Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Electric Power Engineering

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The Influence of Local Energy Tariffs on a Norwegian Local Market

Master's thesis in Energy and Environmental Engineering
Supervisor: Jayaprakash Rajasekharan
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Preface

This master thesis contains my final work as a master student at the Department of Electric Power Engineering at the Norwegian University of Science and Technology. The thesis build on the specialization project [61] delivered in the end of 2019. Chapter 2 partially reuses material produced in the specialisation project. However, the chapter has been modified and extended to cover the thesis scope.

I would like to thank my supervisor, Jayaprakash Rajasekharan, for good guidance with the thesis. I would also like to thank Sigurd Bjarghov, my co-supervisor, for helping me developing my model and for good discussions through the past two semesters. Finally I would like to thank my fellow students, these five years would not have been the same without you!

Abstract

The transition to a clean and renewable consumer-centric energy system is expected to increase the electricity consumption in Norway. An increase in distributed generation (DG) is an expected outcome of this transition. Rapid spread of DG contributed to energy production and challenges grid operation. Combined with digitization it enables new market opportunities as local energy trading. Local energy trading is a key enabler to facilitate a smooth grid operation with high DG penetration. Along with a tariff structure fostering smart energy behaviour this may increase the grid stability and improve the quality of service.

This thesis target is to investigate how increasing tariffs influences the local energy trade in a Norwegian neighbourhood consisting of multiple communities. Furthermore, the local energy trade's influence on current and future market participants is examined. This was achieved by developing an optimization model capable of Peer-to-Peer (P2P) and Community-to-Community (C2C) trading. The communities and the consumers within them have unique load patterns and different amounts of storage and DG. The tariffs tested are aligned with the current tariff structure for domestic homes.

Two cases with 10 scenarios each was created to test the neighbourhood ability to exploit local energy trading when introducing tariffs to P2P and C2C trade. The main distinction between the investigated cases is the introduction of component degradation. Component degradation is introduced to provide a more realistic image of local energy trades capabilities and to analyse its influence.

The results show that increased tariffs reduce P2P and C2C trade within communities and the neighbourhood. However, the neighbourhood's daily morning peak is straightened independent of the tariff structure, with minor variations. By aligning with the current tariff structure for domestic households in Norway, the neighbourhood's yearly load curve is unchanged with local energy trade. Combined with similar yearly peak import it implies that local energy trade is unable to reduce grid stress. Aggregators is a market participant potentially able to relieve grid stress. However, it is uncertain to which extent the aggregators will be able to participate in the Norwegian electricity market, due to market competition. Preliminary results indicate a gradual introduction of aggregators and that aggregators has minor influence on other market participant.

Sammendrag

Overgangen til et fornybart forbrukssentrisk energisystem forventes å øke strømforbruket i Norge. En økning i distribuert generasjon av fornybare energikilder er et forventet resultat av denne overgangen. En hurtig økning av distribuert generasjon bidrar til energiproduksjon og utfordrer driften av nettet. Kombinert med digitalisering muliggjør det nye markeder, som lokal energi handel. Lokal energi handel er en nøkkelegenskap for å lette driften av stømnettet med høy andel distribuert fornybar energi produksjon. Sammen med en tariffstruktur som fremmer smart energiatferd, kan dette øke nettstabiliteten og forbedre tjenestekvaliteten.

Formålet med oppgaven er å undersøke hvordan økende tariffer påvirker lokale energihandel i et norsk nabolag bestående av flere små lokalsamfunn. Videre undersøkes den lokale energiflytens påvirkning på nåværende og fremtidige markedsaktører. Dette ble oppnådd ved å utvikle en optimaliseringsmodell som er i stand til å handle fra node til node (P2P), hvor en node kan være en forbruker eller et lokalsamfunn. Lokalsamfunnene og forbrukerne i de har ulike forbruksmønstre, samt forskjellige energilagringsmuligheter og fornybarproduksjon. Tollsatsene er tilpasset dagens tariff struktur for husholdninger.

To caser med 10 scenarier hver ble laget for å teste nabolagets evne til å utnytte lokal energihandel etter at tariffer for P2P handel er innført. Det viktigste skillet mellom de undersøkte tilfellene er innføring av komponentforringelse. Komponentforringelse introduseres for å gi et mer realistisk bilde av lokale energi handel kan utrette og for å analysere påvirkningen på nabolagets energibruk.

Resultatene viser at økte tariffer reduserer P2P handelen i lokalsamfunn og nabolaget. Imidlertid er nabolagets daglige morgentopp jevnet ut uavhengig av tariffstrukturen, med mindre variasjoner scenarioene imellom. Benyttes gjeldende tariffstruktur er den årlige lastkurven til nabolaget uendret med lokal energihandel. Kombinert med tilsvarende årlig toppimport i begge caser innebærer det at lokal energihandel ikke klarer å redusere nabolagets påvirkning på strømnettet. Aggregatorer er en markedsaktør som potensielt er i stand til å lindre nabolaget påvirkning på strømnettet. Det er imidlertid usikkert i hvilken grad aggregatorene vil kunne delta i det norske elektrisitetsmarkedet. Foreløpige resultater indikerer en gradvis introduksjon av aggregatorer og liten innflytelse på andre markedsaktører.

Table of Contents

List of Tables

List of Figures

Abbreviations and nomenclature

Abbreviations

BRP = Balancing responsible party
C2C = Community to Community
CBA = Cost benefit analysis
CEER = Council of European Energy Regulators
DER = Distributed energy resources
DG = Distributed generation
DSO = Distribution system operator
EU = European union
EV = Electric Vehicle
FCR = Frequency containment reserves
FFR = Frequency restoration reserves
ICT = Information and communication technology
LCOE = Levelized cost of electricity
LEM = Local electricity market
LV = Low voltage
MDS = Mobile distributed storage
MV = Medium voltage
NOK = Norwegian krone
NPV = net present value
NVE = The Norwegian Water Resources and Energy Directorate
OED = The Norwegian Ministry of Petroleum and Energy
P2P = Peer-to-Peer
PEB = Positive energy block/district
PV = Photovoltaics
RED = Responsive end user
RME = The Norwegian Energy Regulatory Authority
SCR = Self-consumption rate
SESP = Smart energy service provider
SOC = State Of Charge
SSB = Statistics Norway
SSR = Self-supply rate
TSO = Transmission system operator
USD = United States dollar
V2G = Vehicle to Grid

Sets

c	Community index, $c \epsilon [1, 3]$
p	Prosumer index, $p \epsilon [1, 8]$
t	Time index, $t \epsilon [1, 8760]$

Parameters

$P_{p,t}^{load}$	Prosumer load [kWhpower]
B^{cap}	Battery capacity [kWh]
$B_p^{ch,max}$	Battery maximum charging power [kW]
$B_p^{disch,max}$	Battery maximum discharging power [kW]
$\eta^{bat,tot}$	Battery round Trip Efficiency [%]
$\eta_p^{bat,ch}$	Battery charging efficiency [%]
$\eta_p^{bat,dis}$	Battery discharging efficiency [%]
$B^{SOC,init}$	Initial battery SOC [kWh]
$B^{SOC,min}$	Minimum battery SOC [kWh]
B^{cost}	cost of battery utilization [kr/kWh]
$B^{soc,final}$	Battery state of charge in last time step[kWh]
$PV_{p,t}^{Prod}$	PV production from consumer p in time t [kW]
$PW_{c,p,t}^{prod}$	Wind production from consumer p in time t[kW]
C_t^{spot}	hourly spot price [kr/kWh]
C^{tariff}	electricity tariff [kr/kWh]
$C_i^{P2P,tariff}$	tariff on P2P-trade [kr/kWh]
$C_i^{C2C,tariff}$	tariff on C2C-trade [kr/kWh]

C^{fixed}, yearly payment [kr]
C^{tax}, taxation of electricity, [%]

Variables

$n_{c,p,t,i}^{imp}$	Neighbourhood grid import [kWh]
$n_{c,p,t,i}^{exp}$	Neighbourhood grid export [kWh]
$p_{c,p,t,i}^{imp}$	Consumer power import from grid [kWh]
$p_{p,t,i}^{exp}$	Consumer power export to grid [kWh]
$b_{p,t,i}^{SOC}$	Consumer battery SOC[kWh]
$p_{c,d,p,t,i}^{exp,c}$	Consumer export to community [kWh]
$p_{c,d,p,t,i}^{imp,c}$	Consumer import from community [kWh]
$p_{c,p,q,t,i}^{exp,p}$	Consumer peer export to consumer p [kWh]
$p_{c,p,q,t,i}^{imp,p}$	Consumer peer import from consumer p [kWh]
$b_{c,p,t,i}^{ch}$	Battery charging power in time step t [kW]
$b_{c,p,t,i}^{disch}$	Battery discharging power in time step t [kW]
$b_{c,p,t,i}^{soc}$	Battery state of charge [kWh]
$b^{tot,i}$	Total electricity bill [NOK]
$c_i^{C2C,tariff}$	C2C tariff [NOK]
$c_i^{P2P,tariff}$	P2P tariff [NOK]
$c^{imp,grid}$	Import expenses [NOK]
$c^{battery}$	Battery expenses [NOK]
c^{P2P}	P2P expenses [NOK]
c^{C2C}	C2C expenses [NOK]
$c^{exp,grid}$	Export income [NOK]
e	Total electricity bill [NOK]

1

Introduction

1.1 Motivation

The worlds energy demand is increasing, due to an increase in the population and the increase in peoples wealth. Synchronously is global warming challenging the existing means of generating energy. A transition to clean, inexhaustible renewable energy is required to fulfill the Paris Agreement[67]. To put it into perspective 304 billions USD was invested in the renewable power sector in 2018, compared to 155 billion USD in 2008. Implying the renewable part of the energy sector is a quickly developing industry. Simultaneously are projections of future development envisaging major changes in the years to come. The whole energy value chain is going to be digitized and renewable energy widespread. Today the energy production is centralized and a transmission network is required to reach consumers. Now, the whole industry is predicted to go through a transition from centralized production to decentralized production, at least as a supplement. Decentralized production, also referred to as distributed generation(DG), is i.e houses with PV or wind turbines installed. The structuring of the decentralized production is still relative unexplored territory. However, as new ecosystems has appeared in other traditional industries this is expected to happen in the energy sector too. Digitization enables a multi-sided and consumer-centric platform for energy markets[14]. As a result the consumer takes a key role in the future energy system and market.

Arranging for the transition, a key enabling mechanism is to enable the consumers to participate in the energy market. EU has taken the challenge to heart. To encourage consumers to take a more active part in the energy system, EU has developed the ”Clean Energy for All Europeans package”. This EU legislation is preparing for the future market, by putting the consumer in the centre of the energy transition [3]. As a first step it allows consumers with DG surplus to sell energy to other consumers, from peer to peer(P2P). In a similar manner, a community with energy surplus could interact with a community with energy deficit to trade energy. Thus a **local energy market(LEM)** can be created with individual consumers and/or communities trading energy locally and bilaterally. LEM pilots has been simulated in combination with DG outside of Europe [57, 20] with inspiring results. The results are promising, nevertheless they do not take into account the cost of grid utilization.

