research center on Zero Emission Neighbourhoods
GCP	The Global Carbon Project
GO	Guarantee of Origin
HK	Haugaland Kraft
IEA	The International Energy Agency
IPCC	The Intergovernmental Panel on Climate Change
kWp	Kilowatt peak-power
NVE	The Norwegian water resources and energy directorate
PCC	Point of Common Coupling
PV	PhotoVoltaic
SRJ	Santa Rita Jail
SOC	State Of Charge
SRH	StavangerRegionen Havn
TSO	Transmission System Operator
V2G	Vehicle-to-Grid
UN	The United Nations
UNFCCC	The United Nations Framework Convention on Climate Change
ZEB	Zero Emission Building

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1 Introduction

Norway is a nation powered by hydropower, 93.4% of Norwegian electrical power was produced this way in 2020 [1]. Norway's accessibility of hydropower has contributed to a high level of electrification. The building of hydropower plants started late in the 19th century. The facilities were placed in areas with access to flowing water and large elevation differences. Power intensive industry facilities were placed close to the power plants. Slowly, the power grid grew to cover the entire country, expanding outwards from the power plants [2].

Presently, there is an increased electrification in several sectors in the country [3, p.2]. To address global warming, Norway has pledged to meet the European Union's climate goals. This means that Norway is to reduce its emissions by 40% compared to 2005 levels within 2030 [4, p.507]. Reducing Norwegian emissions may be achieved by an extensive electrification of the industry, transport, off-shore and construction sector. Electrification alone can provide 34% of the total possible reduction in Norway [4, p.xi].

The succeeding increase in demand for electrical power will act as a powerful incentive to further develop the power grid [4, p.xi]. Reinforcing and expanding the power grid is expensive. Microgrids could function as alternatives to power grid reinforcements, a way to electrify remote areas and improve power grid flexibility. Hence, increased deployment of microgrids could contribute both to sustainable development and increased reliability of the Norwegian power grid [5, p.6].

1.1 Objective and problem statement

Currently, the prevalence of microgrid is not extensive in Norway. Though there is very little experience with microgrids in operation in Norway, there exists a sizeable quantity of different microgrid projects [6, p.46-47].

This thesis is written for FME CINELDI, which is led by Sintef energy research. FME CINELDI is primarily investing its resources towards technical microgrid research. Therefore an overview of national trends and motivations regarding the topic of microgrids is an useful supplement to their research [7]. This thesis considers land-based microgrids, excluding off-shore installations from the scope.

This thesis was supervised by Olav Bjarte Fosso, Professor at the Department of Electric Power Engineering at NTNU and leader of the microgrid work package (WP4) in FME CINELDI, and Kristian Myklebust Lien, Professor at the Department of Energy and Process Engineering at NTNU. Together with the supervisors, the following problem statement was formulated:

"*Map motivations, benefits, challenges and prerequisites required for extensive use of land-based microgrids in Norway.*"

Some key aspects addressed in this thesis include:

- Benefits that follow microgrid deployment
- Opportunities, motivations and trends for microgrid deployment in Norway
- Selected microgrid cases in Norway and comparable cases from abroad
- Important prerequisites necessary for microgrids to become a commercial solution

Approach

In cooperation with supervisors Olav Bjarte Fosso and Kristian Myklebust Lien it was decided that the problem statement was best approached as a combination of a literature study and a series of case studies.

International microgrid status and trends were evaluated based on an extensive literature search. Information about the Norwegian power grid and microgrid trend was acquired through reports published by the Norwegian water resources and energy directorate (NVE), "*Norges Vassdrags- og Energidirektorat*" in Norwegian, unpublished FME CINELDI reports and a conversation with scientists from FME CINELDI.

Six cases were chosen for the case studies. The investigations focused on the motivation and technical scheme for each case, as well as experiences of the microgrid initiators. To obtain case specific technical details and operational experiences, interviews with key figures working with the cases were conducted. In addition, reports published in connection with the projects were used.

Thesis outline

To give an overview of motivations, benefits, challenges and prerequisites within the field of microgrids in Norway, it is important to establish the definition of a microgrid. Chapter 2 provides definitions and descriptions of microgrids and related concepts. Afterwards, the methodology used to acquire information is described in chapter 3. Common motivations to establishing microgrids and an overview of grid development in Norway is given in chapters 4 and 5.

In chapter 6 the results from the case studies are presented. These include motivations, technical solutions and experiences from the selected cases. Then, a discussion addressing the problem statement and the information from the previous chapters is presented in chapter 7. Finally, chapter 8 gives the conclusion of the topics of the discussion and to the thesis's problem statement.

2 Theoretical background

Since the beginning of the modern microgrid research in the late 1990's, technologists and scientists have spent time developing a clear definition of the concept and relevant technologies [8, p.403]. This chapter includes a definition and an explanation of the microgrid concept, as well as an introduction to relevant technology and important concepts related to the subject.

2.1 Definition of a microgrid

A microgrid can be described as a geographically enclosed grid system consisting of electrical sources and loads. Since it is a term without an established definition, there exist different definitions and interpretations of what is considered a microgrid [8, p.403]. The definition used by FME CINELDI is this definition, developed by the Microgrid Exhange Group on behalf of the US Department of Energy:

"[A microgrid is] a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode" [8, p.403].

This definition clearly indicates that a microgrid can draw electrical power from the power grid and be able to disconnect itself from the power grid, so that it can functions on its own [8, p.403]. The International Electrotechnical Commission (IEC) classifies a microgrid that is connected to the power grid as non-isolated. Microgrids that are disconnected from the power grid are classified as isolated microgrids by the IEC [9, p.8]. These are also referred to as islanded microgrids [10, p. 73].

In non-isolated microgrids, the boundary between the microgrid and the power grid can often be identified as a single point. This point is referred to as the Point of Common Coupling (PCC). At the PCC, it must be possible to connect and disconnect the microgrid to and from the power grid. Operation of the microgrid without connection to the power grid is referred to as island mode or off-grid mode. Island mode operation depends on an energy source, either an energy storage and/or a distributed energy generation unit [11].

Although it gives some limitations to what can be categorized as a microgrid, the definition above offers loose guidelines for design. A microgrid can and should be designed to fit the location and desired application. Due to different purposes and premises of microgrid projects, the same system solution will not offer equal results for all projects. Some important matters to consider is the consumers current and future needs and load profiles, available energy resources, geographical position and economics [9, p.14-15].

An additional type of solution is what FME CINELDI refers to as a virtual microgrid. This solution follows the definition above as it has clear physical boundaries and local energy resources. Virtual microgrids focus on autonomous operation and energy balance within a defined grid area. The difference from the traditional concept, is that virtual microgrids are not designed to operate in island mode. In periods, virtual microgrids might have zero power exchange with the power grid and will in these moments be perceived as islanded from the grid operator's point of view [5, p.11].

Power grids with high short-circuit outputs, due to low impedance, are referred to as stiff grids. In stiff grids the voltage will not be influenced by load changes [12]. Larger power grids are voltage stiff due to the mechanical inertia stored in the power system's generating units [13, p.2]. As islanded microgrids lack generators with inertia, the voltage and frequency will vary during faults [14, p.1462].

2.2 Distributed energy resources

A Distributed Energy Resource (DER) is a subject closely related to microgrids. In contrast to traditional centralized energy production, DERs involve locally produced or stored electrical power. This means that DERs harvest the energy closer to the load that consumes it [15, p.725-726]. A grid structure consisting of DERs relies on smaller units spread across various places in the grid [9, p.10].

DERs can be classified as either local or end-point productions. Local production is production that is localized close to the consumer, but the consumer is not responsible for the production. Local production consist of site specific plants and often include renewable energy with an inconsistent production scheme, such as wind turbines. Power producers at end-point are prosumers, which are consumers who also act as generators. An example of this is a house which produces energy from its own rooftop PhotoVoltaic (PV) [15, p.726]. Following the increasing use of intermittent generations and presence of prosumers, decentralized power systems must be able to handle bidirectional flows [16, s.23].

In this thesis, the term DER is used to describe both power generations and energy storage. The distributed power generations can be both renewable and fossil based. Some technologies, such as fuel cells, combustion engines and gas turbines, are often based on fossil fuels and are thus associated with considerable CO_2-emissions. In addition to emissions, fossil fueled DERs are characterized by their low initial cost and well developed technology [15, s.726]. Table 2.1 presents an overview of some common distributed generations.

2.2.1 Renewable energy generation

Many of the DERs applicable in microgrids are based on renewable sources [15, s.726]. Renewable energy generation is energy production from renewable resources such as the sun, wind, rivers, hot springs, tides and biomass [17]. Due to the finite nature and greenhouse gas emissions from fossil fuels, an increased presence of renewable energy production is a necessity to obtain sustainable power systems [8, s.725].

Renewable energy resources are intermittent. Therefore, the instantaneous generated power is not always equal to the DERs rated power [18, p.2]. A generating unit's rated power is the maximal capacity it is capable of delivering. For PVs, the term peak power is used to describe the installed and maximum power [19]. Microgrids that rely on unpredictable renewable energy sources, require advanced and accurate energy management systems. Due to their size, small microgrids are especially vulnerable to unexpected production changes which may result in power quality issues [18, p.2].

Table 2.1: *Overview of some common power generating DERs [15, p.728-731].*

Name	Source	Description
PV	Solar radiation	Known as solar panels. Cells consisting of semi-conductor material absorbs radiation and generate direct current (DC).
Solar thermal system	Solar radiation	Known as solar thermal collectors. Thermal energy collected from radiation heats a working fluid, usually water.
Wind turbine	Wind	Wind turbines draw kinetic energy from moving air to generate DC or alternating current (AC).
Small hydro turbine	Hydro	Turbines driven by low head waterfalls.
Gas turbine	Fossil and bio fuels	Gas, obtained from burning of fuel, is sent through a turbine.
Fuel cell	Hydrogen, fossil and bio fuels	In an electrochemical cell, chemical energy is converted to DC and heat through redox reactions.
Combined Heat and Power system (CHP)	Fossil and bio fuels	Known as cogeneration, excess heat from thermal power generation is captured for water or space heating.
Conventional heating	Fossil and bio fuels	Convection heating produced by burning fuels, generally in a fireplace or an oven.

2.2.2 Energy storage

Although an energy storage is not strictly necessary in a microgrid, it is a way of preventing failures. A microgrid supplied by variable energy sources, such as wind and sun, relies on an energy storage or a back up generator to deliver adequate power quality [8, p.404]. Energy storage or a back up power generator is needed to bridge the gap between power supply and demand, thus improving power quality [9, p.20]. Furthermore, the ability to store energy is a way to avoid loss of energy, for example the electricity produced by wind turbines at night when the consumer's demand is low [15, p.730].

Most commonly, storing energy involves conversion of electrical energy to some form of potential energy [15, p.730]. The range of optional energy storage technologies for microgrids is extensive [8, p.404]. An overview of common energy storage options is presented in table 2.2.

Table 2.2: *Overview of some common energy storage options [15, p.730-731] [20, p.34-35].*

Name	Energy form	Description
Battery Energy Storage System (BESS)	Chemical	Rechargeable batteries are used to store chemical potential energy accessible as electrical energy.
Flywheels	Rotational	The rotor, a massive spinning wheel, is connected to a generator/motor. When delivering, energy is drawn from the driving shaft connected to the rotor.
Hydrogen storage	Chemical	Hydrogen is produced and stored for later use in a turbine or fuel cell.

The term Vehicle-to-Grid (V2G) refers to the usage of the battery within an electrical vehicle as electric storage in a power grid. Electrical vehicles are connected to the power grid when their batteries are being charged, but are unable to return energy back to the grid with conventional chargers. A well designed V2G-charger can offer the right capacity for bidirectional flow and a communication protocol, usually a software component, for an electrical vehicle to power a grid [21, p.1].

2.2.3 Inverters

Today, the most common way to distribute and consume electrical power is with AC. This is valid for both large electrical machinery and household appliances. However, some DERs, such as PVs and BESSs, deliver DC. To convert AC to DC, a rectifier is applied, allowing units such as batteries to store energy. To convert DC to AC an inverter is used [22, p.8].

Inverters are devices that use semiconducting switches, often transistors, to synthesize sinusoidal voltage forms. The switch state (open/closed) is defined by the voltage at the switch terminal. A control unit is coordinating the states of multiple switches in a switch array to emulate a sine wave. Through proper coordination of the switches the output voltage and frequency can be altered [22, p.4]. Inverters typically have an efficiency of 85-96% [23, p.81].

A single microgrid usually contains several inverters operating in parallel. For instance, in a microgrid consisting of a BESS and a PV, there would be at least two inverters present. When several inverters are operating in parallel in a single microgrid, circulating currents may occur amongst them [24, p.158].

Reactive power consumption in a power grid is unpredictable. This has several implications for the power quality, including inefficient use of the distribution system [25, p.1]. Compensating for the reactive power in the power grid allows for a more efficient distribution of real power in the grid. Inverters can be used to compensate for reactive power in the power grid [22, p.8].

2.2.4 ZEB and prosumers

ZEB is the abbreviation of both a Zero Emission Building and a zero energy building, these two concepts have both similarities and differences [26, p.197]. In this thesis the acronym ZEB is used as an abbreviation of the term *Zero Emission Building*. The Norwegian ZEB center defines ZEB as a building that have a net zero greenhouse gas emission over the course of its lifetime [27, p.2]. The Zero Energy Building definition refers to buildings that generate an equal amounts of energy as it consumes. The criteria for the ZEB standard differ across the world. A common features is the presence of a DER, allowing ZEBs to store or generate energy. Although ZEBs can act as a microgrid in island mode, they are usually connected to the power grid [26, p.197].

The ZEB concept is closely linked with energy plus buildings. Energy plus buildings have integrated DERs and generate more energy than what was used for construction, operation and disposal over the buildings lifetime. This means that an energy plus building may be dependent of electrical power from an power grid sometimes [28]. Still, it will on average deliver more energy than it consumes from the power grid. Energy plus buildings, true ZEBs and near ZEBs are dependent on technologies that reduce energy need. Popular measures are strong insulation, high-efficiency heating, ventilation and air-condition technologies and exploitation of daylight [26, p.198].

Owners of Energy plus building and ZEBs with DERs that are connected to a power grid are called prosumers. These act as both consumers and generators from the power grid's perspective [29, p.1]. The presence of prosumers can create problems for power grids. A grid that is not fully developed for two-way flow will experience issues with voltage spikes, harmonic distortion and power output fluctuations as prosumers deliver electrical power to the power grid. Another challenge is the difficulty of storing excess power in power grids. Most power grids are not designed for receiving large amount of excess energy, which could lead to significant over-generation situations if the numbers of prosumers increases rapidly in the future [29, p.4].

2.3 Microgrid control schemes

There are primarily two control schemes applied in micrograms, these are centralized control and decentralized control. Centralized control systems require extensive communication between the controller and resources in the network. The central controller administrates the outputs of all units in the network. In a network deploying a decentralized control system, each unit self-regulates based on locally measured data. Depending on the size and application of the microgrid, a hybrid of the two may be applicable. This hybrid is referred to as a hierarchical control scheme [9, p.26].

Centralized control systems rely on a master unit, controlling the voltage and frequency (V-f) at the PCC in island mode. During grid connected mode the V-f characteristics at the PCC are used as reference. The master uses an extensive communication system to administrate the active and reactive (P-Q) power output of the DERs [30, p.12].

Decentralized control systems utilize equal components, all participating to *P-Q* control in the grid. Voltage and frequency fluctuations are distributed between the DERs. This allows for a smooth transition to and from island mode and does not require an extensive communication system. This results in a flexible and simple deployment of a microgrid, but with a loss in power quality compared to a centralized control system [30, p.13].

2.4 Improving power quality

Power quality describes the stability of the power that is supplied to a load [31, p.5], and is negatively affected by load ramping. Microgrids may be an adequate solution to improve power quality and mitigate these issues [32, p.2-5]. Another method to improve power quality is Demand Side Management (DSM) [33, p.556]. Issues with power quality can over longer periods of time lead to grid problems, as well as breakdown and reduced lifetime of electrical equipment [31, p.6-8].

