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Consumer flexibility in the power market

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Renewable Energy

Acknowledgements

This master's thesis, completed in the spring of 2023, marks the end to my academic journey at NMBU. Combining the demands of a full-time job with master's studies has presented significant challenges, necessitating many late nights and weekends dedicated to reach my goal. Although it has required a lot, it has also been enlightening and exciting. Studying the future of power systems and renewable energy is something I find exciting, and especially consumer flexibility which I did not know much about before commencing my master's thesis.

I would like to thank my supervisor at NMBU, Muyiwa Samuel Adaramola, for advice and guidance through the process. I would also like to thank Matthias Hofmann and Kathinka Thilert in Statnett SF for involving me in Statnett's research projects about consumer flexibility.

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Abstract

Traditionally, power production has been adapted to power consumption, but in a time of increasing electrification, power deficits and rising power prices, it is important to conduct research and knowledge about methods to meet future power needs in a socio-economic way. To save costs and nature from the development of the power grid, consumer flexibility, where power consumption adapts to production, may be important in the future.

Using a quantitative survey to private electricity consumers, this task aims to investigate how private electricity consumers can contribute to a more flexible power market. To answer this, three research questions have been specified. The first research question examines the relationship between electricity prices and flexibility among respondents. The results show that there is a significant correlation between electricity prices and how willing respondents are to save electricity, and how much they pay attention to variations in electricity prices. The second research question examines how much knowledge respondents have about their own electricity consumption. The results show that many have knowledge about effective ways to save electricity, but there is a knowledge gap for the consumers in how much each of the measures amounts to on their electricity bills. Better knowledge about which measures provide the highest financial savings for consumers can contribute to increased motivation to reduce electricity consumption. The third research question concerns whether electric cars can contribute to a more flexible power market in the future. Owners of private electric cars can contribute to a more flexible power market, but this must be facilitated. Vehicle-to-grid is an upcoming technology which seems to be most promising if the consumer can take part in the flexibility market via a third-party aggregator.

Today, consumer flexibility is not a reliable source, but research and facilitation can make it important in the future. Knowledge and facilitation about costumer flexibility can save society considerable financial costs in the development of power and power grids.

Sammendrag

Tradisjonelt sett har kraftproduksjonen vært tilpasset kraftforbruket, men i en tid med økende elektrifisering, underskudd på kraft og økende kraftpriser er det viktig med forskning og kunnskap om metoder for å kunne møte fremtidens kraftbehov på en samfunnsøkonomisk måte. For å spare kostnader og natur fra utbygging av kraftnett, kan forbrukerfleksibilitet, der kraftforbrukene tilpasser seg produksjonen, bli viktig i fremtiden.

Ved hjelp av en kvantitativ spørreundersøkelse til private strømforbrukere har denne oppgaven som formål å undersøke hvordan private strømforbrukere kan bidra til et mer fleksibelt kraftmarked. For å besvare problemstillingen er det spesifisert tre forskningsspørsmål. Det første forskningsspørsmålet undersøker sammenhengen mellom strømpris og fleksibilitet hos respondentene. Resultatene viser at det er en signifikant sammenheng mellom strømpris og hvor villig respondentene er til å spare strøm, og hvor mye de følger med på variasjon i strømpris. Det andre forskningsspørsmålet undersøker hvor mye kunnskap respondentene har om eget strømforbruk. Resultatene viser at mange har kunnskap om hva som er effektive måter å spare strøm på, men at det er kunnskapshull i hvor mye hvert av tiltakene faktisk utgjør på strømregningen. Høyere kunnskap om hvilke tiltak som gir mest økonomisk gevinst for strømforbrukerne kan bidra til økt motivasjon for å redusere strømforbruket. Det tredje forskningsspørsmålet undersøker hvordan elektriske biler kan bidra til et mer fleksibelt kraftmarked i fremtiden. Vehicle-to-grid ser ut til å være mest aktuell i fremtiden, der elbiler bidrar i markedet via en tredjeparts aggregator.

I dag er ikke forbrukerfleksibilitet en pålitelig ressurs til fleksibilitet i kraftmarkedet, men forskning og tilrettelegging kan gjøre det viktig i fremtiden.

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List of acronyms

AMS – Advanced Measurement Systems

KW/KWh – Kilowatt/Kilowatt hour

MW/MWh – Megawatt/Megawatt hour

TW/TWh – Terawatt/Terawatt hour

V2G – Vehicle-to-grid

Introduction

The green shift is gaining momentum. Norway have committed to reduce greenhouse gas emissions by 50-55% by 2030 relative to levels recorded in 1990, in accordance with the Paris Agreement. By 2050, Norway has a statutory goal of becoming a low-emission society. To meet these ambitious climate goals, electrification of transport and industrial sectors are regarded as the most important measures (NEA, 2022).

Today, power consumption in Norway is about 140 TWh per year, with 34% going to industry and 29% to households. The rest of the consumption is distributed between agriculture, transport, and other services(Fiksen, 2022). Due to electrification of transport and industry and establishment of new power-intensive industry such as battery factories and data centres, Statnett SF and the regional grid companies are experiencing strong growth in requests for connection to the power grid. It is estimated that power consumption in Norway in 2050 will be around 200 TWh(Statnett, 2020).

To meet the consumption growth while maintaining competitive electricity prices there is a need for an increased power production, but the power grid in Norway is already limited and we will probably have a power deficit before new production arrives. New capacity for power production will mainly come from intermittent power such as wind, solar and run-off hydro, and more flexibility will be required to balance the power system(Statnett, 2020).

The energy crisis that started in Europe in 2021 has showed how important flexibility is in the power market. In the summer of 2021, gas prices in Europe began to rise due to Russia's limited gas exports and high energy demand due to increasing manufacturing activities after COVID-19 pandemic(Bjartnes, 2023). Relatively low average wind speed in some parts of Europe led to reduction in electricity production from wind power plants in affected areas(ECMWF, 2021). The winter months of 2021/2022 was a season with lack of snow in Norway, in addition to drought in southern parts of the country during the spring. A combination of these factors led to very hight electricity prices in both Europe and Norway since late 2021, and hence, the need for flexibility has become more important than ever(Bjartnes, 2023).