Grid utilization is in Norway compensated through a grid tariff that consumers pays as a part of their electricity bill. Tariffs covers the cost of grid operation, utilisation and development. Lately it has been introduced a new tariff structures from NVE [59]. The proposed tariff structure has faced resistance from multiple organizations, as the organizations claim the proposed tariff structure is unable to promote reduced energy consumption [46]. The NVE proposal does neither include P2P trading. Despite not being mentioned by NVE, P2P trading is mentioned by the Council of European Energy Regulators(CEER), who represents Europe’s energy regulators [33]. CEER states that tariffs should send price signals supporting the energy transition and encourages national regulators and legislators to anticipate the energy transition. The tariff structure should be studied in detail as it is essential to fully realize functional local markets.

1.2 Scope

The decentralization of the energy market, with more active end-users and locally produced renewables, challenges the current market structure. The European clean energy package presents a more market-oriented and flexible electricity market design. The restructuring is yet unexplored territory, where its effect on the market is uncertain. However, EU nations are implementing the new directives from the clean energy package and countries is liable to implement it into national laws within 2021. The directives are embraced by NordREG, the regulator in the Nordic countries. NordREG believes in a thrifty transposition and implementation of the European directives [16].

By simulating a Norwegian neighbourhood this thesis aims to investigate the effect of a decentralized energy market. A decentralized energy market introduces trading between parties who traditionally do not trade energy, revealing a question of whom to cover the expenses of grid utilization. As the distribution system operator(DSO) is responsible for a reliable distribution grid, an approach to cover the DSO's expenses when enabling P2P is presented. This is done by introducing tariffs on local energy trades within the simulated neighbourhood. While analysing the neighbourhood, aggregators opportunities in the Norwegian market will be examined.

1.3 Problem definition

Local energy trading is proposed as one of the solutions to face the decentralization of the electricity production. Whom will participate in the energy market and how the trade energy is going to take place is still up to discussion. Apart from the regulatory issues, the grid has to be maintained, which is likely to introduce tariffs related to the local energy trade to cover maintenance expenses. This leads to the questions this thesis will investigate:

- How is the tariffs effecting the local trading in the neighbourhood?
- How can an aggregator be a part of and contribute to the Norwegian electricity market?
- In which market(s) can a Norwegian aggregator operate?
- How is existing market participants influenced by aggregators market entry?

1.4 Outline

This thesis start off with the introduction in chapter 1 where motivation, scope and problem definition is presented. Chapter 2 contains a literature review covering topics essential to create the local market model. In the literature review local electricity markets focusing on P2P trading, component degradation and flexibility in distribution grids are covered. Chapter 3 elaborates about the Norwegian market structure which is further discussed in the discussion chapter 6. Chapter 4 gives a stepwise introduction to the model and a general approach and the case studies are presented. In chapter 5 the results are presented. The key takeaways are presented in chapter 7, before some thoughts on how to extend the model and further work is given in chapter 8.

2

Literature Review

This literature review covers LEM with focus on aspects related to P2P energy trading. Advantages and challenges is discussed to provide an overall picture of P2P trading. Reviewing P2P trading, aggregators becomes a natural talking point as it could act as an intermediate between supplier or DSO and consumers who offers flexibility or sells DG. Another reason aggregators are covered is to discuss the aggregators possibilities in the Norwegian market. The existing Norwegian energy market has small margins and a review related to appliance costs is preformed to gain insight in feasibility of appliance installation and utilization. Therefore, a review on existing literature related to degradation cost completes this review.

2.1 Local electricity markets

Local energy markets has distinct features according to [45]. A LEM's distinct features is the diversity and characteristics of DG. The specific rules for local electricity prices. Lastly, the role of digitalisation tools to facilitate peer-to-peer trade. As a result, local electricity markets is being developed based on P2P trading. However P2P is a term widely used, what P2P trading is, differs from paper to paper according to these reviews [64, 18]. To explain the different market structures [64] is chosen. A peer can be either a community, a consumer or a prosumer within a market given the market. A prosumer is a consumer who produce, store and consume energy [44] In a **full P2P market** peers has total freedom to negotiate energy prices directly with each other. There are no centralized authority regulatingthe market. A **community based market** is more structured than a full P2P market and each community has a community manager. A community is often illustrated as neighbouring prosumer and consumers, but might be peers sharing a common interest such as local or green energy. A community manager has the responsibility of trading with other community managers, and the utility grid. **Hybrid P2P market** is a combination of full P2P and community based P2P. In a hybrid market prosumers, consumers and community managers will be able to negotiate energy prices.

2.1.1 Peer to Peer advantages

P2P has multiple advantages, primarily P2P trade creates a competitive energy market. A P2P market provides a supplementing source of energy which the consumer can chose from according to preferences such as local or green energy to mention a few. As a result P2P trade increase the profitability of local energy production and enables the peers to consume more locally produced DG [18]. Secondly, the addition of P2P can reduce the number of power outages. This is done by providing local energy sources during outage of the lines connected to the utility provider[18]. Consequently, the overall efficiency of the power system will increase due to ancillary services [27]. Furthermore, it will reduce the operating cost, as P2P trade decrease the demand during peak hours. This is done by storing energy in off peak periods.

In recent years a lot of new opportunities has emerged as information and communication technology (ICT) and power distribution has become more interconnected. The potential of flexible demand has been studied in Denmark [43]. The article describes the demand percentage in residential, commercial and industrial sector. Most relevant for this project is the residential sector, where electrical equipment are categorised. The equipment found with potential is refrigerators, freezers and washing equipment, whereas water heaters and heating cables do not have potential to provide flexibility due to limited possibilities in time shifting. [47] presents ICT concerning the smart grid infrastructure enabling P2P to utilize its advantages. Advantages as the decrease the number of outages, simplified fault detection and easier access to energy consumption is highlighted. The digitization, sensors and management algorithms and the communication in a smart grid home required to take full advantage of P2P is presented.

2.1.2 Peer to Peer challenges

The advantages with P2P are obvious, at the same time P2P introduce a set of new challenges. Among the new challenges are distribution cost, technical issues, privacy, regulations and technical constraints. The challenges and especially technical constraints are useful to gain insight in how to model a P2P market.

Distribution cost

P2P trading does face challenges such as unfair distribution costs, but the issue is addressed and one are able to keep the cost at the same level or lower also for homes not participating in the microgrid, by utilizing Pareto optimization [20]. Optimal P2P energy trading has proven to be time consuming and complex, consequently the ECO-Trade algorithm. ECO-Trade provides a near optimal optimization algorithm with considerably less time consumption and is therefore preferred in P2P energy trading. The willingness to participate is another challenge, but given with equal or lower price if participating this issue seems resolved from a monetary view.

Communication technology

Smartgrid with P2P depends on two-way communications, which has disadvantages as interference with other signals and electromagnetic fields. The smart grids the amount of data transferred will be drastically increased, the fact that it is no standardization is a unresolved challenge. With ICT cyber security becomes a different challenge with a smart gird compared to the current set up of the utility gird [24].

Privacy

Another major challenge yet to be sorted according to Kofi is privacy preservation, both in energy trading and transactions [42]. A secure P2P payment system which is privacy preserving is presented. They achieve user anonymity based on an elliptic curve cryptographic bilinear pairing. Together with ring signature, zero-knowledge proof and commitments they can prevent consumer privacy breaches.

Regulations

There are regulatory barriers in the current market design. The European commission envisions end users as key participant in the future electricity market. However there are regulatory barriers preventing active participation from end users while the current market design lacks incentives for consumers [48]. Resolving the mentioned issues would decrease the electricity bills for the prosumers allowed to trade locally given installed battery capacity and DG. The implementation within a community can decrease the electricity bill with 50%. It would also benefit consumers without any DG given a lower price for locally generated electricity than importing from the electricity grid.

Technical constraints

[25] considers a consumer-centric framework when allocating network usage costs and evaluating network constraints. In this paper the prosumers act as self-interested. Network usage charges are chosen to influence the outcome of P2P markets. The paper proposes three different charges: Sharing all costs equally, according to electrical distance between prosumers and lastly according to zones. A zone, also referred to as community, contains prosumers with an equal trading tariff. This was also the approach of [37], who have created their own algorithm to estimate the impact of a P2P transaction related to power losses and utilization of the network[37]. This is carried out by performing a sensitivity analysis. In the paper external costs associated with the power flow are internalized and bilateral transactions are guaranteed. This is achieved by analytically deriving sensitivity coefficients. They implement voltage sensitivity coefficients, power transfer distribution factors and loss sensitivity factors. By evaluating the pre-mentioned factors network constrains are respected in every transaction. The cost of utilization and power losses are shared equally between trading consumers. Bid/ askes are performed as on the stock exchange, which causes a narrow market when implementing trading zones with few participants.

2.2 Flexibility in distribution grids

Flexibility in distribution grids could be offered in different ways. The end user participation and impact on the grid is dependent on the approach. Active and passive approaches is described in this section.

An **aggregator** to operates the local electricity markets, consisting of considerable amounts of DG [55]. In a local flexibility market, a Smart Energy Service Provider (SESP) operates as the platform for flexibility trading and acts as an aggregator. The DSO purchases flexibility through the SESP platform. Flexibility as a commodity is provided by prosumer, consumers and energy cooperatives. An energy cooperative consists of several end users that could be both prosumer and consumers. This provides flexibility by shifting peak loads through the bids and offers on the SESP platform. [32] describes a network market approach prospering on demand economics of scale. In this approach a smart energy service provider (SESP) acts as an aggregator. The SESP is market maker where demand response and end-user flexibility can be traded. Aggregators is by [58] separated into plug-in electric vehicle aggregators and responsive load aggregators, participating as reserve market regulators. Different methods are applied to investigate the effect of introducing new market regulation where aggregators participate in this virtual market. In [23] the aggregators participates in the balancing market. The EV aggregators are not only considered as flexible loads, but as mobile distributed storage (MDS) units. Allowing the MDS to offer its services to multiple aggregators depending on its location.

Currently the **end user** is unable to participate in grid operation, this changes with the responsive end users(RED) mentioned by [26]. The RED, mentioned as prosumers in this paper, has the ability to impact voltage and frequency control [26] In the paper a control strategy is proposed minimizing voltage deviation, frequency deviation and adjusted active and reactive power. Several RED’s act collaboratively to respond to frequency and voltage changes. The traditional way of structuring the energy sector is about to change [54]. As most end-users are passive the S3C Project addressed the opportunity to engage costumers. The opportunities to change sustainable behaviours involving ”Smart Consumer” aiming to decrease the households consumption and ”the Smart costumer” producing energy is mentioned in [54]. While ”Smart citizen” is the opportunity local engagement EG comparing yourself with others consumption. Here the DSO plays a key role as market tools has to be developed and fitted the different consumers abilities and needs. S3C Project guidelines was tested with a game theoretic approach and provided promising results in the InovGrid project.

YouPower is an open source platform, aiming to facilitate consumers to make sustainable energy behaviour decisions [38] . As the S3C project this is also community oriented and supports social sharing within the community. In addition, YouPower is linking energy data to consumer actions and offering energy saving suggestions. As S3C the preliminary results are indicating that community-oriented approach has significant potential enabling a more sustainable energy consumption.

Batteries as flexible components in local electricity market designs with peer-to-peer trading is review by [45]. Two setups are designed, a decentralized market design where consumers has batteries privately installed and a centralized market design where the consumers has a shared battery. In both cases significant savings, above 20%, are achieved with achieved compared to a reference case. It is pointed out that the different market designs promote respectively energy autarky and higher integration of local market features.