2.4.1 Definition of power quality

The term power quality is usually divided into two main subterms: reliability of supply and voltage quality. Reliability of supply describes the probability of a power outage occurrence. European power outages are divided into two classes: short outages lasting up to three minutes and long outages lasting more than three minutes [31, p.5].

The voltage quality describes the power quality excluding power outages and can be poor in different ways. Poor voltage quality, characterized by both voltage and frequency variations, can cause issues or even outages in the power grid. Norwegian regulations state that the frequency should be kept within 50 $\pm$ 0.1 Hz, and that the voltage should be kept within $\pm$ 10% of the nominal grid voltage [31, p.6-7].

Fluctuations in power demand has traditionally been managed through deployment of spinning reserves. Spinning reserves are reserve capacity available for compensating for power shortages and frequency drops in a power grid [34, p.63]. Due to the increasing penetration of renewable energy in the power system, the spinning reserves are of increasing importance to the power system's stability. A BESS can be utilized in a similar way as a spinning reserves in the power system [34, p.64].

2.4.2 Ancillary services

The increase in renewable energy production introduce increased variability in power generation. Not only does this make it more challenging to settle the load-supply balance, but abrupt power generation changes require more fast response units in the power grid [33, p.555]. Fast response units have traditionally been spinning reserves [34, p.63-64]. Even though spinning reserves help keep the power quality adequate, they are costly and reduce the overall power system efficiency [33, p.556].

Microgrids can provide ancillary services to help mitigate challenges related to net load ramping. Ancillary services are all functions required by generators to keep the power system operating correctly, beyond the production of energy [35, p.868]. Microgrids dispose dispatchable generation units and usually an energy storage system in addition to demand response assets. These units allow the microgrid to improve the power quality, reliability and resiliency within the microgrid. When connected to the power grid, a microgrid manages its own power exchange with the power grid and will therefore be able to mitigate some of the load ramps that occur in the power grid [32, p.2-5].

2.4.3 Flexibility and demand side management

There have been proposed several solutions to mitigate the issues associated with the load supply balance. As an alternative or supplement to grid upgrades, flexibility markets could be a cost efficient solution.

Flexibility is the ability and willingness to modify production and consumption pattern, both at individual or aggregate levels. In a flexibility market, flexibility is bought and sold, with the goal of maintaining stable grid operation and energy supply. Flexibility can be provided by DERs, both by generation and energy storage units, these are covered in chapter 2.2. Flexibility could also be delivered by the demand side [36].

The main objective of Demand Side Managment (DSM) is to actively shape the consumers load profiles to improve the utilization of the overall system. Increasing consumer demand can be met trough load shifting and peak shaving. DSM is implemented by the utilities through direct load control, where consumer appliances are accessed directly, or through indirect load control. Consumer demand can be altered indirectly by using load control concepts such as time of use rates and electric tariff systems [37, p.953-954]. However, DSM requires substantial investments in infrastructure and that the consumers willingness to participate [33, p.556].

3 Approach

This thesis is based on literature searches and complementary conversations with professionals working with microgrids. The following chapter will describe how background information, case data and experience was collected. The composed method is based on two parts: a literature study and a series of case studies. The parts are characterized by different focuses and procedures. During the writing of this thesis the parts were executed in parallel. Chapter 3.1 describes how theoretical premises were established and how a broad investigation of global trends was conducted. Chapter 3.2 summarizes how a reasonable collection of cases was obtained and how the tangible data was gathered and conversations were conducted.

3.1 Literature study

The literature study was conducted to gather reliable background information and to establish present trends and motivations regarding microgrids. To obtain relevant and trustworthy literature for this thesis, the university library Oria and scientific databases were used. Furthermore, articles recommended by professor Olav B. Fosso and papers from FME CINELDI were also used. Throughout the study, professor Olav B. Fosso and Kristian M. Lien were consulted. In addition, a conversation with two FME CINELDI scientist was conducted.

Oria is the search engine of NTNU's university library. Through Oria, students and employees can access most material existing in Norwegian scholar and research libraries, as well as open access materials from selected databases. In addition to these databases, reports where gathered from some other sources. All sources used in the literaturre study are presented in table 3.1. To guarantee the quality and relevance of information, peer-reviewed literature published after 2010 was favored.

Table 3.1: *Sources used in the literature study.*

Databases	Other sources
IEEE Explore	European Union
IOPscience	FME CINELDI
MDPI	The Global Carbon Project (GCP)
Proquest	The Intergovernmental Panel on Climate Change (IPCC)
Researchgate	The International Energy Agency (IEA)
ScienceDirect	Navigant research
SpringerLink	NVE
Scopus	PQA
	The United Nations Framework Convention on Climate Change (UNFCCC)
	The Norwegian Environment Agency
	Statistics Norway (SSB)
	Store Norske Leksikon (SNL)

3.2 Case studies

The case studies were conducted to obtain a deeper understanding of the status, plans and motivations of the individual cases. On the basis of the selected cases, an overview of common objectives, technical solutions and challenges within the field of microgrids in Norway is given. This chapter describes the procedure used in the case studies. The results are presented in chapter 6.

The procedure of the case studies can be divided into two parts. In the first part, the selected cases were chosen, based on the criteria in table 3.2. The second part was the investigation of the cases. A detailed description of the two parts will be given below.

The sources used in the investigation of the case studies were found using a broader search than in the literature study. To get an initial overview of possible cases, the search was mainly based on information and tips from the supervisors. In addition, articles and reports were found using the search engine Google. Further information was gathered from key people working on the projects, websites and articles directly associated to the projects. All information presented in this thesis is based on these sources, or on the sources presented in chapter 3.1.

Table 3.2: *The list of criteria for the final case selection.*

1.	The grid fulfils most of the microgrid definition. It should be possible to operate in island mode, but a single PCC is not a requirement.
2.	The project should be finalized within the close future.
3.	It should deploy existing, and preferably commercially available technology.
4.	The microgrid must utilize at least one renewable DER.
5.	The microgrid must involve more than one energy consuming unit.
6.	Information about the microgrid should be easily accessible.

Selecting cases

Before the cases in the case studies were selected, an overview of the existing microgrids and related projects in Norway was established. The case-search included well-established operational foreign cases, to compare if and how Norwegian motivations, progression and applied technology differs from other countries. This investigation was based on information from supervisor and professor Olav B. Fosso, as well as results from searches in google. The search results were solely used for initial insights in the cases and are not used in the writing of this thesis. The search yielded a sizeable amount of suitable cases. An overview of discarded cases is given in appendix A.

The early stages of the case studies were closely linked to the literature study. The aim was to establish an overview over definitions and established projects. These insights were used to select the cases that were relevant for this thesis. These cases were all compatible with the first criterion in table 3.2. Although this criterion demands the possibility of island operation, it does not exclude cases that are not designed for island operation. Therefore, cases that will have a hard time going into island mode, as well as cases that only have the ability to operate in island mode for a very short period of time, were still included at this point.

To proceed, it was necessary to eliminate the cases not relevant to the thesis and to obtain a reasonable amount of cases. The elimination of the cases was done according to the criteria in table 3.2. For each case, every criterion had to be fulfilled, in order to be included in the thesis. The second and third criterion were chosen to safeguard a valid overview of status and opportunities. These criteria excluded projects early in the planning phase or depending on technological advancements.

The definition of a microgrid presented in chapter 2.1 does not exclude grids powered solely by fossil-based DERs. Criterion 4 i table 3.2 excludes such microgrids from the case studies because they do not contribute to the renewable energy transition. Furthermore, the IEC *guidelines for microgrid projects planning and specification* state that grid connected microgrids should stress the use of renewable DERs [9, p.15].

Based on the microgrid definition in chapter 2.1, a single power consuming unit with multiple loads can be considered a microgrid. To exclude small scale projects and to establish the trends in more complex microgrid systems, the fifth criterion was used. A consequence of this was that plus-houses were not considered.

The last criterion in table 3.2 was important to obtain sufficient results which could be used for the discussion and conclusion. Most cases in the study are relatively new and not often mentioned in publicly available articles. Thus, contact with a key person in each project was important. Before the final case-elimination, efforts were made to contact a key person, who could provide thorough information. Cases where contact was difficult to achieve were eliminated. During the final elimination, efforts were made to maintain a diverse case selection: similar cases to the ones eliminated were given a higher priority. Similarity regarded the sites and projects usage, size, location and technology.

In choosing the foreign cases, it was desirable to include cases from both similar and different environments than Norway. The term environment covers the country's climate and politics. In the end, two cases were chosen. One similar and one with a different environment compared to Norway.

Exploring the cases

The final selection of cases was explored through interviews and studying of reports. Initial contact with microgrid representatives was established through communication by email. A short presentation of the thesis objectives and main themes was provided to the recipients. After a contact person had been established, an appointment for a digital meeting was set. Prior to all meetings, the questions which were elaborated where provided to the interviewee. All questions used in the initial meetings are provided in appendix B.

A minimum of two interviews with each case representative were conducted to ensure the accuracy of the information. Total interview time with each case was kept between 2-3 hours. The second interviews were used to follow up important aspects of the different cases. Since the included cases have fundamental differences, follow up questions were made specific to each case. The aim of customizing interview questions was to gain a better understanding of case specific details.

To ensure that topics covered during the interviews where not forgotten, meeting notes were written by the authors of this thesis during the interviews. The meeting notes were not revised by microgrid representatives. However, once the chapters presenting the individual cases were finished, copies were sent out to the case representatives for approval. In addition to the meeting notes, the interviewees recommended and provided other sources of credible information. These included system logs, reports and blogs.

Note that the American case, Santa Rita Jail (chapter 6.1), is not written using the method presented in this chapter. This case only based on literature.

4 Motivations for microgrid deployment

Microgrids can, as stated in chapter 2, be designed to suit the needs of a specific location. The quality and presence of power grids vary between countries. In some parts of the world, especially in developing countries, residents may not even have access to a power grid. Thus the motivations for establishing microgrids will depend on the surrounding environment [8, p.406]. This chapter will introduce important motivations for microgrid deployment.

4.1 Climate goals

Planning an environmental friendly electrical power supply is important for a sustainable development. Population growth, urbanization and technological development increases the global energy demand [20, p. 1-2]. Since global power generation is mostly based on fossil fuels, this will result in greater CO_2-emissions [38, p.7].

Increased CO_2-emissions will further accelerate climate change and makes it more challenging to achieve international emission goals [20, p.1-2]. Historically, environmental factors have been neglected in the planning of power systems. Today, these factors are more important than ever before. This importance is driven by innovators from all sectors, including governments, regulators, utilities, power producers and end-users [16, p.7].

4.1.1 International climate politics

In the 21st century, man-made climate change is accepted as a fact, thus introducing a series of challenges to the human society. Temperature measurements show that both air and ocean temperatures have increased during the last 100 years due to increasing levels of CO_2 in the atmosphere. Moreover, analyses of the radiative budged indicate that the global temperature will continue to rise [39, p.121].

Consequences of a warmer climate include more frequent extreme weather events, sea level rise and vegetation changes. In addition to causing global warming, the increased emissions are associated with local air pollution [39, p.127, 134]. These effects are damaging for human societies and the impact of climate change will differ across the Earth. For example, some places will experience a dryer climate, while others will experience more floods [40, p.7310-7311].

To avoid the most severe consequences of global warming, the temperature rise should be restricted to 2°C or less. This target is derived by the IPCC created by the United Nations (UN). The IPCC has evaluated the current situation and possible outcomes regarding climate change. Its official view is that their so-called best-scenario outlook is achievable if the average temperature rise is limited to 2°C compared to pre-industrial levels [41, p.1-2].

UNFCCC, founded in 1992, laid the foundation for international climate politics. This framework is still valid and aims to reduce emissions of greenhouse gases to hinder dangerous climate change. An important turning point in international climate politics was the closing of The Paris Agreement. This document was created during the UN's yearly Conference of the Parties (COP) in 2015 [42].

As a result of the Paris agreement there are now emerging goals across many sectors creating new business opportunities, especially within the power and transport sectors [43]. The agreement clearly states that developed countries should take a leading role in the transition required to address climate change. Furthermore, the agreement emphasizes that developing countries should receive support from developed countries to meet their goals [44, p.2-4].

The primary goal of the Paris Agreement is to limit global warming. It reads:

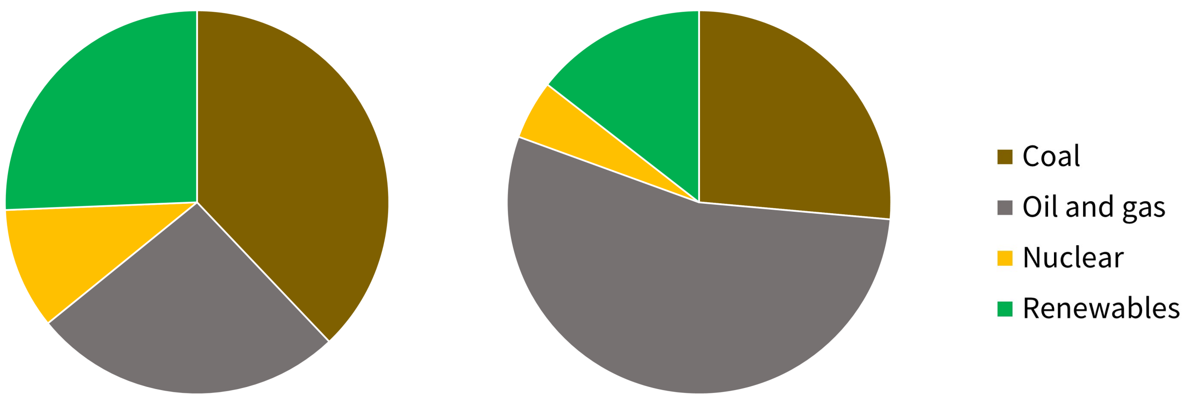
"*Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change*" [44, p.3].

4.1.2 Emissions from the power sector

The energy sector is responsible for most of the global anthropogenic CO_2-emission. According to GCP, the total global emissions amounted to 43.1 billion tonnes of CO_2 in 2019 [45, p.49]. For the same year, IEA estimates the energy related-emission to be 33 billion tonnes CO_2, accounting for 77% of the total emission [46]. Most of the remaining anthropogenic emissions are a result of land-use change [45, p.49].

Even though energy efficiency is constantly improving, the global energy demand is increasing at a greater rate. In 2018, the increase in demand for electrical power caused more than half of the increase in total energy demand. Electrical power amounted to 20% of the 2018 energy demand [38, p.3-5]. The prior year 2017, electrical power made up 16% of the total energy use. The use of natural gas experienced the greatest percentage increase, since it has been used to replace coal fired power plants in many places. However, much of the new demand was also met by renewable and nuclear sources [38, pp. 3, 16].

Based on IEA's 2018-data, the global electricity mix of 2018 was divided by source as presented in figure 4.1a. The total energy mix in 2018 is shown in figure 4.1b. These figures show that coal is the most important electricity source, as well as being important in the total energy chart. Since it is the most carbon-intensive energy source, it is the origin of large amounts of global CO_2 emissions [47].



(a) *Electricity mix* **(b)** *Total energy mix*

Figure 4.1: *The global energy and electricity mix of 2018, divided by energy source [38, p.25].*

In 2018, coal-fired electrical power generation was the source to 30% of the total global emissions. Efforts to phase out coal are met both with renewables and natural gas [38, p.8-9]. Stakeholders most often consider natural gas as a temporary solution and renewables to be the energy source of the future [48, p.1]. Though the total emission from the power sector is growing, the carbon intensity is improving. This means that the CO_2 emissions per kWh produced is decreasing [38, p.16].

The electrical power generated in Norway differs from the global generation in regards to renewable share and emission. Data from NVE shows that 98% of the Norwegian power generation was renewable in 2018. The consumption mix in Norway does not have an equal share of renewables due to international power trade and the market for green certificates [49].

Although it is impossible to identify power flow as renewable or fossil, the EU have created a market for renewable certificates to track production and consumption of renewable energy [49]. These certificates are called Guarantees of Origin (GOs) and serve as labels stating that the consumed electricity is renewable. GOs are handed out to producers of renewable energy for each MWh generated. Power producers are free to sell GOs to other participants on the electricity market. This allows a Distribution System Operator (DSO) who physically delivers fossil generated electricity to label it as renewable [50, p.101]. Norway is, despite not being an EU member, a part of the GO market [50, p.102].