In the power system, flexibility can be achieved from supply and demand sides. High flexibility on the production side means that production can be regulated when needed, while high demand flexibility, consumer flexibility, means that consumers of electricity have the opportunity and willingness to change their electricity consumption based on the situation in the grid(Magnussen, 2023). In fact, the demand side flexibility may become more important in the future to ensure balance in the power grid(Buvik, 2022). For future energy markets characterized by more power-intensive industry and electrification, there is a need for more power and expansion of the power grid. These are costly processes for society that can affect nature and the environment, for example by developing new power plants. One alternative to limiting these processes is to utilize the flexibility of the power system.

In the future, consumer flexibility may be an important factor in adapting consumption to power production, but this requires mapping of the needs and motivation of consumers to facilitate demand response in the most appropriate way. There is a lack of knowledge of how private electricity consumption is affected by variable end-user prices, what knowledge private electricity consumers have about their own electricity consumption and what motivates the consumers to become more flexible. Without good knowledge of end-user price sensitivity, consumption forecasts will show excessive demand for transmission capacity and lead to overinvestment(Statnett, 2020).

Using a survey conducted by Ipsos on behalf of Statnett on private electricity consumers in Norway, the goal of this thesis is to investigate how private electricity consumers can contribute to a more flexible power market in Norway. To achieve this goal, these following specific questions will be addressed:

1. Are electricity prices an important factor to facilitate a more flexible power market for private consumers?
2. To what extent do consumers have knowledge about their own electricity consumption?
3. How can private electric cars owners contribute to flexibility in the power market in the future?

1 Theory

1.1 The power system in Norway

The power system in Norway, showed in Figure 1.1, consists of power generations, transmission, distribution network and consumers. The power producers are responsible for producing the energy, while the transmission and distribution networks transfers the produced energy from production site to the consumer, via the central transmission grid, the regional grid, and the distribution grid. For the power system to be always in balance, produced and imported energy must be equal to the energy used plus losses during transmission(Energifakta, 2022a).

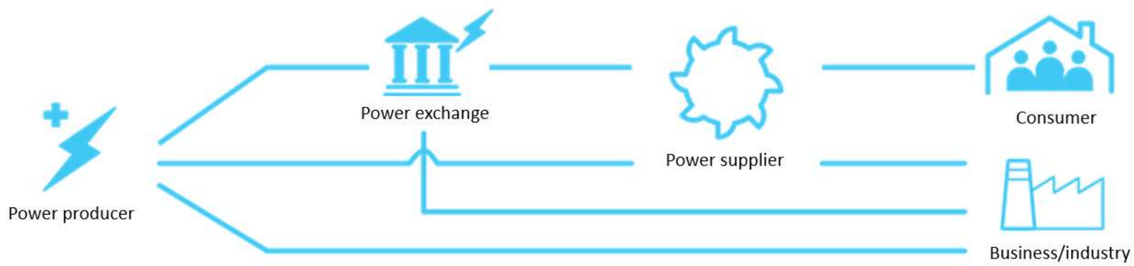

Figure 1.1 Presentation of the Norwegian power system in Norway (Regjeringen, n.d.).

The power companies are power producers that own power plants and produce electrical energy. In total, there are about 175 power companies in Norway, most of which are publicly owned. See table 2.1 for an overview of types of power generation in Norway. Statkraft SF is a state enterprise and is the largest power producer in the country(Rosvold, 2023).

Table 1.1 Overview of power generation in Norway in 2022(NVE, 2023a) (Tvedt, 2023)

Power Technology	**Total installed capacity (MW)**
Hydropower	33 691
Wind power	5 069
Thermal power	642
Solar Photovoltaic power	299
Total	39 715

The power grid is designed to handle peaks in power consumption. This is typical on cold days during the winter months when consumption is high. The grid must also be dimensioned to import power from the ‘neighbouring’ countries when the domestic production is less than demand. The power grid must also have the capacity to export to ‘neighbouring’ countries when electricity production in Norway exceeds domestic consumption. The large variations between domestic consumption and production mean that transmission capacity between regions and abroad must also be sufficient(Energifakta, 2019).

Statnett SF Norway builds, owns, and operates the transmission grid. The transmission grid transports energy between regions and national borders, with voltage levels of 420, 300 and 130 kV. Statnett is also the transmission system operator (TSO) for the power system. As TSO, Statnett must ensure that there is always a balance between production and consumption of power, in addition to power exchange with other countries. Statnett must also consider any capacity constraints in the power system and facilitate satisfactory quality of supply to all parts of the country. In addition, the power stakeholders' decisions must be coordinated in planning and operation(Statnett, 2022). Norway's international power exchange capacity in 2023 is approximately 9000 MW, of which the international cables to Germany and the UK have a capacity of 1400 MW each(Energifakta, 2019).

Next in line are the regional grid and the distribution grid. The regional grid has voltage levels from 66 to 132 kV. The regional grid is owned and operated by local grid companies and acts as a link between the transmission grid and the distribution grid. The distribution grid brings the power to the end users and has a voltage level from 230 V to 22 KV. See Table 1.2 for an overview of the power grid in Norway(Energifakta, 2019).

Table 1.2 Overview of the power grid in Norway

Type of grid	Voltage level	Capacity	Total length
Transmission grid	132 – 420 KV	200 – 2000 MW	11 000 km
Regional grid	66-132 KV	10-400 MW	19 000 km
Distribution grid	230V – 22 KV	1-10 MW	100 000 km

In the context of power, a distinction is made between flexible and intermittent power production. Controllability indicates the ability of a power plant to change production according to the ratio in the power market(Energifakta, 2022b). Stable and safe operation is largely ensured by hydropower. Large power plants help keep the frequency in the grid stable.