2.3 Component degradation

Calculating the net present value (NPV) and levelized cost of electricity (LCOE) of a DG project, the life expectancy of components are among the factors [51, 31]. The viability of a project is highly dependant of component degradation [39]. A review of components degradation is following in the next subsections. Smart metering appliances however, which enables local trading of energy, are left out as the recent implementations limits the research of component life time[17].

Battery

The component degradation is important when estimating the battery cost as shown analysing residential battery systems [57]. Investigating lithium-ion batteries [71] states that to bundle a grid-level storage, rechargeable lithium-ion are promising down to high energy and power density, decreasing cost and discharge rate. The paper also explores a cycle counting method to identify stress from irregular battery activities [71]. Usage pattern is a decisive battery cost variable. The actual cost is still researched as mechanical stress and chemical degradation is evaluated in [62]. However the preliminary results gives indications on how to model it. The battery is inefficiently operated when there is no penalty utilizing low SOC or high SOC. Adjusting voltage, current and SOC the degradation cost by operating differently may vary with a sixfold [19].

PV

The degradation of PV-panels is explored in [21]. Their findings show that multi crystalline silicon PV modules after 30 years are degraded with 13,86%. Still a respectable production several years after the PV-panels warranty is out of time. PV-panels degradation and lifetime as a result of weather and climate impact is investigated in [41, 34, 49]. It is seen that geographical location affects panel degradation, due to temperature and humidity. A reduction in the degradation may eventually result in decreased operation and maintenance costs.

Distribution network

[63] has interviewed field experts to investigate distribution network components. It is found that oversized network components are not uncommon. This is according to [63] due to simpler models, electrical and mechanical qualities. Components are accordingly expected to have a longer lifetime. Weather conditions, humidity and wind is reducing the expected lifetime [39, 68]. Nevertheless, distribution network component lifetime assessments is according to [63] ranging from 30 to 70 years.

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3

Norwegian market structure

The structure of a decentralized market is a consumer concern as much as a DSO concern. From a consumer point of view is it important to avoid increased prices due to the establishment of a decentralized market in their area. The DSO must cover its costs and maintain delivery quality. Simultaneous does the EU's energy policy require the energy markets to be competitive, not discriminate, be flexible and consumer centred. This introduces a new player operating in the traditional markets, namely aggregators.

3.1 Market participants

In this section the current market participants are briefly presented, and how they might experience changes in current role. The electricity market is evolving, and new participants is expected. Their role in the market is yet to be decided. Some of the potential roles envisaged is presented.

3.1.1 Transmission system operator

The transmission system operator (TSO) is Statnett. Statnett is an enterprise owned by the Norwegian state and controlled by OED and is regulated by The Norwegian Energy Regulatory Authority (RME). The TSO is responsible for reliability, adequacy and security in the transmission grid. This is done by managing the wholesale market in real time, adjusting generation according to load, avoiding frequency violations and interruptions. Statnett has a long-term perspective as well, planning the future power system.

3.1.2 Distribution System Operator

The DSO obliged to supply consumer with electrical energy. A DSO is operating within a geographical area as a monopoly. The DSO is grid responsible and owner of the grid. Being a monopoly, regulation is required this is done by a revenue cap decided by The Norwegian Water Resources and Energy Directorate. Currently the DSO is dependent on the TSO voltage regulation when a grid is operating without interruptions.

The distribution grids are exposed to local load peaks. Consequently, the DSO role is evolving and some of TSO's assignments related to voltage regulation is suggested to also be a DSO assignment in coordination with the TSO, while the national responsibility remains with the TSO. A work group from Energi Norge composed by DSO's, proposed controlling reactive production from suppliers, capacitor batteries, installing batteries and controlling production plans as DSO assignments [4].

3.1.3 Balancing Responsible Parties

The traditional way of operating the grid is challenged as local DG widens. It is suggested that the DSO should take part in this [5]. However, in the current market it is the TSO's responsibility to maintain frequency balance and prevent bottlenecks. The TSO is therefore informing about issues regarding system operation. In the current balancing market, commonly, Balancing responsible party (BRP) is providing the increase or decrease in generation when required based different reserves. The BRP participates in Frequency containment reserves (FCR) and/ or Frequency restoration reserves (FRR). Suppliers participate in the balancing market through an agreement with a BRP, allowing supplier not acting as BRP to enter the market. In the future market aggregators is suggested as a balancing responsible party, this will be addressed in the aggregator section.

3.1.4 Supplier

The supplier is a market participant whom produces electricity. Commonly this has been upstream hydro plants in Norway. This still the case, while the local production is increasing[13]. This is not a part of SSB statistics [9], however the stipulated production is 0.1 TWh.

3.1.5 Aggregator

Current legislation requires a minimum bid size to participate in balancing markets, usually 10 MW regulerkraftmarkedet(RKM).This is impossible for an average prosumer to achieve. The solution is multiple prosumers cooperating to provide flexibility and offering it to the market. Managing this is the aggregator, acting on behalf of multiple prosumers in the market. Renewable energy aggregator is legal entities aggregating load or generation. They aiming to optimize energy supply or consumption technically and/or economically [30]. EU requires market solutions as well as DSO's, TSO's to rearrange such that flexibility from prosumers and aggregators becomes integrated.

An aggregators market participation provides multiple opportunities; intraday, day-ahead, balancing market. Aggregators offers a service to those consumers who generates, has energy storage and those offering demand side management. This is potentially industry, domestic or commercial costumers. This provides a service to TSO, DSO, BRP, energy suppliers and prosumers. An aggregator can potentially provide flexibility at a local level to the DSO's by offering flexibility during peak hours. This market will provide an option to DSO's, and become interesting if the DSO gets a balancing responsibility as suggested by Energi Norge. Currently there are multiple barriers for aggregators, nevertheless they are addressed by NordREG [16]. Regulation is required for aggregators to gain market access. Local settlement of generation and demand response must be determined. While the aggregators need access to data, this is a problem statnett is working on with Elhub. Elhub gathers the data, enabling access to multiple market participants as aggregators.

There are multiple business models suggested for aggregators [69].There is key distinction between aggregators, the independent aggregators and the aggregators combining roles.

Combined aggregators

Combined aggregators has an advantage as they are compatible with existing electricity market design. As a result combined aggregators avoid regulatory changes. A con is that a combined aggregator might restrain the competitiveness of the market.

Combined aggregator-DSO is also an option. However, the DSO is under regulation, while an important role of the aggregator is a competitive unregulated market. This option is therefore not further discussed.
Combined aggregator-supplier produces energy and acts as an aggregator. Meaning that aggregator and BRP is the same entity. It reduces flexibility options,but the complexity is low. There is no need for settlement between suppliers and aggregators. It is possible to implement aggregator-DSO in Norway due to a well-functioning wholesale and retail market with sufficient competition.
Combined aggregator-BRP offers services of balancing responsibility without becoming supplier. The result is two BRP's at each connection point, aggregator and supplier. In addition, the aggreagator could trade on other markets such as day-ahead. An aggregator could potentially have consumers form different suppliers. This is a more complex marketing model where imbalances between aggregator and supplier must be adjusted and settled.

Independent aggregator

A more competitive electricity market is as an important advantage of introducing the independent aggregator to the market.
Independent aggregator as service provider for another market player. The aggregator does not sell at own risk. The aggregator has no balancing responsibility, but the other market actor is exposed to risk.
Delegator aggregator sells at own risk to buyers(TSO,BRP, wholesale market), very complex services. Interaction between these market players is not yet discussed and a formalization remains if an aggregator should participate with risk.
Finally it is the **Prosusmers as aggregator** this is a challenge for domestic consumers with respect to the prementioned required power to participate in the market. An aggregator acting on behalf of multiple prosumers is a possibility. Meanwhile, industrial consumers have the opportunity to act on behalf of them self as aggreagators.

3.2 Current status in Norway

Since 1990 the electricity consumption in Norway has increased. Comparing the 2018 electricity consumption with consumption data from 1990 shows a 28.7% increase in consumption. Comparing peak loads from 1990 and 2018 it has increased even more, 33%, according to the Norwegian Ministry of Petroleum and Energy (OED). OED expects this trend to continue as electricity becomes introduced to new services.

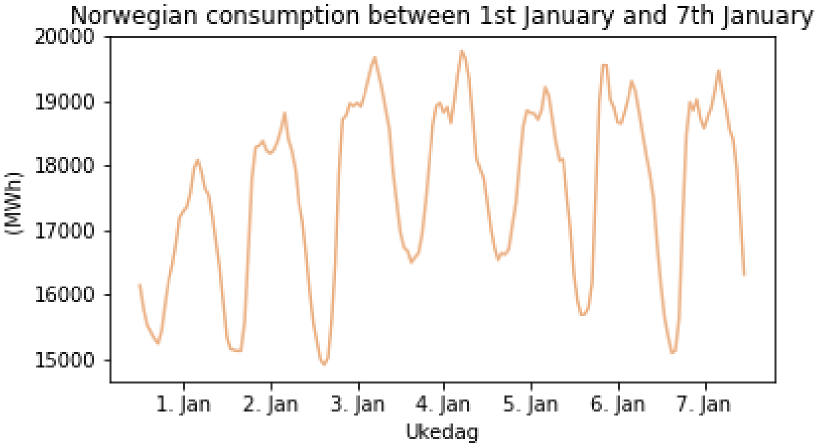


Figure 3.1: Load in Norway first week of January data from [8]

Figure 3.1 presents daily load variation in the Norwegian grid. The fluctuation varies with temperature, but the same pattern is found during the summer months too. These fluctuations are challenging the grid. Whereas the TSO, Statnett, is responsible for balancing the Norwegian grid this as much a distribution challenge as transmission challenge. [59] points out that transmission grid capacity is available. When renovating the grid, upgrading components capacity is a relatively small cost compared to the renovation itself. Consequently, newer parts of the grid are capable to withstand increasing peaks. The remaining parts of the grid, distribution girds and older regional grids not yet upgraded, is however exposed. Distribution grids is likely to continue to be exposed due to the high cost of upgrading capacity in distribution grids.

The current response when approaching gird capacity is mainly to upgrade the grid. Even though the grid capacity is stressed a few hours a year. Flexibility solutions, as aggregators providing flexibility, is usually not considered. This is likely to change as the European Clean Energy Package is paving way for aggregators. The Nordic countries are cooperating to create common guidelines for aggregators operating in the Nordic countries[16], operating within national legislation[35].

Households has little incentives, apart from feeling responsible to act on global warming, to adjust is consumption with an energy-based tariff. Therefore, the INVADE project recommended Smartly to engage multi-tenant buildings, as their tariff is power based. However, adjusting the regulations, a similar opportunity may surface in the residential home market. Allowing this can potentially provide value to TSO and DSO. Given the minimum bid size it requires a certain size to provide a meaningful service to the BRP. An aggregator could provide this service acting on behalf of multiple consumers, or communities, alleviating the grid by providing flexibility.

Today, local energy trading is not an option, due to regulation consumers with DG has to sell excess energy to their DSO. Aggregators is yet to be introduced in the Norwegian market. This is a regulatory concern, and local trade has the potential to emerge if authorized by regulating authority. To investigate the local energy trading this model simulate both P2P- and C2C-trading, as well as interacting with the external grid.

4

Modelling

Introducing P2P and C2C does require a smart home and requires a platform to be developed. Regulatory regimes, computation and communication infrastructure are challenges in a P2P trading system. There are multiple pilots being tested [64], providing promising results to overcome this obstacle. Based on whats mentioned in section 2 and section 3 some aspects appeared, which is to be implemented in the model. The analyses previously preformed is done without tariffs related to local trading. This model aims to investigate how local trading tariffs influence energy flow.