Data from NVE shows that only 17% of the electrical power consumed in Norway in 2018 was sold with GOs. The origins of the electrical power sold without GOs are described in NVE's product declaration for power companies, which is based on national and European electrical power sold without GOs [49].

Combining NVE's product declaration and the fraction of GOs sold in Norway, a representation of the resulting Norwegian electrical mix can be derived. The data giving this representation for 2018 is shown in figure 4.2. This figure shows the share of electrical power sold with GOs, as renewable. The share sold without GOs is described according to NVE's product declaration for power companies, which consists of renewables, fossils and nuclear.

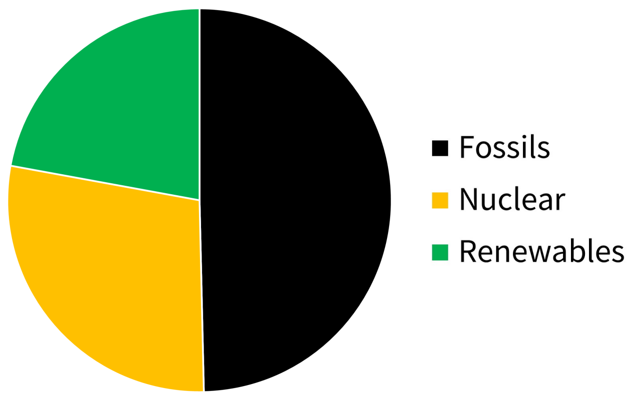


Figure 4.2: *The Norwegian electrical mix of 2018 divided by energy source, accounting for purchases of GOs. Modified from source [49].*

4.1.3 Land use concerns

The power grid spreads across large areas. Expansions and improvements of the power grid can include upgrading and replacing existing lines and transformers [51, p.173]. In such upgrades and in planning of the electricity system it is important to accommodate land-uses and spacial issues. When new grid elements are integrated, landscape concerns must be considered [52, p.2].

In many cases, landscape changes are linked to social injustice and morality. Land and nature have an important cultural role in human societies. Traditionally, humans feel ownership to the landscape and a responsibility to preserve it. An example of this is the public disagreements regarding land use in wind power development. Both the wind turbines themselves and the accompanying infrastructure have raised concerns. The visual impacts of wind turbines and associated infrastructure have been a great debate, and have proven to be a pivotal obstacle in some cases [53, p.552].

For large power grids it is unavoidable to affect untouched landscapes. This is both due to the large facilities and the size of the required transmission capacity. With the increased construction rate of renewables, it is necessary to use more space [53, p.549]. Renewable generations traditionally require more diverse physical sites than fossil generations [53, p.543]. These aspects are motivations for microgrid deployment, since microgrids allow for reduced transmission line distances [53, p.547].

4.2 Reliability and resiliency

Today's modern society is heavily reliant on electrical power. In everything from minor daily task to critical facilities, human life depends on electrical power. In this context, microgrids may contribute to an increase in reliability and resiliency. Failures in one part of large power grids can lead to blackouts in much larger parts of the grid, due to cascading effects. In addition to leaving the consumers without electricity, blackouts could cause strains on electrical equipment. Microgrids have the ability to isolate an enclosed part of the grid from the failure, thus allowing for uninterrupted operation [8, p.404-405].

Remote communities around the world are especially vulnerable to reliability and resiliency issues. Most of these areas depend on stand-alone power systems. These systems can be both microgrids and power grid based systems. Power grid development is often challenging due to difficult accessibility, economical considerations and sustainability perspectives [54, p.37].

4.2.1 Energy transition

The international climate goals and politics call for a substantial change in the energy sector. This rapid change is often described as the energy transition. The basis of the transition is the shift towards a fossil free and sustainable energy system [52, p.1]. In this transition, governing forces emphasized the importance of flexibility, resiliency, cost-efficiency and justice [55, p.1].

A fossil free energy system will rely on more electrical power [51, p.169]. At the same time, the human population and the average standard of living is increasing, demanding even more electrical power [20, p.1]. Consequently, the energy transition will lead to an increase in electrical power demand and the present of renewable generations and DERs. These concerns will demand improved and larger power grids, or alternatives that can tackle the same concerns. Microgrids represent an alternative to such improvements [8, p.404-405].

Expansion of the current power grids could be a problematic solution to the increased electrical power demand. This is due to the high cost and the uncertainty in future demand forecasts. The scope of electrification forecasts is extensive, which makes planning for power grid expansions and upgrades complex. Distributed solutions, like microgrids, can in many cases reduce or minimize the need for upgrades [51, p.173-174].

4.2.2 Power supply and resiliency

Today, common causes of failures in the power grid include wear and tear, attacks, and extreme weather. All these hazards are becoming more pronounced. As time passes and attrition of the grid continues, its fragility increases. Due to an increased implementation of communication technology in the power grid, the risk of cyber attacks increases. Furthermore, as mentioned in chapter 4.1, extreme weather will likely occur more frequently and thus become a larger challenge for power grids in the future. All these factors are incentives to improve resiliency of power grids [8, p.404-405].

While the demand for electrical power is increasing, the resiliency is decreasing. A consequence of electrification and the energy transition is that power grids are pushed closer to their breaking point. This increases the risk of cascading outages, which occur when a load is transferred to an already stressed power line due to an outage. Through relieving the power grid and ancillary services, microgrids can improve the resiliency of the power grid. Furthermore, microgrids could protect particularly vulnerable parts of the power grid by separating selected areas from the power grid through a PCC [8, p.405].

4.3 Economic considerations

Initial investment costs of microgrids are large. In some cases they can be an economically viable solution. To be a worthy alternative to a regular distribution grid-connection, a microgrid must be developed and optimized for the specific location and use. Executed correctly, the deployment of microgrids can benefit both power consumers and suppliers [56, p.7].

For consumers, a microgrid is an opportunity to deploy DERs. Some DERs provide energy at less expensive rates than energy from the power grid, especially in peak hours of the electricity price. Consumers can reduce their electricity bill by managing energy consumption, generation and storage in a smart way. Excess energy may be sold back to the DSO through the power grid [56, p.7-8]. Other economical benefits are closely linked to the improved reliability and resiliency achievable through deployment of microgrids. Improved security of supply will also reduce the Cost of Energy Not Supplied (CENS) [8, p.405].

For Transmission System Operators (TSOs) and DSOs, microgrids represent potential economical benefits regarding transmission and distribution costs. The ancillary service that microgrids can offer to the connected power grid reduces these costs [10, p.78]. Furthermore, local DER solutions decrease the need for large and widespread power grids associated with high investment costs [10, p.73]. Also, cost inefficient upgrades and investments in power grid connections to remote areas can be avoided [54, p.37]. Since microgrid constructions are less comprehensive than large power grid constructions, the investment is also linked with lower risk. Another benefit generating economical gain is the increased flexibility microgrids can offer [10, p.73].

5 Power grid development in Norway

In Norway, electricity is supplied to the consumers through the country's well established power grid. Even though the bulk of Norwegian power comes from hydro, the use of other renewable energy sources is increasing. Such sources include solar PVs and different sources of heat energy [2].

This chapter covers aspects related to microgrid development in Norway. This includes the state of the power grid, future outlook of electricity demand and trends regarding prosumers. In addition, a brief introduction to the international microgrid developments and some important organizations are presented.

5.1 The Norwegian power grid

The electrical power consumption in Norway is high. From 2015 to 2020 it ranged between 130 TWh and 137 TWh [57]. Access to affordable hydropower has led to a high level of electrification in Norway. A bulk of the Norwegian industry is relying on electric power for production, and households are more often than not relying on electricity for heating purposes. This is an important reason for why the electrical power consumption per capita is amongst the highest in the world [2].

The Norwegian power grid is divided into three levels. The transmission grid has the highest voltage, usually between 300-420 kV. It connects the large power plants, the different regional and local distribution grids in the country in addition to transmission grids from abroad. The operators of such grids are referred to as TSOs. In Norway there is only one TSO, this is government owned company Statnett [58, p.11].

The regional distribution grid has the second largest capacity and voltage, ranging between 33-132 kV. Its function is to connect the transmission grid to the local distribution grids. On the lowest level, the local distribution grids is directly connected to the consumers. This grid usually has a voltage between 11-22 kV. DSOs are the owners and operators of both the local and the regional distribution grids. In Norway, each DSO has monopoly in the geographical region it manages [58, p.11].

The transmission grid has good stability. This is also the case for the regional distribution grid in densely populated and heavily industrialized areas. Regional distribution grids in remote districts are generally more vulnerable [7]. Presently the Norwegian power grid is being expanded and upgraded. Some parts of the power grid are aging and have a poor technical condition, resulting in the need for upgrade and new grid. In addition to aging grid components, an increasing power demand further emphasizes the need for an increased capacity in the power grid [3, p.22].

In Norway, the local DSOs are responsible for the energy transport from the power plants to the consumers as well as maintaining an acceptable power quality in the power grid [59]. However, the Norwegian government has decided that everyone connected to the power grid carries some responsibility. As a consequence, in situations where the grid strength is adequate, the consumers might have to carry some of the costs related to grid reinforcement [31, p.4].

The DSOs in Norway operate in natural monopolies. Therefore, market intervention is required to ensure cost efficient grid operation [59]. One of the instruments used for market regulation is the CENS arrangement. This arrangement ensures that DSOs are fined if power or sufficient power quality is not delivered to the consumers. The arrangement was established to ensure a socioeconomic optimal point of market operation [60].

5.2 Norwegian prosumers

Norwegian prosumers utilize the Norwegian prosumer agreement called "*Plusskundeordningen*". This is an arrangement that allows prosumers to deliver up to 100 kW electrical power to the power grid without having to register as a power supplier. The arrangement implies that a prosumer only can sell electrical power to a power supplier, not directly to other consumers [61]. The amount of prosumers in Norway is increasing, especially prosumers with solar DERs [62].

The Norwegian power grid should be capable of handling some prosumers. Nevertheless, since the capacity of the power grid is not sufficiently charted, it is hard to determine the consequences of a future with more prosumers [63, p.8]. A report ordered and published by NVE concludes that Norwegian prosumers could contribute to increased voltage variations and thermal strain on transformers in the power grid [63, p.65].

Some DSOs have expressed concerns regarding these issues. They are expecting that the grid needs to be upgraded and expanded. This will be the case if prosumers install DERs that the local grid is not dimensioned for [63, p.8]. Still, these challenges are only likely to occur in a few areas far out in the power grid. Most parts of the power grid are well equipped to handle prosumers [63, p.66].

NVE expects the presence of prosumers to increase. In 2020, NVE concluded that prosumers in the future could contribute with flexibility within the power marked and reduce the need for new power grid investments. In addition, NVE believes that DERs will be important in this future market [3, p.21].

5.3 Microgrids in Norway

A NVE report from 2019 states that the microgrid trend is not extensive in Norway. There are multiple examples of projects and areas that use microgrid technology, most of these are under development [6, p.46-47]. Some examples are the *Powerhouse Brattørkaia*, the business areas *Smart Grid Services Cluster* and *Solenergiklyngen* [6, p.46-47]. Common for all microgrid projects in the country is that they depend on many different sectors, such as the building and energy industry, research centers, academia, tech and IT-contractors, DSOs, the TSO and municipalities [6, p.37].

There does not exist a register of existing microgrids in Norway. However, there does exist a communication platform for microgrid actors which is called µForum [7]. µForum was established in 2020 when a number of Norwegian actors gathered to create a forum about microgrids. The forum's objectives are to collect and share experience from microgrid research. The contributors include DSOs, tech suppliers, consulting firms and project organizations [64].

Scientists at FME CINELDI have found that the technology for extensive use and development of microgrids is available in Norway. However, a lack of motivation is slowing microgrid development. Even though new technology is more expensive than conventional methods, economic considerations are not the greatest barriers. A more important hinder is the legal system and high number of involved parties that need to be considered [7]. Also, the current legislation affecting microgrids in Norway does not accommodate increased microgrid development [5, p.17].

FME CINELDI's work has shown that microgrid deployment in Norway is most often considered for larger grid areas. This is because larger microgrids usually have larger investment returns than smaller ones [5, p.16]. Examples of such areas are remote communities or large industrial sites. Presently, both the population and the amount of cabin owners in remote areas are increasing in Norway. This creates issues related to power supply and quality [5, p.6].

5.4 Future outlook

Even though the energy efficiency is expected to improve in all sectors, the Norwegian energy consumption will still increase due to electrification. The electrical power consumption is expected to increase to 163 TWh in 2040, 26 TWh higher than the consumption in 2020. The electrification of the oil and gas sector, existing industries and transport are important factors in the presumed increase in consumption. Furthermore, establishment of new power-intensive businesses will also increase the power demand. Some of these industries are a result of climate goals, such as hydrogen production and battery production. Whilst others are results of digitalization, such as data centers [3, p.2].

At the same time as the power demand increases, Norwegian power generation is also expected to increase. Most of this increase will be met by an increased amount of hydro power, and some will come from new wind and solar PV plants [3, p.2]. In addition, NVE expects the presence of prosumers to increase and believes that DERs will be important in the future energy market [3, p.21].

FME CINELDI has identified the crucial factors for further development and research of microgrid in Norway. These factors concern the roles of the different actors, such as the DSOs and the consumers, but also the future legal system and political incentives. FME CINELDI concludes that the environment for microgrid deployment is not ideal, and that finite standardization and guidelines for deployment need to be established [5, p.17].

5.5 International microgrids

Modern microgrid research dates back to 1999, when the Consortium for Electric Reliability Technology Solutions (CERTS) was established in USA. At about the same time, the European project MICROGRIDS started. Afterwards, there have appeared a variety of driving forces for exploration of microgrid technology. Early research on microgrids focused on safe islanding and reconnection to the power grid, control strategies, energy management, security equipment and communication protocols [8, p.403].

Presently, only a very small fraction of the power market is supplied by microgrids. In 2015 the global capacity in microgrids was approximately 1.4 GW, where the U.S. and Asia dominate the sector with 42% each [8, p.405]. For comparison, the global power generation capacity was estimated to 6400 GW in 2015 and 6700 GW in 2020 [65, p.258] [66].

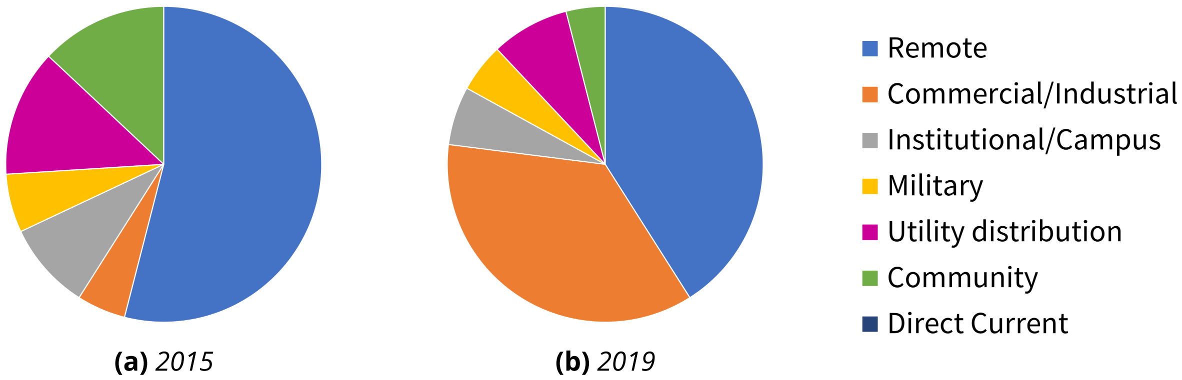


Figure 5.1: *Microgrid power capacity by market segment in the second quarter of 2015 and 2019. The charts are modified from sources [67] [68].*

Figure 5.1 illustrates the diversity in 2019 microgrid applications. In mid 2019, 41% of the total microgrid capacity was installed in remote, non grid-connected microgrids. The figure also illustrates that the microgrid market is rapidly evolving. In 2015, commercial/industrial microgrids had a much smaller market share than what was the case in 2019 [68] [67].

5.6 Research programs and organizations

Research programs and related organizations are often a part of projects regarding new distribution solutions, such as microgrid projects [6, p.37]. Public subsidy schemes, both national and international, are also important for projects using new innovations [6, p.25]. Below, important research programs and organizations related to microgrid projects are presented. Some of these are involved with the cases presented in chapter 6.