By storing water in reservoirs, the individual power plant can adapt its production. The possibility of storing water in reservoirs is a distinctive feature of Norway's renewable power supply.

In recent years, Norway has seen an increase in power production from the intermittent energy sources solar and wind. Wind and solar power have no regulating ability, and production must take place when the energy is available, that is, when it is windy, or the sun is shining. Production can vary widely, also over individual hours and days. This affects the need for grid and flexibility, as wind resources are not necessarily where the need for power is greatest, or in places where there is spare capacity in the power grid. In June 2022, there was 61 developed wind power plants in Norway, with a total record high production of 14.8 TWh, which represents 10.2% of total electricity production, compared to 11.8 TWh and 7.5% in 2021(Energifakta, 2022b) (Holstad, 2023). Figure 1.2 shows the development in installed capacity for wind power in Norway from year 2000 to 2019.

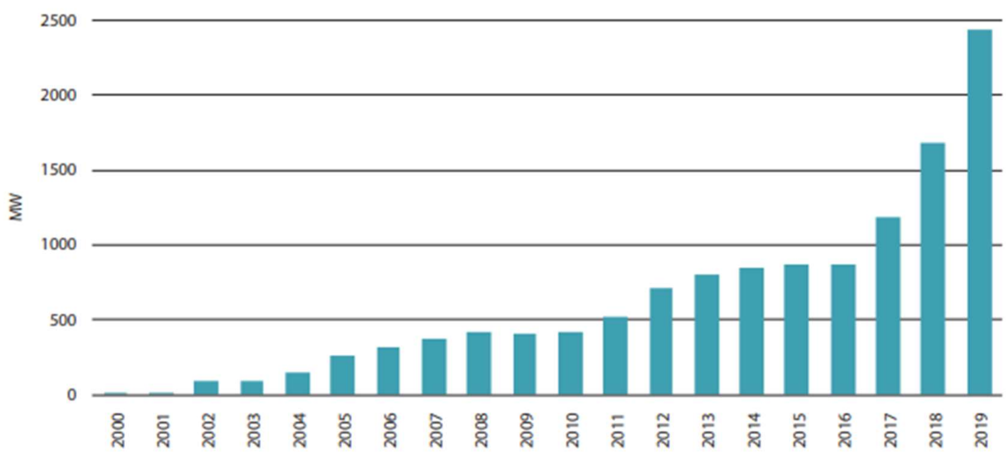

Figure 1.2 Cumulative installed capacity wind power 2000-2019 (Statnett, 2021a).

In addition to the growth in wind power, there is also a rising trend of solar power. Figure 1.3 shows the development in cumulative installed capacity of solar power from year 2004 to 2022. In 2022, approximately 100 MW of new solar power was installed in Norway, resulting in an increase in total solar power capacity of 50 % that year. At the beginning of 2023, the total installed capacity for solar power was 300 MWp in Norway(Energifakta, 2022b).

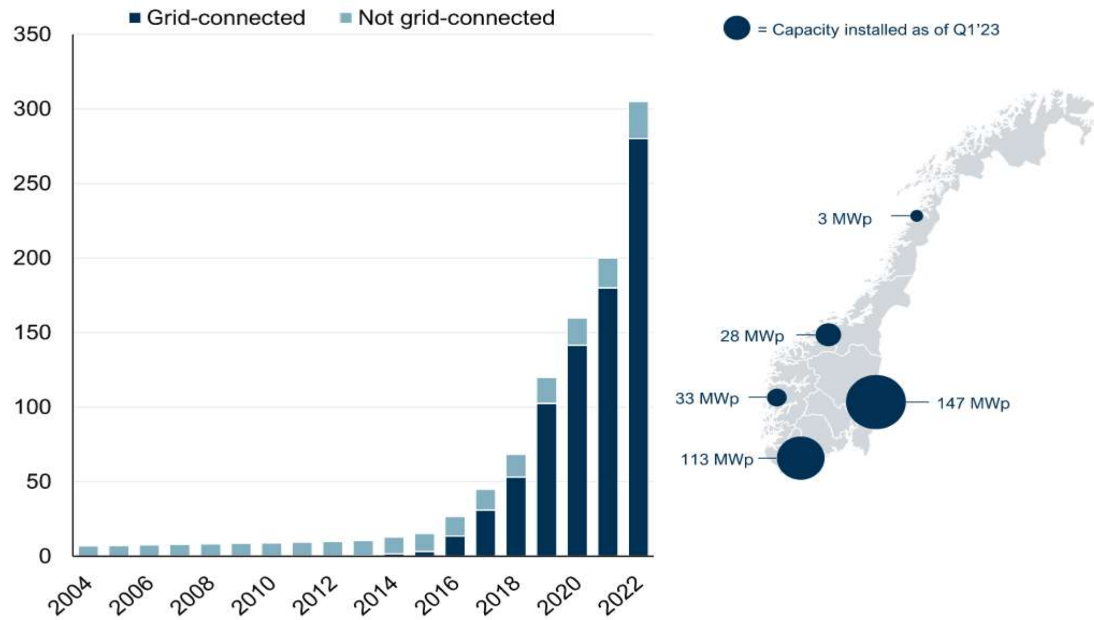

Figure 1.3 Cumulative installed capacity solar power 2004-2022 (Energifakta, 2022b).

1.2 Power markets in Norway

Norway has established three physical markets for electricity, which is the day-ahead market, the intraday market, and the balancing markets. The day-ahead market and the intraday market are subordinate to Nordpool, while the balancing markets are managed by Statnett. In addition, there are the financial markets, but these are not about physical delivery of power(Energifakta, 2022a). Figure 1.4 shows an overview of the different power markets.