4.1 Modelling approach

This model contains a full P2P market with three communities. It is a further development of the model created in the specialization project [61]. The model aims to investigate how a cooperating neighbourhood, located in Trøndelag, is utilizing different appliances throughout a year. This is done to examine how local trade tariffs effect the energy flow within the neighbourhood and how this reflect on grid import. A sensitivity analysis is preformed to highlight the impact of introducing the local trade tariff.

The neigbourhood has unique consumers and their needs are covered while the community aims to decrease the overall bill. This approach does not take into account that some prosumers may contribute more than other to the neighbourhood. This is mentioned by [20] and several approaches to divide the cost fairly is considered. As it is possible to fairly allocate the costs within the community this model will look into who the DSO's can cover their cost while maintaining a functional local market including P2P and C2C markets. At the same time a aggregators opportunities in this market will be investigated. This is possible due to the cooperation within the neigbourhood enabling the neighbourhood to act as a aggregator.

It is in this approach assumed that a community is covered by the same substation. P2P trades, trades happening within a community, are therefore within the low voltage(LV)-grid. The cost related to trading within a community is assumed to be low in correspondence with the assumed electrical losses. While the C2C trading are trades between households in different communities within the neighbourhood. C2C trading is in addition to the LV-grid also utilising the medium voltage(MV)-grid and the tariffs are accordingly adjusted.

Local energy tradings effect on network degradation realted to P2P trading is sparsely documented in the literature and its degradation cost is therefore assumed to be negligible in this model. PV is degraded to some extent, but its degradation is miniscule [21]. The battery degradation is according to section 2 the most influential component is this model.

A general approach is described in section 4.2. The modelling is done with and without the degradation cost of components. CASE I found in section 4.4 represents a locally trading neighbourhood. CASE II is the same neighbourhood, where component degradation is accounted for, this is found in section 4.5.

4.2 General model

Consumers are divided into different communities, where the substations location decide whom is in the same community. Prosumers, the consumers exporting energy, are also within these communities. For simplicity in the rest of this thesis, both consumers and prosumers will be addressed as consumers. In order to analyse the tariffs effect on the model, DG and load are the same parameters in both cases. The battery specifications are also equal both cases. This leaves import, export, P2P trading and C2C trading, and battery usage as model variables.

In the the specialization project the electrical losses decided the trade pattern, in this thesis the energy flow decisions are cost based. As mentioned in the specialization project various ways to allocate costs has been thoroughly discussed by [20]. Cost allocating among consumers are, as a simplification, not considered in this thesis. Flexible resources as refrigerators and water heaters neither considered.

P2P tariff is assumed to be half the C2C tariff, this is as mentioned earlier due to the assumption that P2P trading occurs in the LV-grid, while the C2C requires a transformer and usage of MV-grid as well.

This leaves the consumers with the following possible appliances:

- Battery
- PV
- Wind turbine

As all consumers has the ability to trade within their own community as well as with other communites.

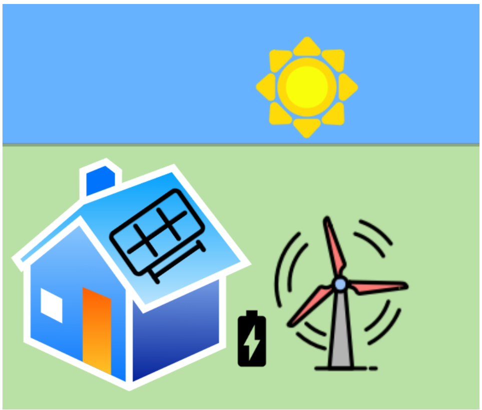


Figure 4.1: A consumer and possible appliances

Figure 4.1 depicts the consumers possible appliances.

The model simulated has three communities, which characteristics are:

Community 1:
8 consumers without DG and battery

Community 2:
4 consumers with PV (4kW and 25 deg tilt)
4 consumers with PV (7kW and 25 deg tilt)
Each consumer in this community has a battery installed.

Community 3:
1 consumer with wind turbine and battery
4 consumers with PV (4kW and 25 deg tilt) and battery
3 consumers no PV and battery

4.3 Constraints and equations

Equation 4.1 is presenting the neighbourhood import and export: (4.1).

$$n_t^{imp} - n_t^{exp} = \sum_p (p_{c,p,t}^{imp,grid} - p_{c,p,t}^{exp,grid}) \forall p, c, t \tag{4.1}$$

where the terms are,
$n_{c,p,t,i}^{imp}$, Neighbourhood, *n*, total import in time step t [kWh/h]
$n_{c,p,t,i}^{exp}$, Neighbourhood,*n*, total export in time step t [kWh/h]
$p_{c,p,t,i}^{imp}$, Consumer,*p*, import in time step t [kWh/h]
$p_{c,p,t,i}^{exp}$, Consumer,*p*, export in time step t [kWh/h]

Community trading is presented in equation 4.2:

$$0 = \sum_c \sum_d (p_{c,d,p,t}^{exp,c} - p_{d,c,p,t}^{imp,c}) \forall p, c, t, c \neq d \tag{4.2}$$

where the terms related to C2C-trading are,
$p_{c,d,p,t,i}^{exp,c}$, Consumer, *p*, exports from community, *c*, to community, *d* [kW]
$p_{c,d,p,t,i}^{imp,c}$, Consumer, *p*, imports from community, *d*, to community, *c* [kW]
$c_i^{C2C,tariff}$, C2C tariff cost in scenario, *i*

The consumer opportunity to trade from P2P is shown in equation 4.3

$$0 = \sum_q (p_{c,p,q,t}^{exp,p} - p_{c,q,p,t}^{imp,p}) \forall p, c, t, p \neq q \tag{4.3}$$

$p_{c,d,p,t,i}^{exp,p}$, Consumer, *p*, exports to consumer, *q* [kW]
$p_{c,d,p,t,i}^{imp,p}$, Consumer, *q*, import from consumer, *p* [kW]

$C_i^{P2P,tariff}$, P2P tariff cost in scenario, i

Within a community the consumers has the opportunity to trade energy from P2P with other consumers. p is unique as the combination of c and p identifies a single consumer.

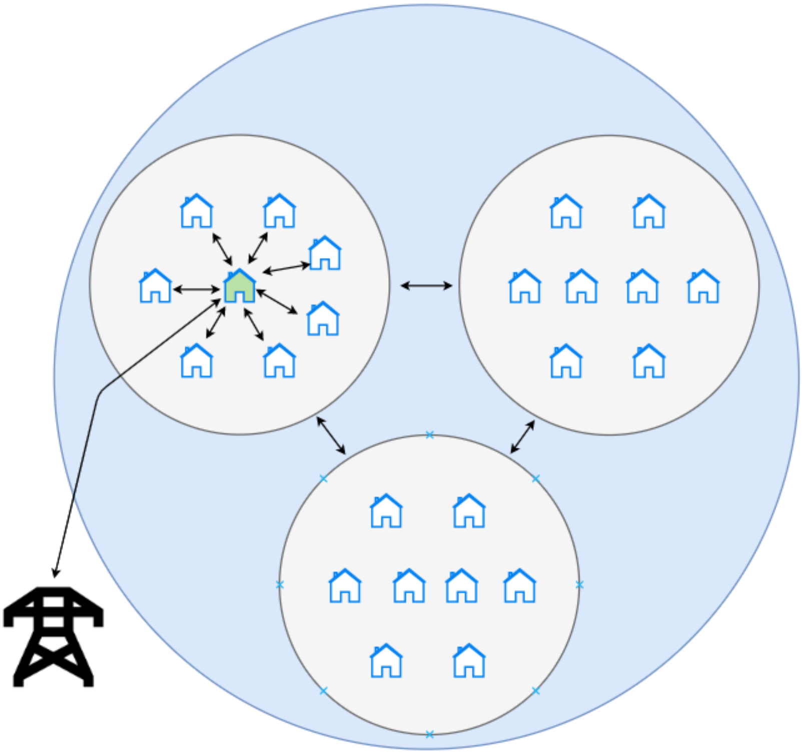


Figure 4.2: Visualization of the neighbourhood from a consumer point of view

Figure 4.2 is a visualization of one consumers energy trade options. Figure 4.2 illustrates the full model with C2C trades described in equation 4.2 and P2P trades described in equation 4.3. The neighbourhood is every consumer within the blue circle, while the different communities are within the grey circles.

Equation 4.4 presents the consumers total energy balance:

$$p^{imp,grid}_{c,p,t,i} - p^{exp,grid}_{c,p,t,i} = P^{load}_{c,p,t,i} + b^{ch}_{c,p,t,i} - b^{disch}_{c,p,t,i} - PV^{prod}_{c,p,t,i} - PW^{prod}_{c,p,t,i} + \\ \sum_{q}(p^{exp,p}_{c,p,q,t,i} - p^{imp,p}_{c,q,p,t,i}) + \sum_{p}\sum_{d}(p^{exp,c}_{c,d,p,t,i} - p^{imp,c}_{d,c,p,t,i}) \forall p, c, t, c \neq d, p \neq q \tag{4.4}$$

Subscript *c* is representing the community where the consumer,*p*, comes from and *t* is representing the time step. The terms in equation 4.4 are:
$p^{imp,grid}_{c,p,t,i}$, Consumer, *p*, import from grid [kWh/h]
$p^{exp,grid}_{c,p,t,i}$, Consumer, *p*, export to grid [kWh/h]
$P^{load}_{c,p,t,i}$, Consumer, *p*, load [kWh/h]
$b^{disch}_{c,p,t,i}$, Consumer, *p*, battery discharge power [kWh/h]
$b^{ch}_{c,p,t,i}$, Consumer, *p*, battery charge power [kWh/h]
$PV^{prod}_{c,p,t,i}$, Consumer, *p*, PV production [kW]
$PW^{prod}_{c,p,t,i}$, Consumer, *p*, Wind production [kW]
$p^{exp,c}_{c,d,p,t,i}$ and $p^{imp,c}_{d,c,p,t,i}$ are explained in equation 4.2
$p^{exp,p}_{c,p,q,t,i}$ and $p^{imp,p}_{c,q,p,t,i}$ are explained in equation 4.3

Battery equations are presented in equation 4.5- 4.9:

$$b^{disch}_{c,p,t,i}/\eta^{bat,disch} + b^{soc}_{c,p,t+1,i} = b^{soc}_{c,p,t,i} + b^{ch}_{c,p,t,i} \cdot \eta^{bat,ch} \tag{4.5}$$

In the initial time step t=0, $b^{soc}_{c,p,t,i}$ is = $B^{soc,init}$ =0. The initial state of charge is equal to the final state of charge in the model 4.6.

$$B^{soc,initial}_{c,p,t,i} = B^{soc,final} \tag{4.6}$$

$$b^{ch}_{c,p,t,i} < B^{ch,max} \tag{4.7}$$

$$b^{disch}_{c,p,t,i} \leq B^{disch,max} \tag{4.8}$$

$$B^{soc,min} < b^{soc}_{c,p,t,i} < B^{cap} \tag{4.9}$$

The terms in equation 4.5 - 4.9 are:
B^{cap} , The useable battery capacity[kWh]
$B^{ch,max}$, Maximum battery charging power [kW]
$B^{disch,max}$, Maximum battery discharging power [kW]
$B^{soc,init}$, Initial battery state of charge in time step ,*t*, =0 [kWh]
$B^{soc,min}$, Minimum battery state of charge [kWh]
$B^{soc,final}$, Battery state of charge in last time step, *t*[kWh]