CERTS

CERTS was founded in 1999. It is a U.S. federal research and development program aiming to address electric power reliability concerns [69]. CERTS is working to protect the grid through developing power electronic interfaces connecting DERs to the grid. One of the consortium's five areas of research concerns DER based microgrids, and how to enhance the reliability of the electricity service through deployment of DERs [70].

The CERTS microgrid concept aims to increase reliability and reduce cost. This is achieved by reducing engineering costs and errors through developing a system with *plug-and-play* capabilities. To achieve this, each CERTS device must regulate its own voltage and frequency [71, p.938]. Decentralized control of microgrids is described more precisely i chapter 2.3.

FME CINELDI

FME CINELDI is a centre for environmental-friendly energy research, which translates to "*Forskningssentre for Miljøvennlig Energi*" in Norwegian, led by the Norwegian science institution Sintef. It aims to establish a cost efficient solution for the future electricity distribution systems. The balance between security of supply, affordability and environmental considerations is referred to as a trilemma. The centre provides and tests smart-grid solutions in both laboratory and real life environments. Results from their research benefit TSOs, DSOs, manufacturers and information and communications technology companies to deploy new technology [72].

Enova

Enova is a Norwegian State enterprise that aims to contribute to reduce greenhouse gas emissions, improving reliability of power supply and supporting technological advancements that could reduce greenhouse gas emissions in the future. In 2016, the Norwegian government determined that Enova should be an important agent in the development of the low-emission society and the future energy system [73]. From 2015-2020, the company's yearly subsidy budgets have been between 1.84 and 5.10 billion NOK [74].

Innovation Norway

Innovation Norway is a company owned by the Norwegian Ministry of Trade and Norwegian county authorities. The company's objective is to contribute to profitable development of Norwegian industry and commerce, with focus on entrepreneurs and industries in growth. Renewable energy industries are amongst the opportunity sets that are most emphasized. The company offers advice and network building for businesses, as well as multiple subsidy schemes [75]. From 2016-2019 their yearly subsidy budgets have been between 2.66 and 2.87 billion NOK [76].

Horizon 2020

Horizon 2020 was EU's framework program for research and innovation that lasted from 2014 to 2020. By investing money in research and innovation, the program aimed to keep European science global competitive. It has been an important financial driving force, granting nearly 80 billion EUR of funding to the European research area. The framework has an open-for-all policy and focused on helping new projects so that innovators could achieve results faster [77].

Interflex

The Interflex program lasted from 2017 to 2019. Its objective was to investigate how local flexibility resources be applied to alleviate congestions in the distribution grid. In total, 20 industrial partners from different countries where involved in the project. The program was partly funded by the EU's Horizon 2020 program and had a total budget of 22.8 million EUR [78].

6 Cases

Chapter 5 states that the prevalence of microgrids is not extensive in Norway. Still, there is a range of microgrid projects in Norway. Although small, the range of projects in Norway is diverse. This diversity provided a fairly broad selection of possible cases for the case studies of this thesis.

This chapter presents the cases that where investigated in separate sub-chapters. In all cases, a microgrid is already established or is to be deployed at the site in the close future. The case selection includes four Norwegian cases, one Swedish and one American case. An overview of the cases is provided in table 6.1. All sub-chapters are built up in a similar way, with three main headlines: *Background*, *Technical Scheme* and *Experiences*.

The results are meant to provide a closer look at the motivations, technologies and experiences of Norwegian microgrid projects. The foreign cases have been included to indicate if and how these factors differ from Norwegian microgrid projects. Together with the findings from the literature study, which are elaborated in chapter 4 and 5, the results in this chapter will be discussed in chapter 7.

Table 6.1: *Overview of the microgrids explored in the case studies of this thesis [79, p.38] [80] [81] [82] [83] [84].*

Chapter	Location	Description
6.1 Santa Rita Jail	Alameda county, U.S.	A large prison hosting 4500 inmates, covering an area of 0.5 km^2.
6.2 Simris	Skåne, Sweden	A neighbourhood of approximately 140 households.
6.3 Evenstad Campus	Innlandet, Norway	A university with about 290 users, student and staff. As well as to 140 dorm rooms.
6.4 Risavika Port	Rogaland, Norway	A port which delivers power to ships, on-shore vehicles and off-shore business, in addition to a building.
6.5 Rye	Trøndelag, Norway	Two farms utilized for farming, only one of the two farm households is inhabited.
6.6 Utsira living lab	Rogaland, Norway	An remote island society with approximately 200 inhabitants. Also, there is some newfound interest of industrial opportunities at the island.

6.1 Santa Rita Jail

Santa Rita Jail (SRJ) is a large prison located in Alameda county, California. It accommodates about 4500 inmates and occupies an area close to 0.5 km^2 [79, p.38]. Officially, the microgrid started operating in March 2012 [79, p.48]. The DERs installed in the prison include a fuel cell, PV installations, a BESS, as well as two diesel generators which are primarily used as backup. In addition, a capacitor bank is used to supply parts of the reactive power demand [71, p.937]. During normal operation the aggregated power demand is approximately 2.5 MW, although some peaks exceed this. The facility is governed by Alameda county, and occupies 30% of the county's total utility budget [79, p.39].

Figure 6.1: *Picture of Santa Rita Jail, cropped from source [85].*

Background

Before the microgrid was deployed, the jail had occasionally struggled with poor power quality. At that time the diesel generators alone served as the power backup. Since they require ten seconds to start, the facility was effectively left without power a short while during failure on the power grid. Moreover, the already existing DERs (the fuel cell and PV) were unable to operate in parallel to the diesel generators. Hence, the prison was rendered unable to utilize clean energy sources during power outages [71, p.1-2].

Goals and motivations

Alameda county had two important motivations to establish a microgrid at SRJ. The first was to give a large scale demonstration of CERTS's microgrid technology applied in a commercial environment. The second was to improve the implementation of the clean DERs already present at SRJ. Before implementing the microgrid and BESS, overproduction from the DERs was quenched, thus reducing economic viability [79, p.48].

Power quality is of paramount importance for the jail. Instabilities in the power supply at the jail cause costly fuel cell outages. Implementing a microgrid may improve the power quality within it, thus allowing for more stable fuel cell operation. In addition to improving the power quality within the microgrid, its presence in the power grid can help improve the power quality in the nearby power grid. This is both because SRJ is a major power consumer, and the ancillary services the jail can provide the power grid are substantial [79, p.48-49].

Technical scheme

Table 6.2 presents the DERs at SRJ. Except for the BESS, all DERs where already present at SRJ before the microgrid was established [86, p.1]. The BESS capacity and power were sized so that the BESS would be able to serve the facility even when its consumption peaks during summer afternoons. Its main purpose is to conduct power grid rate arbitrage. 80% of the battery capacity is used to charge from the grid when power prices are low and discharging from the battery when the prices are high. Rate arbitrage is managed by the BESS's energy management system, according to time of use tariffs. 20% of the capacity, top and bottom 10% of the state of charge (SOC) are reserved for power quality enhancement during grid connected operation [71, p.939].

Table 6.2: *Overview of the DERs at Santa Rita Jail [71, p.937] [79, p.40-43].*

Resource	Power / Capacity	Established
BESS	2 MW / 4MWh	-
Diesel gen.	2.4 MW	-
Fuel cell	1 MW	2006
PV	1.2 MWp	2002

The prison's molten carbonate fuel cell was completely installed at the site in 2006. Due to its high operating temperature, it requires a long time to start up and is supposed to supply the base load of the facility. To improve the overall efficiency of the fuel cell, it is equipped with a heat recovery system that preheats water for consumption. This appliance of co-generation reduces the demand for natural gas [79, p.41]. Before the microgrid was implemented, the fuel cell performed poorly. During the period 2007-2009 it only produced at 100% capacity factor for one month [86, p.2]. The reason for its poor performance was the inferior power quality at the power grid [71, p.938].

Power from the PV arrays is transferred to the jail's microgrid through four separate inverters [79, p.40]. In a similar manner to the fuel cell's under-performance, the PV array operation has also been subject to power quality related issues [71, p.938]. They have rarely delivered a power output greater than 700 kW, which is 500 kW less than their peak rating [86, p.2]. Both the issues with the fuel cell and with the PV system have been mitigated through the implementation of a static disconnect switch, which enables the microgrid to transition seamlessly into island mode within 8 milliseconds [79, p.49-50] [71, p.938].

To maintain supply of critical loads during extended power outages, SRJ is equipped with two diesel generators. The generators are capable of delivering 1.2 MW each, allowing almost normal operation solely based on the backup generators. Since the BESS has been introduced, the generators have been used very little [79, p.43].

Experiences

Alegria et al. ([71]) conclude that the establishment of the microgrid at SRJ proved that the CERTS concept, based on distributed control, eases the installation of a microgrid. Also that an energy management system is necessary to maximize the economical benefit of a BESS. And that the reliability of the microgrid in island operation can be further improved by applying a load shedding scheme [71, p.943].

Thiemann et al. ([79]) conclude that the electric storage at SRJ generates economic savings on a daily basis. This is done through flattening demand peaks and by the use of an energy management system that conduct rate arbitrage. However, considering the capital costs, the BESS is not economically viable with current prices. The same report concludes that SRJ could offer ancillary services to the power grid, though only with minor economical benefits [79, p.160-161].

6.2 Simris

Simris is a village located south in Sweden, in the Skåne region. As is shown in figure 6.2, Simris is a rural village that consists of older houses, approximately 60 years old [80]. In 2016 it became the site of a microgrid pilot project under the auspices of E.ON Sweden [80]. E.ON is a privately owned international energy corporation [87]. For two years, 2017-2018, a microgrid was in operation at the site and provided locally produced power to approximately 140 households and the local welder business [80].

Figure 6.2: *Picture of Simris [88].*

With a positive local community and project management, Simris has become an almost self-sufficient village [88]. Wind and solar energy is exploited to electrify the little community, by both local and end-point DERs. In addition, a BESS plays an important part in the energy system. While E.ON was responsible for the microgrid project, most of the DERs are locally owned [80].

Background

E.ON's activity in Simris can be separated into three innovation phases. The first phase involved the microgrid deployment and ran from 2016 to 2018. In 2017, and the second phase began, when the village became the site of an Interflex project. The third phase, regarding further technology advancement, is currently in progress. Both E.ON's own projects and Interflex were driven by a range of motivations [80].

Development

Phase one was commissioned through E.ON's own pilot project in 2015, which originally was planned for an island north of Stockholm. Due to local dismay from the islanders, E.ON decided to find another site for the project [80]. Areas where E.ON was the DSO were considered. Simris first became a topic of interest since it was located in the vicinity of an already existing wind and solar farm, located in one of Sweden's most sunny and windy regions. Also, the local community was positive to new energy solutions [88].

The objective of the first phase was to construct a microgrid that could function in island mode while powered by local energy resources [89, p.51]. During this phase the PCC was implemented, defining the microgrid. A BESS, a back-up generator and a control system were implemented and the local wind and solar farm was connected to the microgrid. The microgrid was successfully operating in island mode once every five weeks, thus demonstrating that an islanded microgrid based on renewable DERs is feasible in the village. After the first phase was finished in 2018, the system was stripped down, removing components necessary for island operation [80].

While the first phase-project was still running, Simris became an Interflex project, thereby starting the second innovation phase. The objective was to make the village's annual net consumption zero. During the Interflex project, 2017-2020, commercial solutions were deployed and the citizens were included to a greater extent. They were encouraged to install PV and battery packages to their homes, to which E.ON offered financial support and professional consultation. E.ON's efforts in this stage were financed by Interflex, while E.ON provided the citizens with a 20-30% discount on their investment cost [80].

The Interflex project was finished in January 2020. Proving the possibility of energy self-sufficiency for an entire village, using mostly commercial technology solutions. The current work centers around further development within Simris and the use of the Simris technology in other places. This third phase is, like the first phase, funded and directed only by E.ON. The work includes improvement of the PV technology, as well as evaluation of blockchain technology and how this could be used to obtain a closer interaction with the consumers [80].

Motivations

In the Swedish branch of E.ON, the main focus is smart distribution grids and innovative energy solutions. E.ON, who is the DSO at Simris, believes that local energy solutions such as the ones used at Simris represent important and powerful opportunities for the energy industry [89, p.62]. E.ON has a vision of a future where electricity is produced with local renewable generations and the consumers are engaged in energy supply and storage. A goal of the Simris microgrid has been to prove that this vision is plausible, although the motivation is to test new technology [80].

In proving the plausibility of the project it has been important to use marked available technology. This is mainly because E.ON have seen similar projects struggle to deploy in-house developed technology for specific problems in more than one location. Furthermore, E.ON believe that if the Simris solutions are to become common, the deployed technology should be commercially available [80].

The motivation to test and gain experience about microgrids and renewable DERs is connected to the energy transition [80]. Experience on the subject is necessary to battle the challenges accompanying the predicted increase in renewable DERs [89, p.51]. These challenges must be met with suitable solutions, which E.ON aims to provide in an economically sustainable way. The investments at Simris have not yet been, and are not expected to become profitable. Nevertheless, it is important for E.ON to execute this pilot project to figure out which solutions that will work well. These can then be deployed in an economically beneficial way elsewhere [80].

As a result of the difficulties that E.ON experienced at the initial project site, with the local community, it has been a motivation to obtain engagement and support from the locals at Simris. The aim has been to attain a ring of trust between the local community and the company. In addition, E.ON wanted the locals to invest in rooftop PV systems [80].

Technical scheme

The DER solutions of the microgrid in Simris are presented in table 6.3. The system that enabled the network to operate in island mode was present from 2017-2018 [80]. The majority of the locally generated electricity is delivered from the wind turbine. On average, the turbine delivers 1.1 to 1.5 GWh each year [90]. The total installed local generation power is summarized in table 6.3.

Table 6.3: *Overview of the DERs at Simris [89, p.52] [90].*

Resource	Power / Capacity	Established
Wind turbine	500 kW nominal	1996
PV-plant	442 kilowatt peak-power(kWp)	2013
BESS	800 kW / 333 kWh	2017
Bio diesel generator	480 kW / 4.5 L tank	2017
Residents rooftop PV	10 kWp	2017-2020
Resident BESS	6.4 kW / 9.6 kWh	2017-2020

The farm with solar and wind resources is located less than a kilometer from Simris. It is owned by a local, who invested in these DERs years before the microgrid project. Currently, E.ON has an agreement with the owner that allows them to use his assets for their projects. Prior to the microgrid coupling, the farm delivered excess power to the Swedish power grid, since it was not connected to an energy storage. Currently, the excess power from the farm is delivered directly to Simris and the BESS [80].

About 20% of the citizens of Simris have invested in rooftop PVs and complementary battery solutions. These residential DERs are controlled by E.ON, through DSM. Some consumers have also joined the local flexibility marked, by selling power to E.ON and getting a remuneration through their own electricity bill [91].

The BESS is owned by E.ON, it is connected to the wind and solar farm. During the island mode operation the BESS worked together with an advanced control system to keep the voltage and frequency in balance, to answer to the intermittency of wind and solar power production. It was also important for storing surplus power, to supply the microgrid when there was little wind and sun [80].

The biodiesel driven power generator was only used as a back up during island mode, during the period 2017-2018 [90]. E.ON did not wish to use this generator over longer periods of time, since biodiesel is expensive. The microgrid would be connected to the grid when the island mode had been dependent of the diesel generator for over 4-5 hours. This was because the island mode operations were primarily linked to testing. Since the Swedish power grid is relatively stable, it was never reasonable to keep Simris in an island mode that depended on the diesel generator [80].

Experiences

E.ON's team at Simris believes that microgrid deployment is worth while in some remote places. In such places, large grid investments can be avoided through microgrids deployments. This project was not necessary to supply Simris with power and would never have been executed by E.ON if not for experimental reasons. Still, all the projects that E.ON has executed at Simris have given valuable experience that have been used in other areas. This concerns both experiences related to the technology and to the project management [80].

The activities at Simris are not expected to provide profitability in the close future. In accordance with the motivations, the profitability that the Simris pilot offers is through deploying the solutions other places. In total, E.ON's affairs at Simris are expensive. Island mode operation was especially expensive, more so than grid connected operation [80].