The day-ahead market is the main market for power trading in the Nordic region, and the balance between power supply and demand is largely handled in this market. The trade takes place the day before production. In the market, market participants submit bids for the purchase and sale of power. Based on bids and transmission capacity, prices are calculated for each hour the next day. Nevertheless, events may occur after this that cause actual production and consumption to be different than planned. This could be, for example, changing weather forecasts. The intraday market takes place on the same day as production, but before the actual hour of operation. This market is traded continuously in the period between clearance in the day-ahead market and up to one hour before the operating hour. If actual production and consumption are different than planned in the day-ahead market, market participants intraday can trade in balance(Energifakta, 2022a).

The balancing markets take place during the actual hour of operation of power, and Statnett is responsible for the system. Although the day-ahead and intraday markets create a balance between production and consumption, there are events that upset the balance of the operating hour. To ensure instantaneous balance, Statnett uses the balancing markets to regulate consumption and production up and down, by controlling the power transmission frequency and the system is said to be in balance state with the frequency 50 Hz(Energifakta, 2022a).

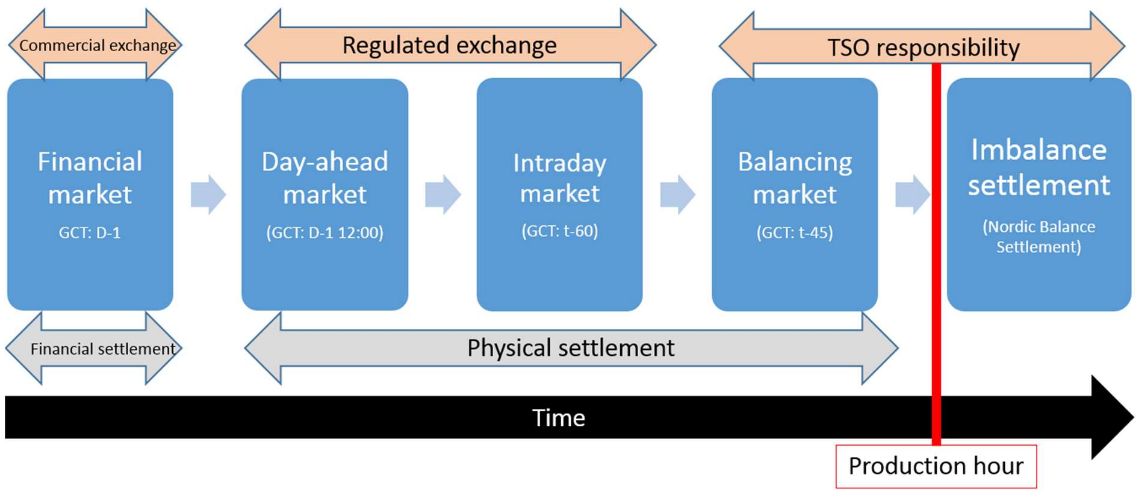

Figure 1.4 Overview of the power markets(NVE, 2021).

In the financial markets, it is not about the physical delivery of power, but about financial instruments. Its purpose is risk management, speculation, and price management(Jenssen, 2021).

1.3 Flexibility in the power market

Electricity is a perishable commodity, which means that production and consumption must always be in balance. For this to be possible, a sufficient share of consumption and production of electricity must be flexible. Flexibility in the power grid means that we can utilize the capacity of the power grid in an efficient way by regulating the consumption or production of power. The solution may lie both in how the grid companies operate and monitor the grid, and with consumers who adjust their electricity consumption based on the capacity of the grid. By getting the most out of the power grid, we can reduce new investments, which will save society both finances and encroachment on nature(Kjølle, 2021).

High flexibility on the production side means that production can be regulated when needed. Hydropower, where water is stored in reservoirs, has a high degree of flexibility, because production can be regulated based on power demand. Hydroelectric power plants can regulate production quickly, and have low costs associated with starting and stopping. The large distribution of hydropower in Norway has meant that traditionally there has been great flexibility in the Norwegian power system, but with more electrification, greater power requirements and more intermittent power production, the power system will be challenged. Wind and solar power make regulation more difficult since the technologies are dependent on the weather and will thus contribute to less flexibility in the power system.

Consumer flexibility means that the consumers of electricity have the opportunity and willingness to change their electricity consumption based on the situation in the grid(Magnussen, 2023). Examples of flexible technologies on the consumer side is battery storage or storage of energy in electric cars. Consumer flexibility may become more important in the future to ensure balance in the power grid. An important contribution to the balance of the power system is that consumption adapts to production, either by moving consumption or reducing consumption. Moving consumption means moving consumption during a day away from a time with a high load on the power grid to a time with a lower load, as shown in Figure 1.5 (Statnett, 2020). Consumer flexibility can improve system operation by relieving grid during planned and anticipated critical periods by reducing peak loads. A flexible power market thus does not mean a reduction in energy consumption overall, but a reduction in peak loads. Consumers must relate to the concepts of energy and effect. Energy is measured in kilowatt hours (KWh), while power is measured in kilowatts (KW). For electric car owners, this means that the amount of energy (KWh) affects the car's range, while the charging power says something about how fast the car is charged(Wagner, 2020).