B^{cost}, cost of utilizing a kWh
$b^{ch}_{c,p,t,i}$, Battery charge power for a consumer ,*p*, in time step, *t* [kW]
$b^{disch}_{c,p,t,i}$, Battery discharge power for a consumer ,*p*, in time step, *t* [kW]
$b^{soc}_{c,p,t,i}$, Battery state of charge [kWh]

Cost related to the different appliances is presented in equation 4.10-4.14

$$c^{imp,grid} = p^{imp,grid}_{c,p,t,i} \cdot (C^{tariff} + C^{spot}_t) \tag{4.10}$$

$$c^{exp,grid} = p^{exp,grid}_{c,p,t,i} \cdot C^{spot}_t \tag{4.11}$$

$$c^{battery} = B^{cost} \cdot b^{disch}_{c,p,t,i} \tag{4.12}$$

$$c^{P2P} = C^{P2P,tariff}_i \cdot p^{exp,p}_{c,d,p,t,i} \tag{4.13}$$

$$c^{C2C} = C^{C2C,tariff}_i \cdot p^{exp,c}_{c,d,p,t,i} \tag{4.14}$$

Where the terms are:
C^{spot}_t, hourly spot price, [kr/kWh]
C^{tariff}, electricity tariff , [kr/kWh]
B^{cost}, the cost of battery utilization,[kr/kWh]
$C^{P2P,tariff}_i$, tariff on P2P-trade, [kr/kWh]
$C^{C2C,tariff}_i$, tariff on C2C-trade, [kr/kWh]

$c^{imp,grid}$, $c^{battery}$, c^{P2P} and c^{C2C} is the neighbourhoods expenses, while $c^{exp,grid}$ is income. The index *i* represents the combination of case and scenario. There is a fixed cost and a tax related to the electricity bill:
C^{fixed}, yearly payment, [kr]
C^{tax}, taxation of electricity, [%]

$$e = (c^{imp,grid} + c^{C2C} + c^{P2P} + C^{fixed}) \cdot (1 + C^{tax}) + c^{battery} - c^{exp,grid} \tag{4.15}$$

The model's main objective is to minimize the neighbourhoods expenses, *e*, when optimizing a whole year.

Objective	**Sense**
Electricity bill of the neighbourhood	Minimize

Table 4.1: Table with objective

Solver: Gurobi

Optimization is done with Gurobi. Gurobi provides solver options to MIP models. MIP problems can be expensive to solve. Which was the case in this study, memory issues when expanding the problem restricted the neighbourhood to 3 communities with 8 consumers. However a parallel barrier algorithm solved the continuous problem.

4.3.1 Data

This section is a rewriting of the specialization project. All data gathered is hourly and any other representation of the data is added up. The models prices are Elspot prices from 2012 in Trondheim. Norwegian household tariffs and tax is additional costs and therefore the total electricity bill consists of spot price, tariff and tax. The tariff used is 0,29 NOK/kWh and the tax is 25%.

Load

The load data is from 2012. The data collected contains a number of different households consumption during the year. Only data from single family houses are used in this model. The data is collected from Steinkjer in Norway.

Battery

Multiple providers offers home batteries in the current market. Home batteries is cost and capacity dependant ranging from 2.4 kWh to modules of 100+ kWh [1]. Home batteries are usually compatible with PV, and packages including solar panels and home batteries is not uncommon. The battery size depends on the prosumer preferences and intentions. As the battery round trip efficiencies are very similar. In this thesis n Tesla Power wall 2 is chosen, as it is well tested, widely used and available for delivery in Norway [50, 40]. The battery Tesla Power wall 2 battery parameters important for this thesis is listed in table 4.2, with spesifications from Tesla [50]
$\eta^{bat,ch} = \eta^{bat,disch} \approx 95$ % is approximated utilizing η^{tot} found in table 4.2

Parameter	Character	Value
Usable Energy	B^{cap}	13.5 [kWh]
Real Power, max continuous	$B^{ch,max} = B^{disch,max}$	5 [kW]
Round Trip Efficiency	$\eta^{bat,tot}$	90 [%]
Initial state of charge	$B^{soc,init}$	0 [kWh]
Minimum state of charge	$B^{soc,min}$	0 [kWh]

Table 4.2: Paramters from Tesla Power wall 2

PV

In table 4.3 the parameters used to generate PV data is listed. MERRA-2 contains solar radiation data collected from satellite data. Energy production is calculated based on data from MERRA-2 [52] and the parameters from table 4.3.

Parameter	Value
Capacity	4 and 7 [kW]
System loss	10%
Tilt angle	25°
Azimuth angle	180°

Table 4.3: Key data for PV generation

The most common tilt on a Norwegian single family home is 25 ° [56]. A simplification is made as all houses is assumed to have this tilt. It is also assumed that all houses are facing south to maximize the potential of installed PV panels, due to a location on the northern hemisphere. The installed PV capacity is divided into 4 kW and 7kW installed capacity. This is due to the assumption of different house sizes. A loss of 10% is accounted for when calculating PV production.

Wind

Wind data is, as PV data, generated based on data from MERRA-2 [52]. MERRA-2 contains global wind data. The data extracted is from Steinkjer in Norway corresponding to load and PV data. The data is calculated by utilizing the parameters as mentioned is table 4.4, the production is found from [60].

A Vestas 225 kW wind turbine data is scaled down to 20 kW wind turbine [70]. This is to approximate what a local producer is has installed.

Parameter	**Value**
Capacity	20 [kW]
Hub height	20 [m]
Turbine data	Vestas V27 225

Table 4.4: Key data for wind generation

The datasheet from a Vestas V27 225 is utilized as residential sized wind turbines data sheets only provided partial or incomplete datasheets. The parameters from table 4.4 is utilized with the weather data to calculate the wind production. Wind is chosen as it has provided promising results, especially in combination with PV [11].

To achieve energy balance, when available DG is not sufficient, the neighbourhood, n, is connected to the external grid. The grid connection also enables the community to export excess DG, when profitable for the neighbourhood. While a community in surplus of energy are able to trade with a community in deficit.

Current legislation allows consumers to sell energy to the grid, and allows the consumer to sell supplus energy to spot price. Trading to cover the load within the neighbourhood is therefore usually benefiting the neighbourhood.

4.4 Case I: Model without degradation cost

The tariff structure presented is chosen to correlate with the current tariff structure in the Norwegian electricity market for domestic households. Therefore the P2P- and C2C-trading tariffs are energy based. Investigating expenses related to different voltage levels lead to a separate P2P- and C2C-tariff. It is assumed an import demand equal to the preexisting and therefore equal grid exposure. The additional losses related to voltage transformation and line losses is consequently reflected in the tariff structure[36].

All parameters previously mentioned are kept constant. This is done to investigate the effect of introducing a tariff and local energy transactions. In this case the model is ran with 10 different scenarios with increasing P2P and C2C tariffs. CASE I is ran without degradation costs in mind. The tariff structure is as shown in table 4.5

Scenario:	P2P tariff	C2C tariff	unit
1	0,015	0,03	[kr/kWh]
2	0,030	0,06	[kr/kWh]
3	0,045	0,09	[kr/kWh]
4	0,060	0,12	[kr/kWh]
5	0,075	0,15	[kr/kWh]
6	0,090	0,18	[kr/kWh]
7	0,105	0,21	[kr/kWh]
8	0,120	0,24	[kr/kWh]
9	0,135	0,27	[kr/kWh]
10	0,150	0,30	[kr/kWh]

Table 4.5: P2P and C2C tariff structure

4.5 Case II: Model with degradation cost

Battery,load, spot prices, PV & Wind turbine parameters are kept constant from Case I to Case II. In Case II the model is ran with 10 different scenarios, as Case I, with increasing P2P and C2C tariffs. The tariff structure in table 4.5 is presenting the tariff structure. CASE II is ran with degradation costs. This model does not consider the degradation of the PV-panels due to the longevity of the panels as reviewed in section 2.3. According to literature 2.3, distribution network component degradation is negligible in this model's context, due to its longevity. The most significant degradation happens to the battery, as mentioned in section 2.3. Degradation of lithium ion batteries is non-linear [71] and effected by number of cycles, depth of discharge, temperature, elapsed time and state of charge. However, this model uses a fixed cost per kWh to price battery degradation based on estimated average usage of the aforementioned factors, to reduce model complexity. This effect of adding a cost to degradation is analysed in section 5.2.

The battery warranty is 10 years, and is limited to 37.8 MWh when the battery is used to trade energy [66]. This is a considerable cost, 1.98 kr/kWh when assuming 1 USD= 10 NOK, which is more than eight times the average spotprice in Norway. As the research still is insufficient the degradation cost is still a uncertain estimate. However with the continued cost decrease and technological improvement the cost is expected to decrease. This model is assuming a battery operated efficiently , and utilizing the cycle depth concept and therefore decreasing the battery expenses [19]. The battery discharge cost is used as a parameter estimated to be 0.22 kr/kWh.

5

Results

This chapter presents the modelling results with visualizations of the results. The neighborhoods battery utilization, P2P trading, C2C trading, export and the average grid import is presented. This is presented to gain insight to the neighbourhoods energy flow and to see how appliances influenced bye cost constraints operate. The trade volume is presented to visualize the different scenarios influence on trade volume, while the demand curves is presented to illustrate the neighbourhoods influence on the external grid. This is presented with an aggregators market opportunities in mind, to investigate if this scenario enables an aggreagators presence.

The two cases are presented in section 5.1 & 5.2. A comparison of the results is showcased in section 5.3. The model is ran with increasing tariffs for P2P and C2C trading as presented in table 4.5. All data is simulated on an hourly time interval. The output data is thoroughly prepared to present differences and impacts of the different cases and scenarios. The different plots showcase behavior based on tariff structure. However it is important to note that, when analysing the plots, the interactions are interdependent.

5.1 Case I: Model without degradation cost

Figure 5.1 presents the Neighbourhoods weekly battery discharge. The battery discharge is chosen to visualize battery usage within the neighbourhood. In this case the battery usage increases as the tariffs increase. The peak discharge is more or less consistent independent of the scenarios. As expected a major part of the battery usage is during the summer. There is a higher battery usage during autumn and winter with low P2P and C2C tariffs. The opposite happens during spring and summer. The trend is found in both communities with DG production.

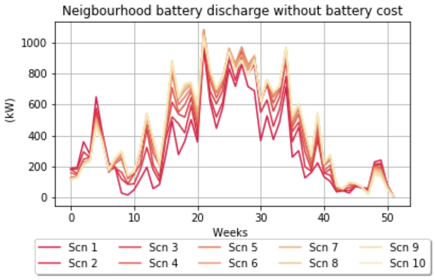


Figure 5.1: Weekly battery utilzation

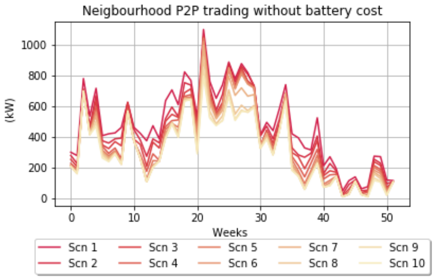


Figure 5.2: Weekly P2P trading

Figure 5.2 illustrates the aggregated volume of P2P trading in the neigbourhood. The P2P trades are trades within a community happening at the same LV grid. The P2P trading pattern with increasing tariffs visualises a decrease in P2P trades. The peaks are concurrent in all scenarios. There is a decrease in P2P trading as the tariffs increase. Comparing scenario 1 and 10 there is a 35% trade decrease in Case I.