Further use of tehcnical solutions

From phase one, E.ON's team made several observation regarding island mode. They experienced that island mode yielded a better power quality, but also that it demands more effort than normal grid operation. These and more insights from phase one gave useful insights that will be used in a project E.ON is currently conduction. This project is called IElectrix and involves a larger area that is going to be islanded sometimes.

The microgrid at Simris is capable of delivering ancillary services to the power grid. Still, this is not the intent or a solution that the Simris team wants to use. This is mainly because this is expensive, but also because delivering ancillary services does not make sense in the power grid environment Simris is a part of [80]. In a future with more complex power systems, this use of microgrid could be applicable [89, p.53].

Community engagement

A key challenge for the project was to raise awareness among the villagers in Simris. Due to the issues experienced at the initial location, measures were taken to avoid conflict with the inhabitants of Simris. Fortunately, the local society has been positive to the project and E.ON's interference in the neighbourhood [80].

The locals at Simris consist of families, elders and summer guests. In their meeting with the villagers during the first and second phase, the Simris team's strategy was to be available to the local community. They communicated with individuals and the society as a whole. Once every couple of months, E.ON would host village meetings. In between these meetings, the Simris team would talk with individuals in informal settings [80].

Although E.ON successfully gathered support from the locals, only a minority of the locals participated in DER investments. Approximately 20% of the houses have smart energy solutions. The same amount, 20%, have invested in rooftop PVs. Even though not all the rooftops are orientated in a suitable direction for PV installation, E.ON would have preferred a greater number of end point DERs. Still, the company is careful not to intervene in the lives of the residents more than necessary [80].

E.ON have seen a value of this type of communication, which is local support and engagement. Still, this method for community engagement was expensive for E.ON. They do not believe that this strategy is feasible in the marked structure, where competing companies barely invest in costumer service. Still, parts of this experience is currently utilized in an E.ON project in Spain, called EMbassador [80].

6.3 Campus Evenstad

Campus Evenstad is located in the south of Norway and hosts the staff and students of the Faculty of Applied Ecology, Agricultural Sciences and Biotechnology, at Inland Norway University of Applied Sciences [92]. Figure 6.3 shows the site, which consists of ten buildings for academical use and as dorm rooms. The daytime users are approximately 70 employees and 220 students. There is a total of 140 dorm rooms at the campus, these are usually inhabited by student or guest lecturers [81].

Figure 6.3: *Picture of Campus Evenstad [93].*

Both the buildings and the microgrid is owned by Statsbygg, the Norwegian government's building commissioner, property manager and developer. The site is Statsbygg's research property for renewable energy and is a pilot project of the research center for Zero Emission Neighbourhoods (FME ZEN). Due to frequent building and research activity on the site, the average power demand varies from year to year. In April 2021, the power demand peak was about 200 kW [81].

Background

The campus features a microgrid, DERs, two passive houses and a ZEB, as well as smart energy solutions. Both buildings, technical components and the microgrid is owned by Statsbygg [81]. For centuries the site was used for farming, but has during the last century been used for educational purposes. After a fire in 1987, large parts of the buildings were reconstructed [92]. Since 2010 there has been continuous technical progression on the campus, when the engineering phase of a PV-roof installation begun. Later, several new buildings, installations and projects have been implemented on the campus. The result is the system that exists today, consisting of modern building and energy technology in interaction with buildings dating back to the 19th century [94, p.2].

Another important initiator in the campus development is FME ZEN and its predecessor [81]. FME ZEN is a project that researches and develops solutions for zero emission neighbourhoods. It is a national research center that is led by Sintef and financed through Forksningrådet. It succeeded the ZEB center in 2017, a center that developed knowledge, products and solutions for ZEBs during eight years. The ZEB center was involved in the construction of the administration building at Evenstad in 2016 [94]. Furthermore, Evenstad was FME ZEN's first test area [95].

Motivations

Deploying a microgrid on the site was first considered in 2018, after a BESS was bought and installed. Instability in the local power grid was part of the background for this deployment, but the main driving force was related to national environment and emission goals. These goals have been the motivation for implementation of self-supplied renewable DERs and the collaboration with the ZEN and ZEB project. Together, these efforts form the basis of and the need of an intricate system that depends on ancillary and innovative initiative, such as a microgrid [81].

As a public management company, Statsbygg has a special responsibility regarding their project selection. They must operate in accordance with the Norwegian governments goals and strategies, regarding climate, land use and innovation. Since the national portfolio is extensive, with an equally large budget, the company stands for large purchases on the private market. This means that the company can act as a prominent contributor to growth in technology, a position the company wishes to use to fulfill its social responsibility [96, p.5].

To obtain experience which can be used in other projects has been important for Statsbygg. Furthermore, it has been interesting to test this type of technology in the climate at Evenstad. The location has several different weather types and a generally cold climate, in contrast to other locations of Statsbygg projects. Another important incentive for choosing Evenstad as a research area was its size, which Statsbygg found to be neither too small nor too large [81].

Technical scheme

All the electrical DERs are connected in the microgrid, which is connected to the power grid. The electrical microgrid supplies all the buildings in addition to the charging station. An overview of the DERs at Evenstad is presented i table 6.4. In addition, the site host two passive houses, a ZEB and two waterborne heating systems.

One of the waterborne heating systems is connected to the passive houses, which were upgraded in 2015. The site's solar thermal system is installed on the roof of one of these houses, and feeds their common water borne heating systems [81]. The second system was constructed in 2016. It serves seven of the buildings, only excluding the process building and a storehouse. Future plans involve a coupling between this system and the solar thermal system [81].

Table 6.4: *Overview of the DERs at Evenstad Campus [81].*

Resource	Power / Capacity	Established
PV-roof	60 kW	2013
Solar thermal system	-	2016
CHP el	40 kW	2016
CHP heat	100 kW	2016
BESS	120 kW / 204 kWh	2018
V2G	10 kW	2019

The loads on the grid are separated in different groups, described as critical and non-critical loads. When operating in island mode the microgrid's critical loads are supplied by the BESS-connected distribution board. The entire campus is connected to the power grid through the main board. The non-critical loads are only connected to the main distribution board and will consequently be disconnected during island mode operation. During grid connected mode, non-critical loads are supplied directly through the main distribution board, whereas the critical loads are supplied *pass-through* from the BESS-connected board. Critical loads at Evenstad include lighting, internet, security functions and UPS functionality [81].

The campus can switch to island mode operation manually. When there is a fault on the power grid, the microgrid automatically starts operating in island mode. The board categories stipulate which DERs that can function in island mode. Both the CHP and the V2G-charging is connected to the BESS board, so that these can power the microgrid in island mode. The PV system is only connected to the main board and can therefore not be used in island mode. The waterborne heating systems are not affected by the grid connections, so that they function as normal during island mode [81].

Experiences

Statsbygg has gathered experiences from Evenstad that have been utilized other places. For example, the solar thermal system solution is currently installed in many prisons in the country. Also, the company has learnt how the BESS could be used to prevent power outages during failure on the power grid. Furthermore, the rooftop PV solution has become a common solution for state buildings. In general, there have been several challenges at the site which Statsbygg has learned from. This has been important since Statsbygg manages all of the buildings owned by the Norwegian state [81].

Since the site has many ongoing projects, there are some opportunities that have not been explored yet. For example, delivering ancillary services to the power grid has not been considered yet. While wind and hydro power have been considered, they where dismissed due to poor accessibility. Hydrogen has also been considered and could possibly be implemented on the campus in the future. However, Statsbygg wants to focus on the present projects for the time being [81].

Challenges

Statsbygg has not chosen to use the type of CHP that is installed at Evenstad in other places. This is mainly because the operation and maintenance are costly. The CHP is a Volter 40 model, which is very sensitive to wood chip quality, relying on clean material and correct level of humidity. Another issue has been the access to good quality wood chips. There are only a few vendors of wood chip for this use on the market. The CHP requires a continuous power supply to operate the circulation pumps. Since the microgrid offers improved power quality with fewer outages, the utilization of the CHP has been improved [81].

Another challenge is the connection of the solar thermal system. The system produces more heat than is needed by the two passive buildings that it is connected to. Usually, excess heat is stored as hot water in the hot water tanks of the buildings. Sometimes, there is so much excess heat that the tanks are filled up. When this happens, the water that circulates in the system boils and wears down the equipment. This is mainly a problem in the summer, when there is a lot of sun and the heat demand is low. Statsbygg wishes to connect the system to the large water borne heat system, that serves seven of the buildings [81].

In general, the solutions at Evenstad have been very expensive. Statsbygg's role as a public management company includes a responsibility to test new technical solution regardless of the profitability. Therefore, lack of profitability is not a hinder for the project. Still, profitability represent a challenge that the project concerns itself with. Although Statsbygg does not exclude profitability for the future, the project has not been profitable to this point [81].

Testing island mode operation

Statsbygg has experimented with island mode operation. This has usually been tested in the summer, when the campus users are not present. Nonetheless, it has operated in island mode during the school year during power outages on the power grid.

Statsbygg experienced some issues involved changing short-circuit outputs during island mode. Therefore, the size of protective fuses had to be reduced. The fact that the technology behaved slightly differently in practice than expected, created valuable learning opportunities for Statsbygg. In the end, the microgrid managed to function properly in island mode. The longest island operation in the school year, with normal consumption, lasted five hours [81].

For testing, three different island mode-operations have been tried. One with the system powered only by the BESS, a second powered by the BESS and the CHP, and a third powered by these two and the V2G-station. For all three operations the solar thermal system and the chip firing produced heat. Statsbygg wishes to connect the PV-system to the BESS-board, so that it too could function in island mode. This has not been done yet due to interference between the PV and CHP inverters [81].

Statsbygg found it easiest to operate the microgrid in island when only the BESS was connected. This is expected to be the best alternative for short power outages. For longer island operations, Statsbygg found the CHP and BESS combination to work the best. Although this operation would be more complex, it is the one with largest capacity, as it allows for re-charging the battery. Using the V2G solution as a back-up works well in all cases. The efficiency of the V2G system is low, therefore it is not desirable to use this method frequently [81].

6.4 Risavika port

Risavika is a port in the western part of Norway. The site hosts shore power facilities, charging stations for on-shore vehicles and a 6000 m^2 building. This building is used as a ferry terminal, cafeteria, for offices and customs services. A picture of the location is shown in figure 6.4. The port is situated in the municipality of Sola, west of Stavanger. There is currently being established a virtual microgrid on the site, expected to be in place in August 2021 [82].

Figure 6.4: *Picture of Risavika Port [97].*

The port is owned by StavangerRegionen Havn (SRH), which is an inter-municipal company. The company's board consist of representatives from the municipals which own it [82]. These municipals are Stavanger, Sola, Randaberg and Rennesøy, with Stavanger being the main owner with over 80% of the company shares [98].

Since the microgrid will be virtual, there is no owner. The local DSO, Lyse Elnett, owns the technological equipment that is not present at the port. Within the port SRH owns the DERs, cables, a building and vehicle charging units [82].

Background

The primary motive behind the DER deployment and microgrid solution at Risavika is the increasing trend of port-electrification in Norway [99]. However, this is not the sole objective for the activities in the port. SRH is also involved in a collaboration with some other companies from the region. This collaboration has motivations and plans that span pass the port's own [82].

Elnett21

SRH is collaborating with the airport Sola, the industrial park Forus, the local DSO Lyse Elnett and their branch company, Smartly, to test and deploy innovative energy solutions. This collaboration is named Elnett21. Elnett21 is going to carry out a series of innovation projects on Risavika Havn, Sola and Forus [99, p.1-3].

The projects in Elnett21 have a collective project management, although not all parties are represented in each project. The projects include the installation of local energy solutions on all three sites, as well as the development of different control systems and business models.

Smartly will develop a smart system to measure, control and optimize electricity usage and transmission. Lyse Elnett will develop a common operational control to ensure that the power grid benefits from the energy solutions on the sites. In general, many aspects of the Elnett21 project concern all three sites simultaneously. Thus, SRH does not have the entire responsibility or entitlement to the Elnett21 related activities at its port [99, p.6, 11–12].

In the installations that are being deployed at Risavika, the directly involved parties are SRH, Lyse Elnett and Smartly. Since Elnett21 functions as a hub where the parties can consult and help each other, Sola and Forus might also play a minor part in the installations at Risavika [82].

Motivations

Several of the harbour activities are already transitioning from the use of fossil fuels to emission-free solutions [99]. This electrification trend is mainly caused by national and international climate goals and politics [82]. It is necessary for the port to take actions to handle the challenges accompanying the trend. Since the solutions are based on relatively new technology, an important motivation is to use the site to gain experience and learn how to use this new technology in the most beneficial way [82].

Since the port is heavily utilized, the electrification of the port will lead to big peak power demands in the area. This will cause problems both for the power grid and the port itself. Elnett21 wishes to relieve the power grid of future peak demands from the port, which DERs and a microgrid can make possible. The possibility of island mode operation is not a goal and will not be possible with the current plan. The aim is solely to relieve the power grid from big peaks in power demand, not to exclude the site from the grid [82].

Another motivation is to use Risavika as a case study for other sites. Risavika is a relatively isolated area, in regards to nearby industry, making it a suitable candidate for a microgrid project. Therefore, it is likely that there are many ports and other sites that will encounter the same challenges and require similar solutions as Risvika. However, many of these solutions are not well tested in Norway. SRH wants to gather experience, and find a distribution and business solution that could fit more of their ports [82].

The motivation for joining Elnett21 is also directly linked to the UN's sustainable development goals. In addition to dealing with challenges regarding the electrification trend, SRH supports the goals that drives the trend. SRH wishes to show its dedication to the climate goals, and willingness to fulfill the goals. Therefore, the company wants to be an initiator in the ongoing electrification trend [82]. Another reason for this is the company's ambition to be a central logistics hub in western Norway. The company finds it important to be prepared for the port users future needs [99, p.3].

SRH's owners are also important driving forces for the new solutions at Risavika. Although SRH does not receive direct funding from the municipalities, the board which they constitute makes the company's framework plan. The biggest shareowner, the municipality of Stavanger, have a political board with ambitious climate goals. Consequently, Stavanger sets strict demands to the company regarding such goals. In addition, internal forces in the company have also called for more progressive climate action [82].

Another element that is important to the company is landscape concerns. The Elnett21 collaboration is focused on the strain that expansion and reinforcement of the power grid will cause on nature. A reinforcement of the current power grid in the country will result in new pylons and transformers, sometimes in untouched nature. In addition, this will demand much energy and resources [82].

Although profitability is not a primary goal of the project, SRH wishes the experience of the pilot to offer some financial opportunities. For once, SRH expects to avoid some cost of future challenges by being prepared. Secondly, the BESS solution is expected to pay off if the power price increases. There are political signals regarding the increase of the power price. This will make it more expensive for the port to import electrical power when the power demand is high. This is a challenge that SRH believes that the BESS solution could hinder [82].

Technical scheme

The grid solution chosen for Risavika is a virtual microgrid [82]. In January 2021, a contract was signed with the entrepreneur Kverneland Energi AS to deliver the technical solutions for the virtual microgrid [97]. It is set to be finished by August 2021. The DERs in the finished microgrid are presented in table 6.5. SRH belives that other elements could be integrated in the microgrid later [82].

Table 6.5: *Overview of the DERs at Risavika port [82].*

Resource	Power / Capacity	Established
BESS	800 kW / 500 kWh	2021
PV-roof	125 kWp	2021

As of now, the port has several measuring points to the power grid. A considerable amount of these will be gathered in three physical measuring points. Subsequently, the three points will be united digitally into one virtual measuring point. All the information about electricity flow to and from the microgrid, through all three measuring points, will be gathered in this virtual point. Precisely how this will be solved is not yet certain, but will be decided before the commissioning in August. It is also uncertain how many of the present measuring points that are going to be merged. Only the measuring points included in the merge will be part of the virtual microgrid [82].

The port, in addition to the other Elnett21 sites, will sometimes produce excess power. If the BESS is fully charged, this excess power will be fed to the power grid. Elnett 21 has come to an agreement where Lyse Elnett will purchase this excess power. However, the DSO will only purchase a minimum of 1 MW. Therefore Smartly is developing a method to bundle the power flow from all three Elnett21 sites so that the total power fed to the grid is at least 1 MW [82].