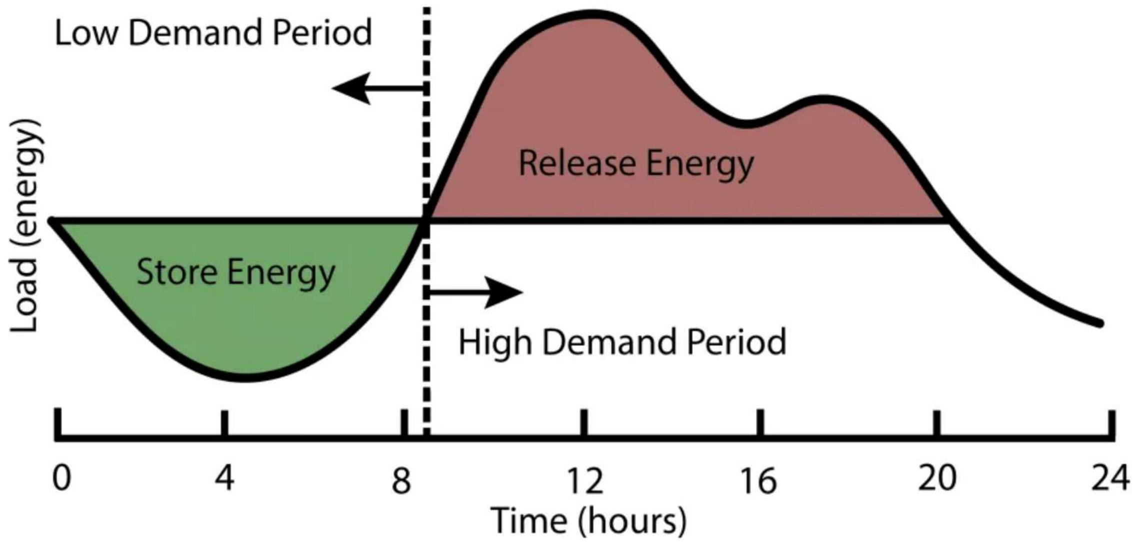

Figure 1.5 Moving electricity consumption from hours with high demand on the grid to hours with low demand (Michigan, 2022).

Flexibility for consumers essentially means money saved in the form of moving or reducing consumption during hours of high electricity prices. Consumers will contribute flexibility when they see easy ways to save or make money. Today, one can only save money by reducing one's own consumption, but by facilitating it will be possible to facilitate a market system for buying and selling flexibility. We distinguish between implicit and explicit consumer flexibility. Implicit pre-flexibility means that consumers respond to market signals after the market is cleared, and thus do not have a direct impact on the spot price. Explicit demand response means that consumers actively participate in spot or break-even markets via a third-party aggregator(Kringstad, 2018).

1.4 Power system economics

The power market aims to maximise short-term and long-term social profits. The price of electricity is determined by supply and demand, that is, how much power is produced and how much is consumed. There are many factors that play a role in determining electricity prices, but some important factors are precipitation and inflow, temperature, imports and exports, price of coal and gas, price of CO2, the dollar exchange rate and the euro exchange rate, the available amount of production and the amount of consumption(NTE, 2023). In the event of socio-economic maximisation, costs will be minimised and consumers' willingness to pay will be maximised(Stoltz, 2021).

The merit order system is a method that determines power prices, based on ranking available resources of energy based on their short-term marginal price for production. Marginal price means the price it costs to produce a unit, usually stated in megawatts. Marginal pricing ensures that society's resources are used in a way that ensures that the value of the resources available is maximized(THEMA, 2022). When there is an increase in cheap power supply within the system, the merit-order system results in a reduction of power prices. The producers who offer the cheapest power are always bought first, but all manufacturers get paid the same. This means that those with higher marginal prices get less profit than those with low marginal prices and provides an incentive to produce power as cheaply as possible. If demand is so high that even the expensive producers are needed to fill the demand, those with the lowest marginal price of power earn the most money. The system also means that with low cheap renewable production and expensive gas prices, the price of electricity can skyrocket. Figure 1.6 shows the merit-order principle. The renewable power producers with low marginal costs end up on the far left on the Y-axis, while the fossil power producers with high marginal costs end up on the far right. The intersection of marginal cost and demand determines the price of electricity.

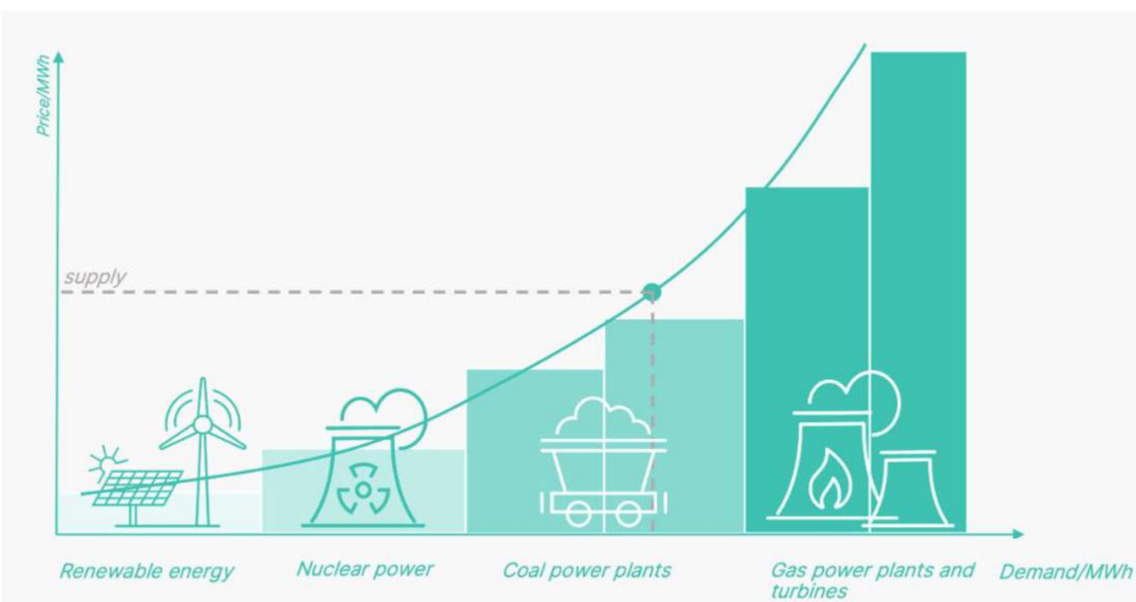

Figure 1.6 Merit-order system. Cost per unit produced on the x-axis (Marginal price). Demand for power on the y-axis(Kunkel, 2021).