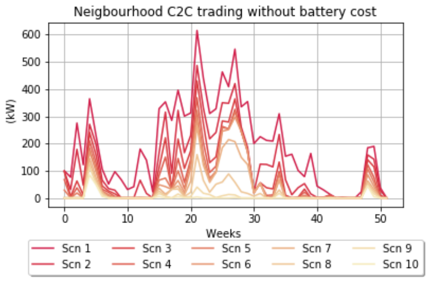


Figure 5.3: Weekly C2C trading

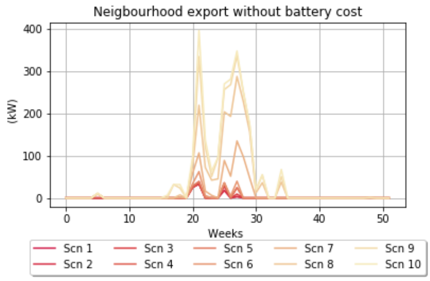


Figure 5.4: Weekly export

Figure 5.3 presents the C2C trading in the neighbourhood. As the P2P trading the C2C trading decrease as the local trade tariffs increase. The effect of a C2C tariff twice as big as the P2P tariff seems to restrict the C2C quite substantially. This should be seen in context with figure 5.4 where grid export is shown. Comparing scenario 1 and 10 only 2% of the trades is still present with increased tariffs. This applies to both trade volume and number of trades.

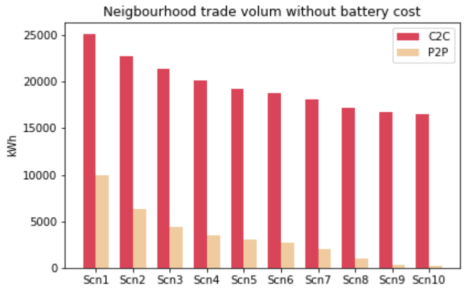


Figure 5.5: Total trade through the year with varying tariffs

Figure 5.5 showcases the total P2P and C2C trade volume. As expected both C2C and P2P trading fades as a higher fee is introduced. While the P2P trading remains at volume above 16 000kWh, the C2C almost vanishes with the highest tariffs.

Whereas the C2C trading decreases, the export has a dramatic increase From almost not exporting anything at all in the first scenarios, the tariff increase triggers export instead of C2C trading after a certain threshold. A high DG during the summer combined with lower consumption enables export to the grid.

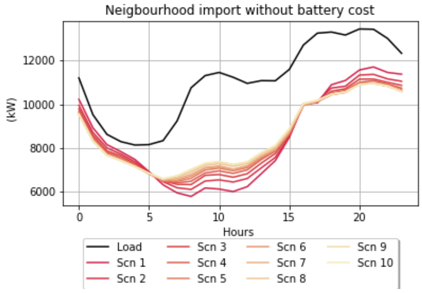


Figure 5.6: Avg hourly imp with varying tariffs

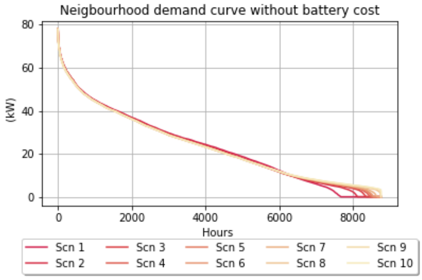


Figure 5.7: Demandcurve with varying tariffs

By analysing all households consumption throughout the year the average daily load pattern is found, this is represented as the black line in figure 5.6. The colored lines in figure 5.6 presents the different scenario's import. In the same way the neighbourhoods load is found, the different scenario's import is found by analysing the hourly load of each household through the whole year. The peaks are less significant when the tariff is increasing. The lower tariffs especially decrease the import during day time, while the late afternoon peak is more aligned with the load. Especially the 1st and 2nd scenario is resulting in a greater variation between maximum and minimum grid import.

Figure 5.7 illustrates the demand curves in each of the scenario. There appears to be a difference in the import. The consumers has equal load and DG production in each scenario. The reason the import changes is the increased cost of P2P and C2C trading, resulting in increased export from the neighbourhood.

5.2 Case II: Model with degradation cost

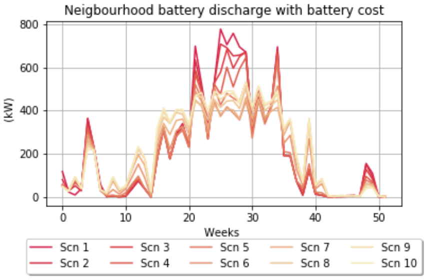


Figure 5.8: Weekly battery usage

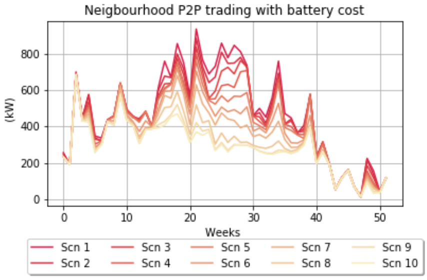


Figure 5.9: Weekly P2P trading

Figure 5.8 presents the Neighbourhood's weekly battery discharge. The battery usage decreases when comparing the major peaks during summer as the tariffs increase. During the winter a similar pattern can be observed as higher tariffs results in less battery usage. The battery utilization peaks during spring and autumn is increasing with increasing tariffs. Overall the battery discharge is decreasing linearly from scenario 1 to scenario 5, where the Case II minimum appears. From scenario 5 the discharge output is increase until it reaches a global maximum in scenario 10.

Figure 5.9 is the neighbourhood's P2P trade volume during a year. The P2P trade is typically similar during late autumn, winter and early spring in all scenarios. During the summer a decrease in trades is seen when the tariffs increases. The peaks during the summer is substantially reduced. Peaks occurring apart from the summer remains, with increasing tariffs. The overall trade volume decreases in Case II as a result of rising tariffs. Comparing the trade volume(kWh) from scenario 1 and 10 in Case II reveals a 38,5% decrease in P2P trading. The trend is similar in each community with DG production.

C2C trading on weekly basis is presented in figure 5.10. The results is concurring with a energybased tariff. There is a steady decrease in C2C trade volume. The C2C-trading almost eradicated in scenario 10. The decline is obvious and the reducing in C2C trading is 97% comparing scenario 1 and 10.

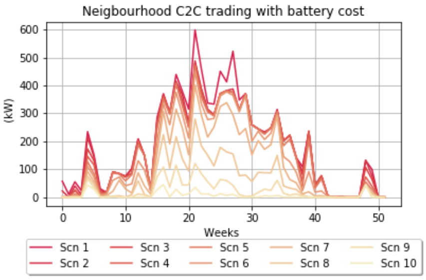


Figure 5.10: Weekly C2C trading

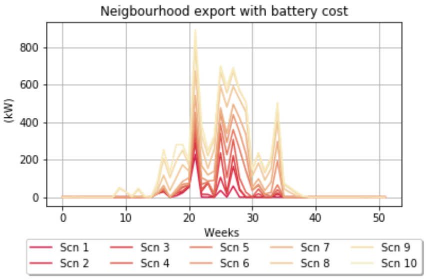


Figure 5.11: Weekly export

It is an increasing export as the tariffs increase, as seen in figure 5.11. The increase is seen from spring till autumn. The export peaks remains in the same time periods, but rises with higher tariffs. Export also appears in new areas with the highest tariffs.

Figure 5.12 shows the total P2P and C2C trade volume. P2P trading is still present in all scenarios with at least 15.000 kWh. C2C trading is evidently influenced as the trading almost disappears in the scenarios with highest tariffs. The C2C trading is steadily declining from scenario 1 to 6. A threshold is found between scenario 6 and 8 in the C2C-trading. After scenario 6 a rapid decline appears in the trade volume. P2P-trading has a linear decline but, as C2C trading, has it’s biggest decline from scenario 7 to scenario 8.

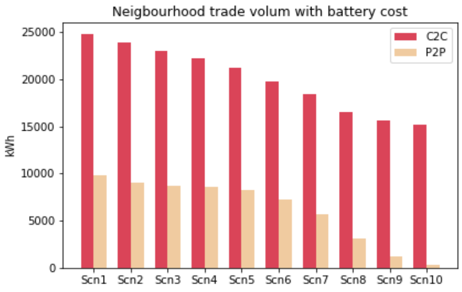


Figure 5.12: Total LEM trade

Figure 5.13 illustrates Case II’s demand curves in each of the scenarios. The demand curve is based on grid import. As in CASE I the reason the import changes is the increased cost of P2P and C2C trading, leading to a export rise in the neighbourhood. The rising tariffs has minimal impact on demand curves.

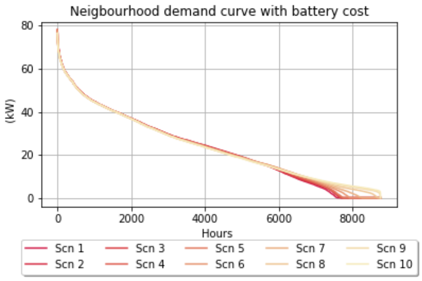


Figure 5.13: Demandcurve

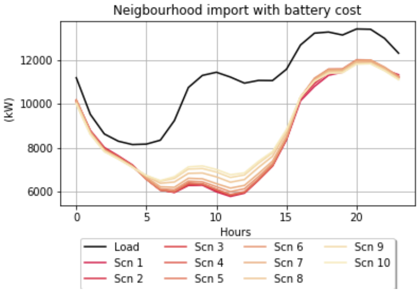


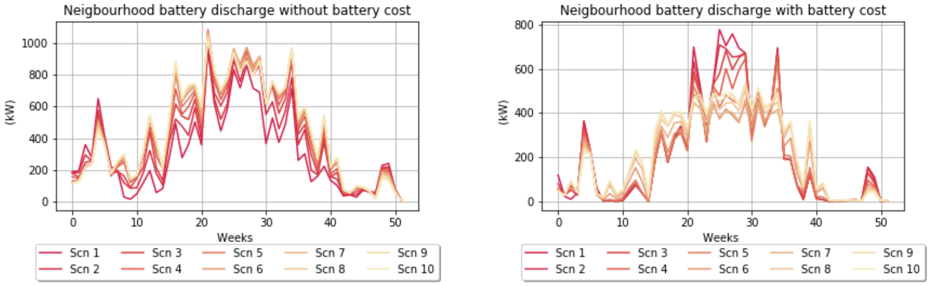
Figure 5.14: Avg hourly imp with varying tariffs

Figure 5.14 shows that with the neighbourhood is able to slightly shift the morning peak import, as the peak now appears earlier. A more distinct morning peak appears looking at scenarios with higher tariffs. The first peak in the afternoon is slightly reduced as well. The first afternoon peak is highest in scenario 6 decreasing toward both scenario 1 and scenario 10 .

5.3 Comparison

This sections contains results previously presented, plots from Case I and Case II is presented together to simplify comparison.