Experiences

The experiences from the virtual microgrid will be unique in Norway. SRH believes this is a sensible solution for such a site. There are multiple actors, with different activities and needs, present on the port. This makes it difficult to implement a conventional microgrid. SRH believes that it would be a technically challenge to gather all the measuring point into one virtual measuring point [82].

SRH does not expect the virtual microgrid at Risavika to be profitable initially. This is mainly because the pilot relies on expensive investments. Still, it is regarded as a logical solution for the expected challenges of high peak power demands. Moreover, the BESS at Risavika is mobile, providing additional flexibility. The BESS provides an opportunity to test ways to shave power peaks and control frequency, which SRH values. It is expected that the investments will provide valuable experience. This will be utilized in future projects, mainly when the price of these solutions have decreased [82].

A future challenge for the site is the handling of electricity bills. The different actors that operate on the port all rent space from SRH. Some of these actors have their own electricity bill and contracts with the DSO, while some contracts are a part of SRH's [82].

An essential challenge regards the current laws and regulations. The solutions in this project is uncommon and not adapted for in the established regulations. Consequently, the project depends on multiple dispensations to be allowed execution. Getting dispensations takes time and is a resource demanding process. Furthermore, these dispensations will only last in a limited time period. For the solutions to be used in the future and in other projects, longer dispensation periods or changes in regulations are required [82].

SRH has had a close dialog with their tenantries during the Elnett21 project. The company believes that their owners, tenantries and customers expect the company to deliver on climate goals. Consequently, they experience that these parties are supportive of Elnett21 and consider the project as intriguing. SRH believes that this has made the processes of the project easier [82].

6.5 Rye

The microgrid at Rye, located to the west of Trondheim, is a part of the EU project REMOTE and Enova's PILOT-E project. It is partly owned by the local farmer Lars Hoem and supplies power to his two farms. Originally, the project was planned at Froan, which is a remote group of islands that presently consist of 15 consumers that draw electric power from the power grid through an aging subsea cable. However, due to local regulations and wildlife, the process of establishing more wind turbines would be too lengthy. Therefore the pilot project was moved to Rye [83].

Figure 6.5: *The technical installations in the microgrid at Rye [100].*

Background

The microgrid is a part of the EU project REMOTE, funded through EU's Horizon 2020 program. REMOTE is an abbreviation for Remote area Energy supply with Multiple Options for integrated hydrogen-based TEchnologies. It is a project that investigates the feasibility of microgrids supplied by renewable energy and with hydrogen energy storage. The project includes four demonstrations, located in Italy, Greece and Norway. [101].

Project partners and ownership

The wind turbine and the grid connected to it is owned by farmer Lars Hoem. These components were purchased earlier due to his interest in wind power. Trønderenergi, the power supplier of the farm, owns an additional transformer, the BESS and a diesel generator. The diesel generator is mainly used as a backup, during energy shortages. REMOTE has set requirements to their microgrid projects that limits the use of the diesel generators to 5%, measured as an annual average [83].

The project at Rye involves different project partners, where Trønderenergi and Sintef are the Norwegian project partners [83]. Trønderenergi is a power supplier partly owned by 18 municipalities within the county of Trøndelag. It's core business is related to energy production from wind and hydro, as well as to facilitate for an efficient and well functioning power system based on renewable energy [102]. The other involved partners are the French company Powidian, the Danish company Ballard and the Belgian company Hydrogenics.

The components in the hydrogen system are lent out to the project by the partners. If no other suitable site is found for the components before the pilot project at Rye is finished in late December 2021, the components will be returned to their respective owners [83].

Trønderenergi has invested a total of 15 million NOK in the project. They received 5 million NOK from both Enova and Tensio, the local DSO, while investing 5 million NOK of their own funds. REMOTE's budget for the pilot project at Rye is limited to 10 million NOK. Of these 10 million NOK, 30% are provided by the REMOTE partners, and 70% is invested by Horizon 2020 [83].

Motivations

Through the microgrid project at Rye, REMOTE aims to test alternative solutions to supply power to remote areas. Trønderenergi tests concepts that could take the place of the old subsea cable at Froan without replacing it, since a replacement would be very expensive. A microgrid, such as the one at Rye, deploying hydrogen as primary energy storage might be an economically viable alternative to grid expansion [83].

REMOTE's objective is, in their own words, "*to demonstrate the technical and economical feasibility of two fuel cell based H_2 energy storage solutions*" [101]. PILOT-E aims to contribute to a faster development of environmentally friendly energy technology, in order of reducing emissions both in Norway and abroad [103].

Technical scheme

The microgrid consists of a wind turbine, a PV system and both a BESS and a hydrogen based energy storage unit. Table 6.6 provides the most important DER specifications. The DERs supply an annual load demand of 160 MWh, with peaks of 90 kW. They are dimensioned so that the microgrid can operate exclusively in island mode, only reconnecting to the grid during emergencies. A PCC is used for grid connection, the switch state is controlled automatically [83].

Table 6.6: *Overview of the DERs at Rye [83] [104, p.10-13].*

Resource	Power / Capacity	Established
BESS	550 kWh / 330 kWh usable	2019
Hydrogen	55 kW electrolyzer, 100 kW fuel cell / 3.33 MWh	2021
PV	86.4 kWp	2019
Wind turbine	225 kW (nominal)	2015

The wind turbine is a Vestas V27, it has been operational since before the microgrid was established. It's yearly production is about 170-180 MWh/year [104, p.10]. It utilizes two different sized induction generators, which are usually operated connected to a stiff grid. Using induction generators in smaller grids, such as this, is not common [83].

In April 2019 the ground installed PV system was connected to the microgrid. It covers an area of 481 m^2, thus making it the largest of its kind in Norway. PV modules are delivered by the Norwegian manufacturer REC. The inverters used to convert DC to AC power have a claimed efficiency of 98% [104, p.11]. The annual power production from the PV is approximately 85 MWh [83].

Energy is stored both in a BESS and as hydrogen for long time storage. The Nidec BESS is essential for maintaining the correct voltage and frequency on the power grid [83]. The BESS SOC is kept between 20% and 80%, resulting in an usable capacity of 330 kWh. Energy storage in the BESS is prioritized, so that its SOC reaches 80% before the electrolyzer starts producing hydrogen. When power demand exceeds production from the DERs, the BESS will supply the remaining power demand. If the DERs continue to produce a power deficit, the fuel cell starts generating [104, p.13].

Experiences

Induction generators are usually operated connected to stiff grids, with fixed frequencies and voltages. This is not the case at Rye when the microgrid is operating in island mode. During the first week of island operation the control systems of the wind turbine had to be adjusted several times. Changing between the two different generator sizes proved to be particularly challenging [83].

The hydrogen storage system was sourced from abroad, and was supposed to be mounted by the suppliers own technicians. Due to COVID-19 this was not feasible, and Trønderenergi had to assemble the system using augmented reality glasses. This turn of event required more resources from Trønderenergi than initially expected. Moreover, the delivery of the electrolyzer was repeatedly delayed, thus forcing Trønderenergi to start operating the microgrid without it. To make the operation without the electrolyzer as realistic as possible, purchased hydrogen was used during the first weeks of microgrid operation [83].

Multiple challenges turned up during the period when the project was originally planned to be placed at Froan. Realization of the project at Froan would have required additional wind turbines. Due to the legal system and wildlife this would have been a lengthy process which there was not time for in accordance with the REMOTE projects time frame. Another challenge was the transport expenses Trønderenergi would have had to pay to visit the site. Boat rental would have cost 12 000 NOK/day [83].

During normal operation of the microgrid, the farmer is experiencing minor instabilities. The lights flicker when larger loads are connected to the grid, illustrating the temporary losses in power quality. Moreover, some adjustments to microgrid parameters require the disconnection of all loads from the microgrid, leaving the farm without power for about 30 seconds. Neither the flickering lights nor the short periods without power affect normal farm operation. Hoem, providing his two farms as test site for the pilot, accepts these minor discrepancies. Besides, he is compensated with significant reductions in electricity bills through his participation in the project [83].

6.6 Utsira living lab

Utsira is a small island in the northern sea, located as shown in figure 6.6. Nearly 200 people live on the island, making it the least populated municipality in Norway. Today, the island is supplied by an aging 22 kV subsea cable that barely satisfies the island's power demand-peaks of 1 MW [84]. Future projects on the island may include fish farming facilities and an electrical ferry, which are likely to increase the island's total power demand. Since establishing a new cable will be costly and a microgrid might be a more economically viable solution. Today, there is an ongoing microgrid project on the island [105, p.4]

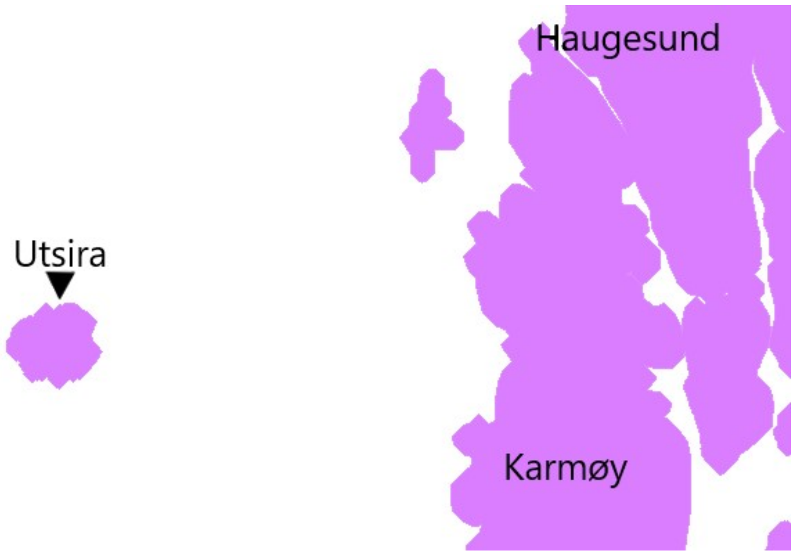


Figure 6.6: *Map showing Utsira's location, modified from source [106].*

Background

Utsira has recently hosted a combined wind energy and hydrogen project, this was terminated in 2010 [107]. Today, Haugaland kraft (HK) and FME CINELDI are working on an extensive microgrid test project on the island, aiming to develop and test new technology [84].

HK acts as the DSO and a power supplier in the municipality of Utsira. HK's primary businesses are the production, transport and distribution of electric power, in addition to operation of fiber internet infrastructure. The company is partly owned by the municipalities surrounding Haugesund and Karmøy [108]. Together with FME CINELDI, they are involved in a series of innovative projects on the island [84].

HK has invested a total of approximately 19 million NOK in future energy systems on the island: 6.5 million NOK of their own funds, 11.5 million NOK is provided by NVE from their research and development budget, and the remaining 2 million NOK are provided by Innovation Norway. A new subsea cable would have cost twice as much as the price of the current microgrid. Yet, due to the uncertain future of the power grid on and around Utsira, it is hard to conclude on the economic viability of the microgrid [84].

Goals and motivations

Because the subsea cable at Utsira is operating close to its maximum capacity, the island has suffered poor power quality. When the consumption peaks, the DSO struggles to keep the consumer-side voltage within the required limit of $\pm10\%$. Moreover, due to the new-found interest in industrial opportunities at Utsira, power demand is expected to increase. The goal at Utsira is to provide both an increase in power quality and capacity through a microgrid that primarily operates with a grid connection [84].

Today, DSOs generate income through tariffs on the usage of the power grid. The need to implement more renewable energy in the power mix is likely to increase the amount of distributed generation. Deploying more DERs will make the consumers less dependent on the power grid, and in the case of an islanded microgrid completely independent of the power grid. This renders DSOs with a reduced income. As a DSO, HK participates in microgrid projects to influence future market models to their benefit [84].

HK is responsible for several parts of the power grid that require an upgrade. Smart power grid and power grid control systems have the potential to reduce the size of required investments. Gaining experience through projects such as the one at Utsira makes HK a more competitive DSO, while also reducing the economical size of the investments in their part of the power grid [84].

Utsira, the hydrogen society (2004-2010)

In 2004, an autonomous wind-hydrogen demonstration was launched by Norsk Hydro and Enercon at Utsira. The system could supply 10 households energy demand for 2-3 days through an AC microgrid. Its primary goal was to demonstrate how renewable energy and hydrogen systems can provide a reliable and efficient power supply to rural areas. Utsira was chosen as the location due to favourable wind conditions [107, p.1841-42].

The microgrid's system schematic is shown in figure 6.7. The two Enercon E-40 wind turbines were the main power source, with a total capacity of 1.2 MW. 900 kW of wind power was directly connected to the grid, and the remaining 300 kW were reserved for the autonomous system. In the project, power quality was supported by grid stabilizing equipment such as a flywheel, a synchronous generator connected to a hydrogen engine and a BESS for redundancy [107, p.1843].

Ulleberg et al. ([107]) concluded that it is possible to supply a remote area with wind power using hydrogen as primary means for energy storage. The primary reason that the system could only remain in autonomous operation for 2-3 days was because of limited electrolyzer capacity. Increasing the size of the electrolyzer would have resulted in a substantial increase in system cost, thus further deteriorating economic viability. Overall, only 20% of the wind energy was utilized with the chosen electrolyzer systems (including energy loss in the compression stage) [107, p.1850].

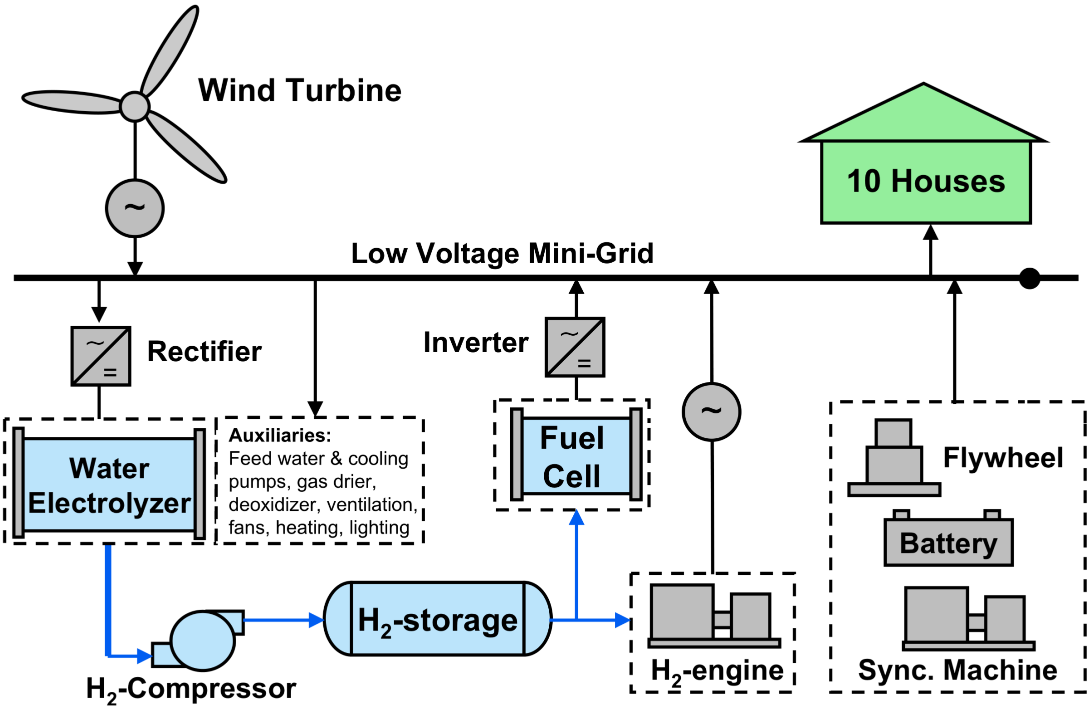


Figure 6.7: *Schematic representation of the demonstration plant at Utsira from 2004 to 2010 [107, p.1844].*

Technical scheme

The first stage of the current microgrid project at Utsira involved the installation of a BESS on the island. This BESS has previously been used for charging an electric ferry. Now it is to function as a supplement to the two wind turbines at Utsira. The BESS, power electronics and control systems are delivered by Wärtsilä and owned by HK [84]. The Enercon wind turbines are remains from the earlier Hydrogen society project [107, p.1841] [84]. Today the wind turbines are owned and operated by the company Solvind [84].