Power is not always produced where it is needed most and must therefore be moved, but transmission from one area to another has limited transmission capacity. Norway is divided into 5 bidding areas, and when there is a restriction in the transmission of electricity between the bidding areas it's called a bottleneck. Bottlenecks arise when we get a surplus of electricity in one part of the grid and deficits in another part. Within each bidding area, a separate power price is set, which means that price differences occur internally in Norway. Areas with lower access to electricity will have a higher price than areas with higher access. Congestion revenues occur when electricity is traded between two areas with different area prices. The area with a power deficit that must buy the electricity pays the price in its own bidding area, while the producer from the area with the power surplus is paid the price in the bidding area where the electricity is produced. The price difference is called congestion revenue and goes to the owner of the power cable. The different area prices also provide a signal to the market so that consumers and producers can adapt their consumption. Over time, area prices will signal whether new production or consumption should be invested(NVE, 2022).

1.5 Energy storage technologies

Energy storages technologies can be used to increase demand response in the power market by storing energy when there is a surplus of power, and used when there is a deficit(Kjølle, 2021).

The differences between the energy storing technologies include capacity for how much energy can be stored, in what form the energy is stored, how long it can be stored and at what cost. There are also large variations in how quickly an energy storage can be utilized and what purpose it can be used for. The most common is to categorize energy storage according to the form in which the energy is stored, and the main categories are mechanical, electrochemical, electrical, and thermal storage, as shown in Figure 1.7(DNV, 2020).

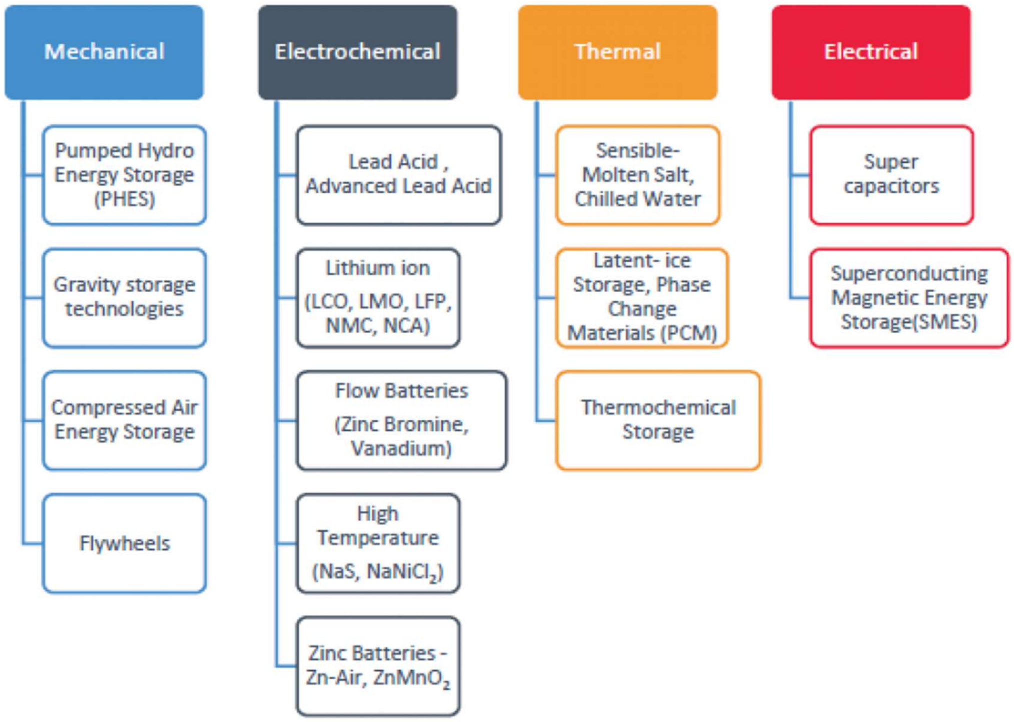

Figure 1.7 Different ways of storing energy(IESA, 2020).

Mechanical energy storage harnesses potential energy, kinetic energy, or pressure to generate electrical energy. Examples include pumped-storage power where electricity is used to pump water into reservoirs, such as hydropower in Norway. This is a mature technology with a high service life, low maintenance and well suited to long-term energy storage. The technology has a fast response time and is flexible. Some disadvantages are that it is geographically limited and environmental consequences in the form of encroachment on nature.

Electrochemical energy storage is essentially batteries. Batteries consist of one or more galvanic cells that can convert chemical energy into electrical energy. There are several different battery technologies depending on which chemical substances are involved in the process, where the most common types are lead-acid batteries, lithium-ion batteries, nickel, sodium-sulfur, and flow batteries. Lithium-ion batteries are the most common type in rechargeable batteries and dominate with a market share of 90% for stationary batteries and 95-99% for electric vehicles. Lithium-ion batteries have characteristics that make them attractive, which has helped drive prices down. From 2010 to 2019, prices fell by 87%, and DNV GL assumes that costs will fall another 67% until 2035. "Lithium-ion" is an umbrella term for batteries that use lithium as electrolyte. Batteries are charged and discharged by electrons moving from one pole to the other. Changes in the chemistry of the cathode and anode give rise to variations in properties such as rated power, lifetime, safety and cost(DNV, 2020).

Thermal energy storage involves storing energy as heat or cold in thermal mass. Storage is most relevant when the energy can be utilized directly as thermal energy. Thermal energy storage can provide flexibility by reducing the need for electric heating during peak load hours, for example as district heating. Surplus heat from industrial processes can technically be stored for later use, and surplus power from renewable production can be used to heat or cool medium that can later be used for heating or cooling. Shopping centres and data centres can accumulate thermal energy in their systems, where the inertia and storage of the system can be harnessed for flexibility by adjusting power requirements up or down. By replacing electric heating with other forms of energy, such as district heating, it will be possible to reduce the peak load in winter and thus also the need for grid investments(DNV, 2020).