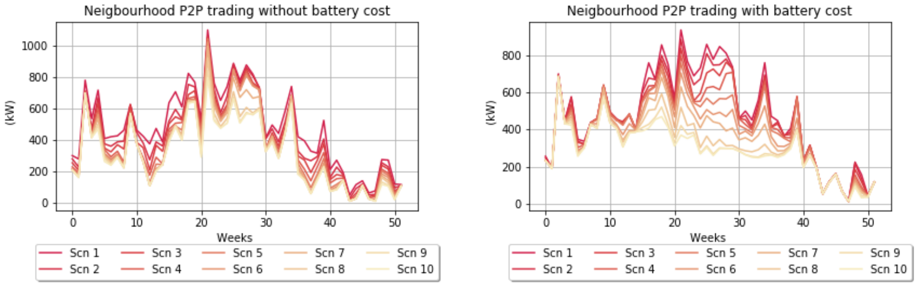
Less able to avoid the afternoon peak when taking into account the battery degradation cost when comparing figure 5.20b and figure 5.20a. This is an effect of considering degradation.



(a) Case I: Weekly battery usage with varying tariffs **(b)** Case II: Weekly battery usage with varying tariffs

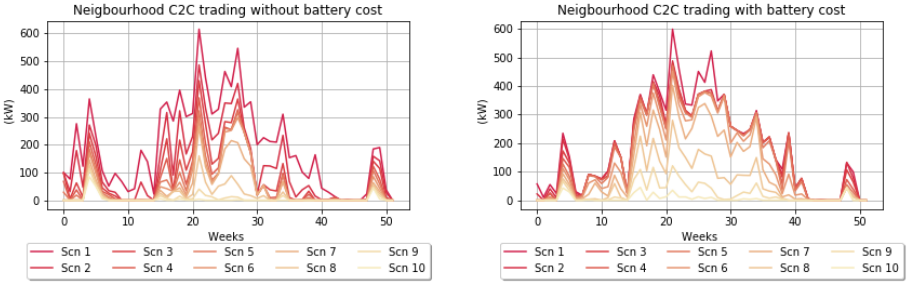
Figure 5.15: Battery usage comparison

Figure 5.15 is illustrating the battery utilization. Introducing a battery cost decreases usage as seen in figure 5.15b compared to figure 5.15a. The overall usage decreases with at least 30 % in all cases when comparing scenarios from the two cases. The impact of a cost is most pressing in scenario 5 and scenario 6 with a 57% reduction. The utilization of the battery occur concurrent in both Case I and Case II.



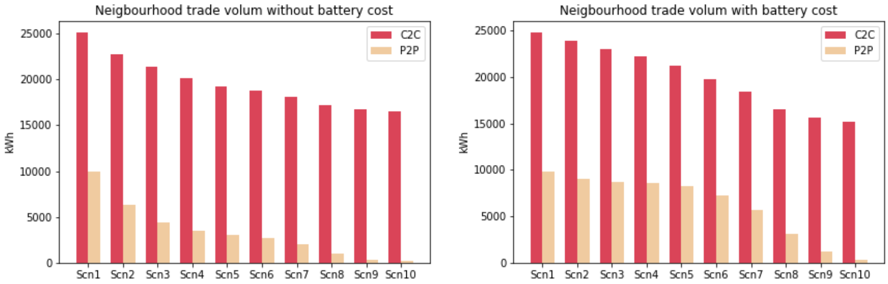
(a) Case I: Weekly P2P trading with varying tariffs **(b)** Case II: Weekly P2P trading with varying tariffs

Figure 5.16: P2P trading comparison



(a) Case I: Weekly C2C trading with varying tariffs **(b)** Case II: Weekly C2C trading with varying tariffs

Figure 5.17: C2C trading comparison



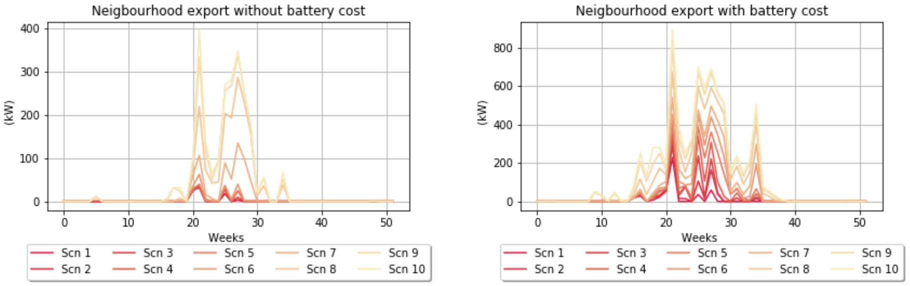
(a) Case I: Total yearly trade with varying tariffs **(b)** Case II: Total yearly trade with varying tariffs

Figure 5.18: Trade volume comparison

The peaks during the summer are reduced in 5.16b compared to figure 5.16a. The total trade volume in Case I is on average 6% higher from scenario 2 to scenario 7 compared to Case II.

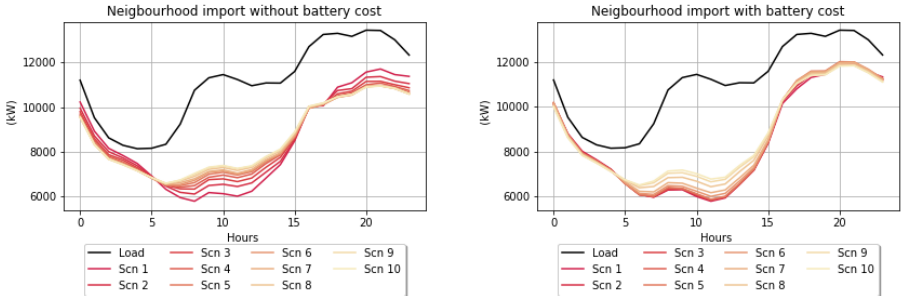
As the tariffs increase both case's C2C trading is reduced as illustrated in figure 5.17. The C2C trade volume's slope are however not similar. The trading in Case I is rapidly declining from scenario I, seen in figure 5.18. This differ from Case II which slowly decreases C2C trade volume until scenario 6, where the slope steepens. The total C2C trade reduction is respectively 98% in Case I and 97% in Case II.

Export from the neighbourhood to the grid is more common i Case II, as illustrated in 5.19. The export is on average 9 times higher when comparing the two cases' scenarios. In scenario 5 the unevenness is at its maximum, with 16 times more export in Case II than Case I. The peaks during the summer is concurrent in time for both cases.



(a) Weekly export with varying tariffs **(b)** Case II: Weekly export with varying tariffs

Figure 5.19: Grid export comparison



(a) Avg hourly imp with varying tariffs **(b)** Case II: Average hourly import

Figure 5.20: Hourly import pattern in the neighbourhood

The import demand curve comparison is not presented as the results are correspondingly in both cases. Nonetheless the consumption is altered when analysing an average day. The import demand comparison is presented in 5.20. Case I more able to reduce the afternoon peaks than Case II. Especially when comparing cases with high tariffs, as scenario 8-10. On the other hand the consumption during the morning peak is less reduced in Case I than Case II. In addition, Case I's scenarios has a smoother consumption through the morning, where as Case II fluctuates more in the same time period.

6

Discussion & Analysis

Firstly, the model results are discussed. Secondly, sources of errors is presented. Thereafter European directives is considered from a Norwegian LEM perspective. A discussion on who and how this influences current and expected market participants concludes this chapter.

6.1 Results

Battery utilization

Case I has regular battery usage throughout the year to take advantage of price fluctuations, this is illustrated in figure 5.15a. This is not seen in Case II, figure 5.15b, due to degradation costs. This leaves the neighbourhood with reduced flexibility and opportunities to reduce the overall bill.

Analysing figure 5.15a a fluctuation between winter and summer months was found. This is due to spot price variation. Regarding Case I, degradation is not accounted for and only the battery efficiency is relevant when optimizing resources. Secondly, high spot prices are an important factor. Combined with low P2P- and C2C-tariffs during the autumn and winter, it allows the neighbourhood's consumers to charge their batteries and make a profit of it when trading locally. The question becomes whether the battery is efficient enough to compete with the expense of P2P trading and/or take advantage of spot price variation. During the summer the spot price is low compared to the winter months. Looking at the scenarios with low P2P and C2C tariffs this is showcased as the neighbourhood reduces battery usage. Battery usage becomes less profitable and P2P trading of the available energy becomes the preferred option, as seen in figure 5.16a. The high P2P and C2C tariff scenarios has higher battery utilization during summer months. However, this is self-consumption as opposed to P2P trading in low tariff scenarios. Implying that storing energy to sell it locally is unprofitable .

Case 2 is with battery cost and battery usage is evidently less common. During the winter is the spot price fluctuation high enough to save money even with the cost of utilizing the battery. As the tariff increases the savings shrink and battery utilization decreases. The peaks during spring and autumn is caused by high penetration of DG. As tariffs increase, self-utilization and storage of DG becomes more economically viable, resulting in higher peaks in high tariff scenarios. During the summers is it a new situation as the spot price is low. The scenarios with lowest tariffs are able to make savings utilizing battery capacity in combination with P2P when it is a surplus of DG. However, as the tariffs increase this business opportunity fades away. The margins is substantially reduced and navigating the market becomes more difficult. Being able to save money requires a high level of cooperation and that the solutions are automate, this holds for both Case I and Case II. Automated solutions are mentioned by [22] as important to reduce consumption. This holds for demand response too, however demand response is not investigated in this thesis.

P2P trading

In Case I P2P trading follows the same pattern in all scenarios and is only influenced by increased tariffs, obliviously reducing the P2P trading. Case II has similar results, apart from the summer months, where high tariffs reduces some of the trading peaks within the neighbourhood. This is on the other hand sold as export to the grid. The DSO benefits from a smooth out of grid import peaks, this is further discussed talking about demand curves.

C2C trading

C2C trading contributes, as P2P-trading, to smooth out the grid import demand. C2C trading contributes to a less extent than P2P trading. This is however only representing the economic market as electricity follows the laws of physics. The contribution to the DSO is therefore depending on DG and battery usage and not P2P and C2C trading alone.

The load increases during the winter and PV generation is heavily reduced. With small amounts of DG self-consumption is prioritized and the amount of trades is reduced. The simulations show that the market is miniscule in the winter months. This is potentially a challenge for an independent aggregator that no market supply is locally available.

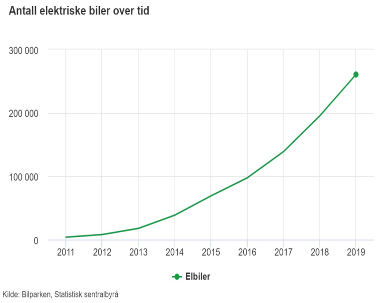
Peaks
Investigating figure 5.13 and figure 5.7 separately C2C and P2P does not contribute anything apart from DG alone. However, when investigating figure 5.20, the value of P2P trading is evident. Irrespectively of Case and Scenario introducing local energy trading contributes to peak alteration. As the tariffs increase in Case I & II the consumers becomes more invested in spending DG within the community, resulting in a more even import curve during the average day and reduced peaks. The morning peak load is shifted compared to the peak import. This is also happening in the afternoon but to less extent. The current tariffs structure does not allow any significant savings or earnings during the peak hours. The result is likely to be further improved with a power-based tariff, especially with respect to reduced peaks. A tariffs restructuring could send price signals more aligned with grid impact. This could potentially boost independent aggregators market opportunity and incentivise local energy trading.