Primarily, the BESS is to provide voltage and electrical power support to the grid on the island. Using it to compensate for the reactive power flow in the cable increases the cable's real-power capacity, as well as increasing the power quality on the island. HK estimates that the cable, with reactive power compensation, can provide the island with up to 2 MW of electrical power. The BESS has a capacity of 500 kWh, enough to power Utsira 0.5-1 hours on its own. Combining the BESS with wind production, the microgrid can stay in island operation until wind resources are insufficient [84].

In addition to supporting the grid, the BESS allows Utsira to operate in island mode. The microgrid will be capable of a seamless transition to island operation, though this will only be used during power outages [84].

Flexibility markets

FME CINELDI is involved in a project related to flexibility markets at Utsira. The research objective is to demonstrate how and if a market-based solution can be used for congestion management in the distribution grid [36].

Future grid operation will rely on both production and load-demand predictions. HK is currently developing a data lake database system to create precise and accurate predictions for the power demand at Utsira. The demand side predictions are to be combined with a system that will predict the power supply from the wind turbines and PV system developed by HK. The system will apply machine learning to increase the accuracy of the predictions. Then the NODES marked database is to be used for distribution of requests of power regulation needs out in the marked and will also complete the business transaction of accepted bids [84].

To supplement the existing DER capacity at Utsira, some end-point resources are to be established. A full overview of the DERs at Utsira is provided in table 6.7. The end-point resources are to be partly privately owned, they include residential PV and batteries, and possibly micro-wind turbines. Their main purpose is to enable a full scale test of flexibility markets on the island. For a full scale test, HK needs to involve a minimum of 5 households in weaker parts of the power grid at Utsira. These households will have to invest in PV facilities, but will be offered to use batteries owned by HK. At the same time, HK will also encourage other inhabitants on the island to establish residential PVs [84].

Table 6.7: *Overview of the DERs at Utsira [84][107].*

Resource	Power / Capacity	Established
BESS	500 kWh	2021
Residential batteries	-	Planned
Residential PV	-	Planned
Wind turbines	1.2 MW	2004

The future grid at Utsira

Future plans for the microgrid are closely linked to the establishment of fish farms, either on- or off-shore. It is likely that there will be established one or more “sub-microgrids” within the existing microgrid on the island in connection to the industry. A re-implementation of hydrogen production is also considered since fish farming requires both heat and oxygen, which both are by-products of electrolysis [84].

HK is not certain of how Utsira will be supplied with energy once the existing subsea cable breaks. This is because Solvind, who operates the present wind turbines at Utsira, has applied for concession to establish three additional 5 MW turbines. Since this exceeds the current cable’s capacity, this would trigger a new cable. Due to the size of the generating units, Solvind would be partly (60%) financially responsible for the grid expansion [84].

Furthermore, the Norwegian government has opened up for the development of a offshore wind farm just outside of Utsira. The government allows for a wind farm with maximum 1500 MW installed power capacity at the area called Utsira Nord. It is possible that a wind farm at Utsira Nord will trigger the establishment of a power grid station on Utsira, which could provide power to the island. Exactly how a wind farm is going be connected to the mainland, and thus how Utsira will be supplied with power in the future, is very uncertain [84].

Experiences

The microgrid project is taking longer than expected. Tough the municipality wishes to support the project, there is a lot of bureaucracy, slowing the progress. In addition, the COVID-19 pandemic has slowed the progress even further. The microgrid has not yet been operational, consequently HK has not experienced any operational issues. The planned date for powering up the BESS is in week 22, 2021 [84].

HK believes that the microgrid technology in many cases can reduce the cost usually affiliated with modern grid development. They hope to gain useful experience from Utsira which they can deploy in other areas. For example, HK supplies an area occupied by cabins, where there have been issues related to under-voltage. This is harmful to some of the grid-connected equipment in the area. To overcome the issues, a BESS for 400 000 NOK has now been installed instead of a grid upgrade for 1.6 million NOK. In this case, a BESS was a more economical solution [84].

7 Discussion

An important finding of this thesis is the accessibility of technology for microgrid deployment. Chapter 5 and chapter 6 show that the establishment and deployment of microgrids are not hindered by the presence of required technology. Instead, it is evident that other barriers are more limiting to microgrid development in Norway. Lack of incentives to choose microgrids over alternative power system reinforcements is an important barrier to microgrid development.

This chapter will reflect upon the findings presented in chapters 4 through 6. The results from the case studies will be discussed in context to the preceding chapters to compare differences and similarities between the motivations for microgrid development. Finally a short evaluation of the method presented in chapter 3 is given.

7.1 Motivations for microgrid deployment in Norway

All the cases considered, both Norwegian and foreign, are driven by multiple motivations. FME CINELDI has found a lack of motivation to be a significant barrier for microgrid development. Motivation seems to be a significant aspect in microgrid deployment.

7.1.1 Research and testing

The case studies confirmed many of the findings presented in chapter 5. In Norway, microgrid applications seem limited to pilot projects, usually with the purpose of research and testing. All the Norwegian cases in chapter 6 are pilot projects which are expected to provide useful experience. The objective of gaining experience is most evident at Evenstad and Rye, where the microgrids were developed solely for testing. Testing and learning is also important at Risavika and Utsira, although these sites are actually in need of new distribution solutions.

The fact that gathering experience is an important motivation in Norway, indicates just how new and unexploited microgrid solutions are in the Norwegian power grid. Both literature and the studied cases indicate that the technology is both functioning and available in the market today. Despite this, the microgrid concepts and technology is not much used in Norway today.

The high price of and consequent slow development of new technology, might be a hinder for some initiators. The opposite is the case for campus Evenstad. Statsbygg stated that they, as a publicly funded company, has an implicit responsibility to test and develop new technology. The governmental funding of Evenstad offers an economical security which private initiators do not have. Therefore, the project is not bothered with expensive technology, but rather the aim of developing it to make it less costly.

The companies leading the projects at Risavika, Rye and Utsira are not as fortunate in regards to public funding as Statsbygg. HK, Trønderenergi and SRH operate as independent companies without direct funding from the public. Still, all these companies are partly or completely owned by the public sector. This means that the companies are still committed to follow their public owner's goals regarding research and climate, even if they are not directly publicly funded.

At Risavika and Utsira, microgrid testing is considered a way to prepare for future challenges. In contrast to the pilots at Evenstad and Rye, the ones at Risavika and Utsira are designed to satisfy a future need. Both places expect an increase in power demand which will require a new distribution solutions in the future. Through early deployment of new technology, the operators get the chance to test new solutions and be well-prepared when the capacity demand actually increases. An obvious disadvantage for these cases is that the investments are more expensive now compared to later, when the technology is likely to be cheaper and better.

The desire for experience is driven by the possible services that microgrid solutions can offer. As pilot projects, it is not necessary that the microgrids yield the expect results. Establishing the qualities of a solution is an important part of pilot projects, since there is value in knowing if a solution is worth pursuing. At this stage, in the well developed pilots at Evenstad and Rye, some parts of the projects have proven themselves useful in other places. Moreover, E.ON is already applying microgrid technology in other places, and the initiators at Risavika and Utsira are confident that this will be the case for them as well.

7.1.2 Climate goals

The exploration of microgrid solutions which is seen in Norway seems to be driven by multiple motivations. Most evident are motivations related to climate concerns. Increased electrification and growth of power demanding industries, such as hydrogen and battery production, are consequences of international climate goals. Microgrids can help reduce the strain on the power grid caused by the increase of electrification, due to the energy transition, which will reduce cost related to grid service and maintenance.

Microgrids are particularly interesting when considered as an alternative to grid expansion, which will be necessary in some places due to electrification. Future forecasts show that Norway will not lack the energy needed, but the distribution capacity. In addition to the aging of the power grid, this is the reason for the expected upgrades and expansions of the national power grid. Expanding the power grid introduces challenges, due to the required costly investments and encroachment of nature. The pilot at Risavika is an example where microgrid solutions allow for increased capacity, without creating a bottleneck in the power grid or the need for grid expansion.

Microgrid deployment should be seen in the context of the increased renewable DER deployment. A recurring motivation is the facilitation for renewable DERs, thus increasing the amount of renewable power production. Both at Santa Rita Jail and at Evenstad, the deployment of a microgrid helped improve the exploitation of DERs. The increase of prosumers in Norway will provide an increase power production capacity, but will at the same time pose an additional strain to the power grid. Connecting the DERs to a microgrid, instead of directly to the power grid, could be a solution that decreases the stress on the power grid. Currently, there are not enough Norwegian prosumers for this to be an issue in the current power grid.

7.1.3 Remote societies and investment savings

Both at Evenstad and Risavika, the energy transition and climate goals are the main driving forces. This was not the case at Rye and Utsira, were the main objects were to test alternative ways to supply power to a remote society. Utsira and Froan, where the pilot at Rye was originally planned, are islands located a significant distance off the mainland. Due to the distance, the current way to supply power to the islands is expensive. In such, and similar remote locations, a microgrid may be an economically viable option.

Since both the number of inhabitants and cabin owners in remote areas in Norway are increasing, the power demand in such locations is likely to increase. In these cases, microgrids are can be a good alternative to avoid costly grid upgrades and grid expansion. Usually microgrid solutions represent an expensive investments today, but the costs might decrease in the future. Utsira is an example which shows that microgrids today could be more economical than grid expansion. The current investments in the microgrid amount to approximately 19 million NOK, while a new subsea cable is likely to cost twice as much.

Except for the pilot at Utsira, none of the Norwegian pilots from the case studies have offered significant economic savings. However, since cost has been a focus in the pilots, they are likely to give important insights on cost efficiency. This insight will be important in the future, when the need for solutions to challenges regarding electrification or the energy transition increases. Like other technological solutions, economical viability will likely be essential for extensive use.

7.1.4 Differences between Norwegian and international microgrids

The most obvious motivation of Norwegian cases is also shared by the two foreign microgrids from that were studied. Both the American case at SRJ and the Swedish case at Simris are pilot projects. They aim to test new technology, where E.ON searches for commercial applications in the Simris project and SRJ served as a test site for the CERTS microgrid concept. These motivations are closely related to the required energy transition, as described in chapter 4.

The findings from the literature study presented in chapter 4 gives an overview of general motivations in the international microgrid trend. SRJ is different from the Swedish and Norwegian cases since improving the reliability and resiliency of the power supply is an important motivation. Provided the stability of the Norwegian power grid, improving stability and resiliency is not a motivation in all the Norwegian cases, nor at Simris.

In contrast to SRJ, expectations regarding the energy transition are very important driving forces in the Simris project. In general, SRJ seems to focus less on the energy transition and climate concerns than the other microgrids in the case studies. This should be seen in context of the state of Alameda's power grid and SRJ's purpose. As a jail, the site is dependent on good power quality, which the power grid does not always offer. Although climate concerns are universal, SRJ issues regarding power quality seem more acute than future challenges regarding energy transition.

7.2 Practical benefits of microgrid deployment

All cases presented in chapter 6, show that the microgrid initiators are driven by a clear set of goals and motivations. These are based on the possible benefits that microgrids could provide. The following section will discuss to what extent the goals of the different microgrids have been reached.

7.2.1 Power quality within the microgrid

Implementing microgrid concepts has been beneficial for both power quality and resiliency at Evenstad and Utsira. At Evenstad, this allows for an improved exploitation of the sensitive wood-chip fueled CHP, which is especially important during extended island mode operation. In a similar manner, the fuel cell at SRJ has also suffered issues due to poor power quality.

At Utsira, the BESS is used to compensate for reactive power. As a result, the cable's real power capacity is doubled, thereby delaying a potentially expensive investment and improving power quality on the island. In addition, the BESS allows for island mode operations during periods when power from the grid is unavailable.

Simris is located in an area where there are usually no issues with power quality. Deploying microgrid technology further improved the power quality in the microgrid during island operation. However, due to the operational costs, island mode trials where discontinued after 2018. It is unlikely that non-governmental funded companies will use islanded microgrids, unless there is an economical or research related incentive to do so.

7.2.2 DER utilization

In some cases, DERs require an external power supply to generate power. This is the case for both the PV and CHP facilities at Evenstad. If such DERs are connected to a microgrid that could operate in island mode, they will be able to continue generating power also during power outages in the power grid. Should non microgrid connected DERs produce a substantial amount of a nations power demand, a power outage would have much larger consequences than today. Therefore it could be reasonable to deploy DERs in a microgrid environment providing some sort of UPS functionality.

The prosumer arrangement limits prosumers to feed a maximum of 100 kW power to the power grid. This makes a microgrid a suitable alternative when a prosumer can generate more than 100 kW. Since the amount of prosumers has increased without the need for change in this arrangement, it is probably sufficient in most cases. Still, some of the DERs in the case studies have installed DERs with over 100 kW of installed power. In moments with low demand and high production, this arrangement would be insufficient for these DERs.

At Rye, the wind turbine alone generates 225 kW nominal power, surpassing the prosumer arrangement by 125 kW. If the wind turbine only was connected to one unit and served the power grid, a lot of energy could be wasted. Alternatively, the farmer must register as a power supplier, demanding more bureaucratic and financial effort from him.

If the microgrid at Rye was to operate in grid connected mode, the power transfer to the power grid could be controlled. It is possible to store the excess power within the microgrid, using the BESS and hydrogen system. This allows for operation of larger DERs within the prosumer arrangement limit of 100 kW. Not only the DERs at Rye exceed this limitation, this is also the case at Risavika and Utsira.

Another solution to the 100 kW limitation is to increase the limitation. This would demand a thorough evaluation of the power grid. Since the power capacity currently is insufficiently charted, a change of the limitation could be risky. It is possible that the power grid can not handle an increased amount of DERs that deliver more than 100 kW. As the cases show, microgrids can be a part of the solution to this challenge, since they can control the power exchange with the power grid.

7.2.3 Ancillary services

Microgrids have the ability to support the power grid by adjusting the power flow between the microgrid and the power grid. Still, considering the microgrids in the case studies, only Utsira delivers ancillary services. The BESS at Utsira supports the surrounding power grid. It compensates for reactive power flow within the subsea cable, thus doubling real power capacity in the cable and increasing the power quality on the island.

Today, SRJ relieves the power grid through rate arbitrage and peak shaving with the BESS. At Risavika, the BESS will be used to reduce peak power consumption from the power grid to reduce their own expenses. In a similar manner, Evenstad is also adjusting their power consumption from the grid to reduce their electricity costs. Though this reduces the strain on the power grid, neither Risavika, Evenstad nor SRJ use their microgrids directly to support the surrounding power grid.

The microgrid at Simris does not provide ancillary services to the power grid mainly for two reasons. Firstly, the power quality in the power grid surrounding Simris is generally good. Secondly, E.ON has experienced that the operational costs of microgrids are high. As a consequence, the microgrid at Simris is an expensive way to provide ancillary services.

7.2.4 Island mode operation

In all cases, except SRJ and Rye, the DERs do not offer the capacity needed for constant island mode operation. Still, some of these have made considerable efforts to test island mode operation. At SRJ, Simris, Evenstad and Utsira, island mode is possible, but only used for testing or during power outages. This behavior correlates with the motivations of the different projects. In cases where the power grid can satisfy all of the power demand, the motivation is to increase the resiliency of the power supply.

Rye is the only Norwegian site with sufficient DER capacity for sustained island mode. Although this is neither profitable nor practical at Rye, it could be at the group of island Froan which the project initially was planned for. A permanently islanded microgrid is considered an alternative to a new subsea cable, since it could be less expensive to establish than a new subsea cable.

A striking observation from the case studies is that constant island mode operation is redundant. In contrast to remote societies, such as Froan, it seems unreasonable to plan for islanded microgrids in central areas. If areas in need of increased capacity are supplied by an islanded microgrid, the DERs would have to provide both the capacity lost from the power grid and the increase in power demand. Both from an economical and practical point of view, this does not make sense. Still, such sites will benefit from the ability to island when there is fault on the power grid.