Electrical energy storage is the direct storage of electricity, either in capacitors or superconductors. This is a not very widespread form and can only store energy for short periods of time. In chemical energy storage, energy is stored by converting energy into chemicals. Here, surplus power from renewable production can store energy over long periods of time, but one challenge is that it is not very energy efficient.

Of the various technologies, mechanical energy storage is the most widespread, with pumped storage power plants accounting for over 90% of the total installed energy storage capacity in the world. The remaining is distributed between the remaining different technologies, mainly thermal energy storage and lithium-ion batteries, see Figure 1.8. Pumped storage power plants are largest on installed capacity, but lithium-ion batteries dominate in the number of projects(DNV, 2020).

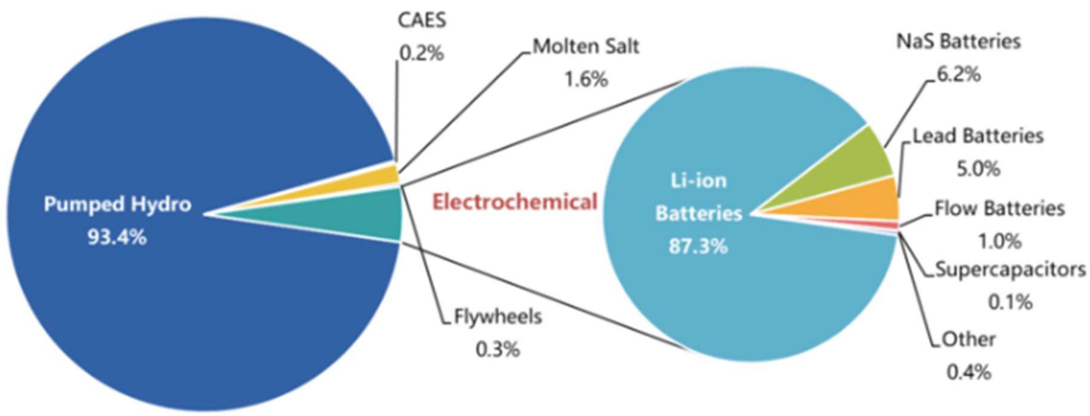

Figure 1.8 Global total operational energy storage project capacity (MW)(CNESA, 2019)

1.6 Aggregators and smart charging of electric vehicles

Today's electric cars use lithium-ion batteries. In the cell, positively charged lithium ions are transported from the anode to the cathode via a separator using liquid electrolytes. Through this movement electricity is generated and supplied to the car's engine(Honda, n.d.).

There are several ways to charge electric cars, and with smart and flexible charging systems, many of the challenges with capacity in the grid can be reduced. Electric cars' large lithium-ion batteries can be charged at times when the grid is not heavily loaded, making them flexible. Furthermore, charging a larger number of vehicles can be coordinated so that they function as a virtual battery capacity in the grid, acting as frequency regulation and bottleneck management. In this way, electric cars can contribute to increased robustness in the power grid rather than creating capacity problems. Smart charging is defined as charging systems where charging of the electric vehicle can be controlled automatically and adapted to the power system, often based on price signals(Horne, 2019).

Due to minimum bid size requirements in the regulating power market, it will be difficult for small players to participate with flexibility to the market. One solution to this is companies that represent several households or businesses and compile their offer of flexibility and offer it further in the markets. Such a company is called an aggregator. Demand response through aggregation can give the system operator a new tool for balancing the power system(Samfunnsbedriftene, 2020).

Most home chargers installed in Norway today do not go under the category of smart charging but, begin to draw power as soon as the vehicle is plugged in and does not end until it is disconnected, or the battery is full. We have four different charging methods for electric vehicles:

- Standard charging
- Timed charging
- Smart charging
- Vehicle-to-grid (V2G)

Standard charging is when the vehicle charges from the time it is connected in the charger until the battery is fully charged or disconnected. Timed charging is when charging takes place within a predefined point in time. Smart charging means that charging is controlled automatically in response to external signals, such as power price fluctuations. Vehicle-to-grid charging (V2G) means that electrical power can also be returned from the vehicle's battery to the power grid, which is a further development of smart charging. (Samfunnsbedriftene, 2020)

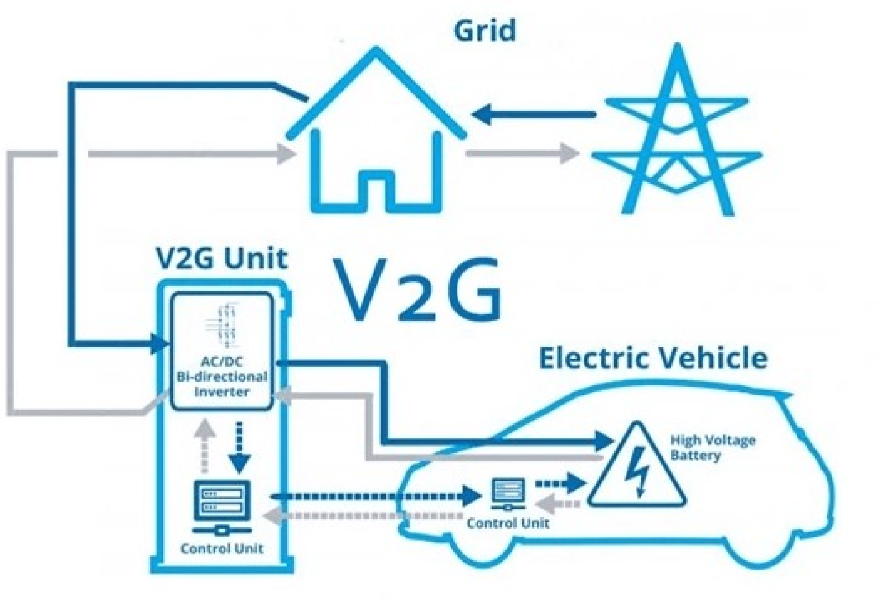

Figure 1.9 Example of vehicle to grid using an aggregator(Electric Veichle Evolution LLC, n.d.).