Apart from the battery installed there are no other source of flexibility in the model investigated. Therefore, including demand response could further contribute to smoothing the grid import demand and contribute to counteract yearly peaks. Flexible loads combined with suitable P2P and C2C tariffs, is according to these results providing value to the DSO as daily peaks are reduced and load shifted.

When tariffs in Case II increases above the battery discharge cost the opportunities to benefit from an installed battery increase. While a tariff higher than the spot price allows the neighbourhood to export excess energy. However this is a last option as imported energy has a tariff added to the spot price. By investigating the data, it is found that the neighbourhood exports when; very high spot prices or a lot of renewables available.

6.2 Sources of error and loss of accuracy

The **load data** available for this thesis is from 2012. This a significant source of error as a major transformation has happened in the fleet of cars. It is 32.5 times more EVs in Norway in 2019 [10] compared to the EV fleet from 2012. The EV fleet is influencing both load and available flexibility. The influence on load pattern is uncertain, however as load fluctuations is expected to increase [12], and the EV fleet is expected to grow it contributes to this development [65].


Antall elektriske biler over tid

Kilde: Bilparken, Statistisk sentralbyrå

Figure 6.1: Amount of electric vehicles in Norway [10]

Degradation cost

Research show that the PV, and overhead lines lifetime outlasts the lifetime expectancy. The prosumers can keep the PV-panels for a longer time period with little influence on production. This was considered an acceptable component degradation and not included. As a result, the only degradation cost accounted for is the battery cost. Accounting for other appliances would increase the neighbourhoods' cost.

Other aspects influencing the results are efficiency, DG penetration, tariff structure and neighbourhood composition. **Efficiencies** are continuously developing as research provides technical improvements, which influence the profitability and opportunities of different appliances. This is especially important when optimizing the battery utilization due to the degradation cost related to usage. The **tariff structure** chosen is aligned with the current tariff structure for domestic households. It is a energy based tariff, and offers no incentive to reschedule load to avoid peaks periods. This represent the current environment, but if the proposed power tariffs are introduced this could potentially alter the results. The composition of the communities within the **neighbourhood**, as well as composition of consumers is also related to uncertainty. Resulting in communities with unique abilities to investigate the effect in the LEM. The fact that all consumer load in the neighbourhood is single family homes is not representative of an average Norwegian neighbourhood. However, to create a market it was necessary with high **DG penetration**. The DG penetration was considered and a moderate approach, compared to other studies, was chosen. Nevertheless, the DG penetration is, considering the current DG spread, unrealistically high.

6.3 European perspective

The Clean Energy for All Europeans package provides multiple directives and legislation to promote locally produced renewables[2]. To maximize the DG value it should be consumed locally. To achieve local production and consumption a LEM with a consumer-centric approach is required. However, the LEM implementation depends on multiple factors as transparency, simplicity and cost-reflectivity. There is no tariff model that fits all countries as each country has unique characteristics. RME, as a part of NordREG, Council of European Energy Regulators (CEER) and Agency for the Cooperation of European Energy Regulators (ACER), is responsible for developing good power market solutions. Thus RME strives to facilitate the introduction of European directives to the Norwegian market.

France has already embraced a consumer centric approach and aggregators operating on behalf of multiple consumers are participation in the electricity market. In Frandce the aggregators faces difficulties participating in the market, a modest 313 MWh was sold at wholesale electricity market in 2014[29]. The capacity market opened in 2017 providing independent aggregators with new opportunities.

6.3.1 Norwegian case

The model investigated in this thesis provides promising results during the summer with high trade numbers. Promising results is provided in other publications, as [23] whom has a high penetration of PV and wind compared to current situation in Norway. Studies tends to rely on a high percentage of consumers with DG. This is far from the Norwegian case, with only 0.1 TWh stipulated PV production and wind seldom installed locally

[6]. Indicating that independent aggregators and P2P trading will be of little influence to the established market.

The local energy trading and consumer centric approach is a result of European legislation and technological development. The socio-economic value of local trading comes from reducing grid stress. In Norway peak loads is most efficiently reduced by insulating houses, not by local energy trading due to the uncorrelated DG and peak load. This is related to the climatic conditions in Norway. Without any price incentives, local energy trading in Norway is offering little regarding yearly peak to DSO's. The results show that the current tariff structure results in local trading from spring until autumn. There are multiple papers showcasing local energy trading opportunities, however the climatic variation diminishes the opportunities in Norway. However, from a consumer perspective it could be argued that P2P market and aggregation increases the competitiveness in the market. A competitive market provides the consumer with more options.

Norway has a unique feature with the high amount of hydro power, allowing quick regulation of supply. Combined with the cost-efficient production this might have halted the energy transition in Norway, as clean and cheap energy has been available. Despite the high percentage of renewable energy production DG is scattered. However, the introduction of DG is according to the model creating fluctuations not yet seen in Norwegian distribution grids. This creates an opportunity for independent aggregators P2P trading in Norway as local balancing is expected to become increasingly important [4].

Electrical heating requires grid reinforcements in many areas [7], an alternative, to some extent, is to trade flexibility. However, Norway is in a unique position as it is common to utilize electricity when heating buildings. [7] mentions four principles an aggregator has to present that is important from a consumer point of view. The first one is to have a compelling story to tell. This is a challenge in Norway as the grid already covers the heating.

To assess the value of local energy trading it is natural to investigate grid import peak. The model illustrates that contribution when the grid is most stressed is miniscule. The P2P & C2C trading's contribution is small compared to the effort required establish a market analysing the current market.

To put it into perspective the clean energy package is meant to facilitate the future energy transition. The day ahead market opportunities seems limited. However, the future DG spread, new power markets and uncertainty related to tariffs are major unknown variables. Currently, actions as demand response and/or thermal insulation are more of public utility than P2P trading. This may change as increased of DG is expected, carrying increased price volatility and therefore increases flexibility's market opportunities [28].

6.4 Influence on market participants

Considering only the day ahead spot prices an aggregator will find it difficult to enter the market. Allowing an independent aggregator to offer flexibility services to BRP is not investigated as this market requires a considered amount of accessible power provided. This is in accordance with development in Europe. Aggregators are at a later stage involved in balancing markets. Balancing is an area that [7] mentions could be covered by aggregators.

TSO & DSO

The **TSO** responsibilities and assignments regarding LEM remains the same [16]. The TSO is expected to cooperate farther with DSO's in order to maintain frequency and voltage control. The **DSO** however, is affected by the energy transition introducing a LEM may influence grid stress A market framework is required as high level of PV and uncoordinated P2P trade may cause overvoltage. With responsive consumers voltage and frequency control can be provided through a LEM, but this is not compensated with the current tariff structure [26]. [57] mentions that grid investments may reduce if batteries are introduced in the distribution grid. The Australian study, with 7kWh battery and 5 kW PV, shows less than 15% grid reliance [57]. While this model shows that DG generation with 8 kW PV and 13.5kWh battery covers maximum 75 % of the load requirement. Apart from the increased grid reliance, this thesis finds it difficult to reduce yearly peaks irrespectively of case and scenario due to the uncorrelated load peaks and DG production. Nevertheless, a local market may reduce yearly peaks if demand response is introduced. This thesis finds it difficult to see local trading relieving grid stress, but recognises that demand response is not considered.

Balancing Responsible Parities

The influence on BRP is depending on which aggregator models being implemented by NordREG. The clean energy package requires a framework for independent aggregators. However, according to numbers related to flexibility and DG is indicating little immediate influence to the BRP[6]. This is expected to change with the increased price volatility[15]. Increased volatility remunerative new and existing flexibility.

Consumer

According to multiple reports [53, 59], the electricity consumption and grid investments are expected to be substantial. Consequently, the tariffs increase. However, there is available capacity during none peak hours. Iron out the usage pattern and tariffs decrease, due to reduced investments required. It is often mentioned, but measures are commonly advises to consumers. While adjustments could be done by consumers, this is a business opportunity for aggregators. Aggregators can be an intermediate acting on behalf of the consumers while the consumers compensated for flexibility or generation. This increases the consumer market influence by disclosing additional markets.

Irrespectively of a consumer acting on with self-interest or through an aggregator is the automation key. Automatic controlling contributes to convenience, as consumers do not want to spend or effort implementing flexibility[7]. It has the potential to simplify the user experience and saves energy. This is supported by this study [22] showing that demand response for households only succeeds with automated services or when centrally controlled.

Aggregator

This model looks into day ahead market and how the market evolves with increasing tariffs. An aggregator acting on behalf of the neighbourhood could potentially participate in balancing markets and become a more viable market solution. The aggregator could potentially fulfill multiple roles as mentioned in section 3.1.5.

In 2013 France become the first country in Europe to open the wholesale and ancillary market services to aggregators and demand response. France was in 2016 one of 3 countries engaging residential consumers in the mentioned markets. The trading service has been limited as most of aggregators and consumers revenues is paid to the retailer. In 2015 the market only generated €1.783 for aggregators.

However, by opening the market to independent aggregation allows a crafty market-driven management of the power system. This render possible innovations from other sectors, potentially influencing all market participants. The challenge is to simultaneously maintain the advantages of the current power market. A step by step implementation of aggregators to monitor and investigate market influence is desirable. This indicates a gradual introduction of aggregators.

7

Conclusion

The model is capable of presenting how energy based tariffs influences the local trading. The neighbourhoods sensitivity to costs on local energy trades contributes to investigate market opportunities. Regarding market opportunities the demand curve shows there are no difference in peak import with altering tariffs. Higher tariffs are obviously reducing the P2P and C2C trading volume. Local energy trading contributes to reduce peaks, preformed by a combination of smoothen out the load to shifting it, as seen in figure 5.20.

The modelling shows that an aggregator have very limited market opportunities in the day ahead market with the suggested tariff structure. Aggregators is left with miniscule DG contributions when the yearly peak load occurs. Consequently, the aggreagator is dependant on battery capacity to contribute in the most demanding periods. From case II it is highlighted how the battery degradation cost limits aggregators scope of action. It should be noted that demand response is an additional aggregator feature but not considered in this thesis.

Potential markets for aggreagator in Norway will face though opposition from the current suppliers. The Norwegian energy production is very responsive due to the high amount of hydro power this restrain the aggregators opportunities. Pointing out which market segment an aggregator could operate in is difficult and requires further research. Nevertheless, the influence on other market participants when introducing aggregators as a market participant is for the time minor.

8

Further work

This thesis investigated the influence of a tariff structure like the existing one in a neighbourhood with battery flexibility and DG. There are multiple alternatives to extend this work.

Investigate how the EV increase, mentioned i sources of error, effect the load pattern is one option. EV's effect load and flexibility through their storage capacity. It would be interesting to analyse how the EV flexibility influence the energy flow in the neighbourhood and the grid interaction.

This model creates a reference and enables new research to compare results with the current tariff structure. Exploring how different tariffs may effect the local energy trade could. A power based tariff is proposed by NVE. There are several ways to implement a power based tariff, investigating which power based tariff that relives the grid most or maximizes community savings are two options.

Another possible extension is demand response, by introducing automated flexibility as refrigerators and water heaters. Thereafter allow the consumer or the community to define acceptable demand response.

Given the quick response from aggregator controlled appliances balancing markets is a market opportunity to investigate. The aggregators ability to impact voltage and frequency services could be provide services to the DSO. This implementation depends on the new DSO responsibilities.

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