7.3 Important premises for microgrid deployment

During the case studies, similar premises for microgrid development were discovered in the Norwegian and sometimes also the foreign cases. These were not absolute requirements, but nevertheless important for the planning and results of the projects. Since pilot projects aim to gain experience and test new solutions, challenges are an important part of the process since the solutions can be used in future projects. Consequently, the premises and obstacles experienced by the microgrids in the case studies can be useful in future projects of similar nature.

7.3.1 DERs and legal framework

Already existing DERs seem to be important when selecting sites for microgrid projects. All, except one microgrid considered in this thesis are established in the vicinity of pre-existing DERs. Utsira, Rye and Simris where placed close to existing wind turbines. SRJ and Evenstad were established close to existing PV facilities. Only the microgrid project at Risavika does not have any pre-existing DERs nearby. Establishing microgrid control infrastructure in addition to the required DERs increases the required investment. This would likely make microgrid development rely even more on financial support from third party organizations.

Although the current legal framework has not been considered a major issue in the Norwegian cases, FME CINELDI consider the national legislation and guidelines insufficient for microgrid development. At Rye, the microgrid was moved to Froan due to challenges caused by local regulations. The legal system prolonged the process of installing additional wind turbines, which eventually lead to a change of site.

Since Norwegian grid regulations are not adapted for microgrids, dispensations from these are often important for implementation of such a concept. The project at Risavika is an example of this. It is stated that accommodating the microgrid project within the legal framework has cost significant effort and resources. The project requires substantial exceptions from current legislation. Should microgrids become easily deployable and manageable, there would be a need of changes in the legal frameworks of power supply and consumption.

7.3.2 Communication and local support

Engaging the users of the microgrid was an important aspect of microgrid development at Simris. E.ON's pilot project was relocated due to dismay from the local population. After the relocation, significant resources were directed towards communication with the local community. This change allowed for a successful completion of phase one and two of the project. The inclusion of the local community was especially important because the microgrid supplies many households. Furthermore, an objective of phase two at Simris was to implement household DERs. E.ON found active communication to be important to convince citizens to invest in household DERs.

Tough E.ON was successful in communication with the locals, this was costly. The company had to allocate resources solely for the purpose of communication with the local community. This was a considerable expense for E.ON. Such facilitating for communication, which seems necessary to deploy microgrids in local communities, is likely to further increase expenses. If the increase in microgrid deployment in the industrial sector continues, communication expenses might be reduced. When a company is the consumer, instead of several household consumers, less resources would be required to maintain sufficient communication.

In the Norwegian cases at Risavika and Utsira, there was focus on communication with involved parties. The initiator at Risavika believe support from tenantries, customers and company owners to be important. At Utsira, HK encouraged the local community to invest in residental PV. Even though the two cases allocated resources to communication with the local community, this was not an equally important aspect as at Simris. Hence, community engagement does not seem to be an important prerequisite to execute microgrid project in Norway.

7.3.3 Availability of technology

An obvious necessity for microgrid deployment is the availability of the proper technology. Functioning grid solutions are a very important premise for the present human societies, who have made themselves dependent on electricity. If microgrids are to be used, they have to function properly at all times.

An important observation from the cases that have tested island mode, is the technical complexity of this operational type. The microgrids seem to be more susceptible to load-change in island mode than when they are grid connected. This is reasonable since microgrids lack the stiffness of large power grids. Due to rapid technology progress, island mode operation might become easier to execute in the future.

The presence of multiple microgrids in Norway indicates that the technology required to establish microgrids is accessible. Still, market diversity is not granted. At Risavika for example, there are being developed completely new solutions. Which means that the technology is available, but not established on the commercial market. Still, pilots depend on the existence and possibility of developing the right technology, not market availability. Consequently, commercially available technology is not a necessity for the Norwegian projects in the case studies.

At Simris, an effort was made to use commercial solutions in order to prove that microgrids are more than a research area. The success of the Simris microgrid indicates that large parts of the solutions are in fact commercial available. Though Simris was established using mostly commercial technology, it does not prove that the range of suppliers is wide. A wide range of suppliers and solutions would ease the installation of microgrids in a broader range of application. In addition, a larger market range and more market competition will most likely contribute to lower cost, which could increase the economical motivation.

7.4 Comments on method

The method used to acquire the information presented in this thesis is presented in chapter 3. How the chosen approach to the problem statement has affected the results of this thesis is discussed below.

7.4.1 Case selection

Although most criteria presented in chapter 3 are well defined, the motivation of gathering a diverse selection is not. What makes two projects similar depends somewhat on the observer. However, the objectives of the case studies were not to gather as many types of microgrids as possible. The aim was to achieve a better understanding of the trend, while the aim of literature study was to give an overview. Still, it is possible that some valuable insights were lost when eliminating cases.

As specified in chapter 3.2, usage, size, location and technology were considered when evaluating similarity. However, cases with such similarities could still posses different experiences. Therefore, they could still have provided a valuable contributions to this thesis. Despite this, all the Norwegian cases provided independent and unique experiences. In the end, the cases had some similar experiences, that also corresponded to the information gathered during the literature study.

Choosing a diverse set of cases for the case studies was important to properly address the microgrid activity. The intention of this thesis is to give en overview of the different motivations, solutions and experiences within the field of microgrids in Norway. Alternatively, a selection of similar cases could have been chosen. This would allow for a closer comparison of the success, adequacy and function of different technical solutions and approaches. Moreover, it is likely that a homogeneous selection would provide only limited insight in existing solutions, motivations and experiences. Thereby excluding some of the insights given by the diverse selection considered in this thesis.

Another point of interest of the case selection is the number of chosen cases. It is possible that a larger case selection would have yielded insights that have not been presented in the investigated cases. On the other hand, with the same amount of time to investigate the cases, a larger selection would have reduced the quality of the investigation. Because the cases had similarities, it is possible to argue that one or two cases would have been sufficient. In that case, more time could have been spent on other interesting topics, instead of the case studies.

The choice of foreign cases can also be questioned. It would be erroneous to assume that one American and one Swedish case is representative for all foreign microgrids. Nevertheless, the objective of this thesis was to give an overview of the Norwegian trend. The foreign cases were included to compare some aspects of foreign microgrids to the Norwegians cases.

7.4.2 Interview conduct

A detailed plan for the meeting was important. As the interviewee had access to interview questions beforehand, this increased the efficiency of the meeting. During the second interview, key features of the cases were discussed in greater detail. In many cases this revealed important aspects not yet discussed in the thesis. It also helped correct erroneous information that would not have been discovered without conducting a second interview.

The meeting notes written during the interviews were used during the writing process to verify statements from the interviewees. Though the notes where written carefully and revised in direct succession to the interviews, none of the notes were verified by the microgrid representatives. This could have resulted in erroneous information in chapter 6 Cases. Therefore it was important that the final case presentations where sent out to the case representatives for approval.

Conducting the interviews in parallel accelerated the interview process, but also made it possible for the interviews to affect each other. When new aspects were discovered in one case, questions about that particular aspect were added to the other cases. While this helped uncover information about the case, it may also have induced a confirmation bias.

7.4.3 Literature study

Since similar tendencies were found in both the case and literature study, the validity of the case studies is strengthened by the literature study itself. Therefore, it is also important to consider the origin of the information obtained in the literature study. Since peer reviewed literature was preferred and scientific databases used, the content of the study should be correct. Even so, the microgrid field is young and dynamic, which could leave even recently published literature outdated. Still, communication with FME CINELDI's own scientists and university professors should secure the relevance of the obtained sources.

A significant drawback in the literature study was the absence of a proper charting system that provides an overview of microgrids in Norway. This makes it difficult to draw any definite conclusion, since some aspects might be overlooked. Yet, multiple sources confirmed the infancy of the trend in Norway. Consequently, significant projects and technologies should be easy to discover.

8 Conclusions and further work

The object of this thesis is to give an overview of the microgrid trend in Norway. Important aspects are motivations, benefits, challenges and prerequisites for microgrid deployment. The four key aspects presented in the introductory chapter 1 are addressed throughout the thesis. Some answers to the problem statement were obtained through the combination of the literature and the case studies.

8.1 Conclusion

The extent of ongoing microgrid project in Norway is small, and the amount of microgrids in operation is even smaller. There is not an absence of technology for extensive deployment, but a lack of sufficient motivation. The most evident motivation for Norwegian microgrid activity is research and testing. All microgrids considered in this thesis are pilot projects where gaining experience and testing new solutions is important. The background for microgrid research is often driven by climate goals. These goals require more renewable energy generation and further electrification of the society. Microgrids offer the possibility of increased installation and deployment of renewable DERs. Furthermore, they can be alternatives to costly grid upgrades and expansions that come as a consequence of increased electrification. Avoiding grid expansion could also hinder encroachment on nature.

There is no economic incentive for extensive microgrid deployment in Norway. The energy demand in some of the country's remote areas is increasing due to increased population and amount of cabin owners. At such locations, microgrids could be more affordable than an equal grid upgrade. Internationally, a common motivation to establish microgrids is to increase reliability and resiliency of the power supply. Since the Norwegian power grid is stable in central areas, this motivation is not as important for all microgrids. Though the capacity of the Norwegian power grid is sufficient today, it is not well charted. A lack of capacity is likely to become a challenge in the future as electrification increases the strain on the power grid.

Within a microgrid, technology provides improved power quality. This can enhance the exploitation of DERs, since these often require an external power supply with good stability and power quality. Although it is not likely to be profitable, microgrids can enable prosumers to install DERs with larger capacity than the Norwegian prosumer agreement allows for. The power grid could benefit from microgrid deployment, since microgrids that have an energy storage can provide ancillary services. Furthermore, a microgrid's ability to operate in island mode can provide a continuous power supply of high quality during power outages on the power grid. Also, constant islanding could be a permanent alternative to power grid connection.

There are some important prerequisites for microgrid deployment in Norway. The legal system is currently a hinder. Additional and time consuming efforts from initiators are required since the legal system is not adapted for microgrid establishment. Further, the availability of technology is an important factor. The technology is currently applicable and has to be readily available in a wide range for extensive microgrid deployment. The presence of pre-existing DERs is beneficial for microgrid projects, as it reduces the initial investments. Finally, communication with affected parties such as customers or locals is an important aspect, but not a necessity.

The dynamic development and absence of a proper charting system for the Norwegian microgrid trend affects the reliability of this thesis. However, the similarities between the literature and case studies are evident, supporting this thesis's validity. Conversations with scientist and supervisors further secure the validity. A different approach of the case studies might have yielded some additional, but not significant, aspects and findings.

8.2 Further work

Both the literature and case studies could have been expanded if the time frame of this thesis was extended. Given more time to conduct interviews, it would be interesting to contact DSOs in regards to the literature study as well as the case studies. Then, the DSOs could have given a broader insight in their role in the microgrid development. For the case studies, more time would enable the possibility to conduct more interviews with project partners. It would have been reasonable to interview more parties in each microgrid project. This would have provided more detailed and nuanced information from the different cases.

A detailed examination of the legal framework that affects microgrid deployment would be relevant to conduct as a supplement to this thesis. This could give an evaluation of how legislation could be changed to benefit microgrid projects. Further, it would be useful to investigate the available technology. To establish the range of the market could give a better insight in the state of the microgrid trend.

It would also be interesting to conduct a detailed analysis of the economic viability of the microgrids in the case studies. Such an investigation should establish which criteria and assumptions that are necessary for microgrid deployment to be economically viable. Furthermore, the study could give an accurate suggestion for possible areas for microgrid deployment.

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A Discarded cases

Starting up the work on this thesis, a broad investigation on microgrid cases was conducted. The investigation yielded a large case selection, which where not all included in the thesis. Table A.1 gives a brief description of the cases that where considered, but not included in the final thesis. A short explanation on why the cases were not included is found in the same table. The sources to the descriptions are given as hyperlinks after the case descriptions.

Table A.1: *Overview and description of cases that where considered but not included in this thesis.*

Case	Brief case description	Reason for rejection
Heimdal high school, Trondheim, Norway	New high-school at Heimdal outside of Trondheim. Disposes over smart energy solutions, CHP and rooftop PV. ***Link to source*** visited 03.05.21	No BESS planned. Island operation unlikely.
Fusion grid, Namibia	Project merging PV power generation, a battery and LTE connectivity ito a single unit. The concept is to be deployed in developing countries with a weak or non-existing power grid. Ease of deployment is important. ***Link to source*** visited 06.05.21	Discarded as it does not fit the scope of the thesis. The case was first considered to illustrate the diversity of existing microgrid projects.
Olsengården microgrid, Oslo, Norway	Olsengården is an apartment complex consisting of 50 apartments in Oslo. There is to be installed PV and a BESS for supplying common facilities and EV-charging. This allows for peak shaving. ***Link to source*** visited 03.05.21	There is no plan to implement island operation. The BESS will be used primarily for rate arbitrage. In addition, it was difficult to find information about the case and a contact person.
Samsø, Denmark	Island in Denmark generating its entire electricity consumption with renewable energy. Energy is generated with wind turbines partly owned by the inhabitants on the island. The island also has a district heating system. ***Link to source*** visited 05.05.21	Discarded due to its lack of BESS. The islands interconnection with the Danish power grid allows for 100% net renewable energy consumption.

Continuation of Table A.1

Case	Brief case description	Reason for rejection
Sandbakken microgrid, Hvaler, Norway	Microgrid project at Sandbakken. The project is to dispose over 1200 m^2 PV and 4 wind generators producing 171 MWh annually. The microgrid should be able to operate in island mode for up to 20 hours. ***Link to source*** visited 03.05.21.	Utsira is a similar project. FME CINELDI is involved in innovations at Utsira. It was difficult to get in touch with relevant personnel.
Skagerak energilab, Skien, Norway	A FME CINELDI research centre used for full scale microgrid tests integrated in a football stadium. The microgrid has 4300 m^2 of PV and a 800kW battery. The battery is capable of delivering enough power to light up the entire stadium for the duration of a football match. ***Link to source*** visited 06.05.21	Discarded since it seemed to be a more limited project than the others included in this thesis. The supervisors of this thesis discouraged the use of this case.
Sola airport, Stavanger, Norway	Avinor aims to electrify all national fligths in Norway within 2040. To do this they need access to enough elecrical power. Through the Elnett21 Project, they aim to find the best solutions for local energy production. ***Link to source*** visited 03.05.21	Discarded due to the inclusion of Risavika havn which is also part of Elnett 21
Svalbard, Norway	Svalbard is currently supplied by a coal power plant. The installation of a BESS will improve the fuel efficiency and resiliency of the power supply at Svalbard. The 5 MWh/5 MW BESS alone will be able to supply the power demand for up to one hour. ***Link to source*** visited 03.05.21	Discarded as it only includes the implementation of a BESS. No renewable DERs.

B Interview questions

To initiate a conversation with case contacts, the questions found below were used. They are divided into two categories: where the first aims to establish a general overview of the microgrid, its components, objectives and purpose. The second category contains a set of broader and more open questions about key experience gathered from the project.

Questions about the microgrid:

- Who is the owner of the microgrid and who contributes to operating the grid?
- Is the microgrid a part of a larger project or research program?
- Which entrepreneurs have been a part of building and establishing the microgrid and accompanying constructions?
- What will/did the project cost and how is/was it financed?
- Who are the users of the grid? Could you give a short explanation of the area of application.
- When was the project first approved? And when did the construction process start?
- What relation does the microgrid, and its owner, have to the distribution grid and the utility company? What TSO (transmission system operator) and electricity company is connected to the microgrid?
- is the microgrid connected to the distribution grid? Where is the PCC? Are there multiple PCCs? How are the different units placed regarding PCC?
- How often have the microgrid operated in island mode? How many hours have it operated in island mode during its lifetime?
- What energy sources (DERs) is a part of the system?
- What is the electrical capacity to the DER and the degree of self-sufficiency? How much electric energy in kW/kWh is produced and used?
- Is heat utilized in some way in the microgrid? Is it used or stored? For example, are you connected to a district heating central?
- Are any energy efficiency efforts taken, which not already have been mentioned?
- What is the average power loss in the grid? And what are the main causes for this loss? (For example, conversion processes)
- What is the energy payback time for the project? (Given that the microgrid have energy production, DER)

Questions about project experiences:

- What technical issues have you experienced?
- Is the project economically viable?
- What are the goals and motivations of the project?
- What are your experiences with island mode operation?
- Is there anything else you would like to mention?