Figure 1.9 shows an example of V2G using a control unit to connect the electrical car to the grid. V2G makes it possible to make better use of the grid. At times when there is a lot of capacity in the grid, the electric car battery can be charged with electricity from the grid, while during periods of high load, the electric car can deliver electricity into the grid and thus help relieve the grid. The technology is still under development but is being tested in various pilots and projects. Just as batteries from vehicles can provide flexibility, stationary batteries in consumers can also provide flexibility in the future. V2G will also be useful for electric car owners who have installed solar cells. The vehicle's battery capacity can then be used as a storage facility to increase the utilisation of self-produced electricity. By doing so, electric cars can contribute to increasing security of supply internally to buildings and installations when the main supply fails. With V2G, cheap electricity can be stored and then used at a time of higher power price.

1.7 Smart home technology and AMS

AMS meter is an electricity meter that provides the opportunity for consumers to monitor their own consumption, analyse their own consumption patterns and provide help for smarter electricity consumption. AMS stands for advanced metering and control systems(NVE, 2023b).

One measure that has been imposed to increase the consumers knowledge of own electricity consumption is the requirement for the installation of AMS meters(Lovdata, 1999). The purpose is to make the consumer more aware of their own electricity consumption, and thus contribute to a smarter electricity consumption with a more even load on the grid. AMS provide a basis for consumers in households and commercial buildings to contribute flexibility to the power grid. With the technology, consumers can adapt their electricity consumption to power prices, and thus use electricity smarter. This will reduce the risk of overload and power outages. In the event of a power outage, the fault can be identified more quickly and thus corrected more quickly. All AMS electricity meters are equipped with a physical input called the HAN port, which stands for Home Area Network. By connecting to the HAN port, you will have access to information about your own power consumption, power consumption last hour and voltage level. If the home is equipped with solar cells, you can get information about surplus power and how much electricity is fed into the grid(NVE, 2023b).

2 Method

To make long-term consumption forecasts and forecasts for peak load in a future power system, it is important to have knowledge of consumption flexibility and future price sensitivity. The problem for this thesis is to investigate how private homeowners in Norway can contribute to a more flexible power market.

The data for this study is based on a survey conducted by Statnett in the period from 30 March 2022 to 3 May 2022. The survey is answered by private electricity consumers living in Norway. Figure 2.1 shows an overview of the different price areas in Norway, where Oslo, Bærum, Asker and Lillestrøm is placed in NO1, Bergen in NO5, Trondheim in NO3 and Tromsø in NO4. The survey includes no respondents from area NO2.

Figure 2.1 Overview of Norway's 5 price areas(Kragerø Kraft, 2023).

2.1 Methodological approach survey

The purpose of the survey is to gain knowledge about how variable end-user prices could affect electricity consumption during the peak load period in the future which could partly be due to frequent changes in electricity tariff and more availability of technological opportunities. Since 2021, Norway has experienced increasing variation in power prices, especially between southern and northern Norway. The purpose of the survey is to contribute to increased knowledge about how the price differences have affected electricity consumers in the various price areas.

In the survey, the selected population consists of households in the urban areas Oslo, Bærum, Asker, Lillestrøm, Bergen, Trondheim and Tromsø. The questionnaire survey was administered by Ipsos on behalf of Statnett.

The questionnaires deal with topics that include energy consumption in the respondents' homes. The survey is used to collect data on the respondent's electricity consumption, examine if the respondents are aware of their own electricity consumption, obtain information about their electricity consumption and whether they have taken actions to reduce or move the electricity consumption from hours with higher electricity prices, and investigate what motivates to a more flexible power consumption.

2.2 Sample size

The sample consists of a total of 4446 respondents living in urban areas in the various price areas NO1, NO3, NO4 and NO5. The sample is divided into respondents from Oslo, Bærum, Asker, Lillestrøm, Tromsø, Trondheim and Bergen. The selection criterion has been people over the age of 18 who are responsible for household electricity bills. Table 2.1 shows number of respondents in each selected location.

Table 2.1 Overview of respondents in each price area

Location	Price area	Number of respondents
Oslo	NO 1	1783
Bærum	NO 1	198
Asker	NO 1	96
Lillestrøm	NO 1	200
Tromsø	NO 4	385
Trondheim	NO 3	790
Bergen	NO 5	994

2.3 Data Analysis

The research questions are used to analyze the data and answer the problem statement. The responses are compared with similar research and reports from SSB, NVE, Statnett SF and SINTEF.

Excel was used to analyze the data. Using Excel, it is possible to sort the data and filter the results. The first step was to get to know the data, before starting the process of extracting data that were relevant to the research questions. Relevant data were then categorized based on the research questions.

Research question 1: Are the electricity prices an important factor to facilitate a more flexible power market for private electricity consumers?

The aim of this part of the analysis is to investigate correlations between the respondents' responses to the electricity price level in the period the survey was conducted, including correlations between the respondents' habits, motivation to save electricity and will to change consumption due to the electricity price level. To answer this research question, it was evident to collect data about:

- How has the electricity price developed the last years?
- How many of the respondents pay attention to variations in electricity prices?
- Why is some of the respondents not paying attention to variations in electricity prices?
- How many of the respondents took actions to reduce or shift consumption during hours with high power prices?

Research question 2: To what extent do consumers have knowledge about their own electricity consumption?

The aim of this part of the analysis is to investigate the respondents' knowledge related to their own electricity consumption. To answer this research question, it was evident to collect data about:

- Whether or not the respondents monitor their own electricity consumption.

- If the respondents had taken any actions to reduce or shift their electricity consumption from hours with high electricity, and what actions they did.
- If the respondents know how much money they saved doing actions to save energy.

Research question 3: Can private electric cars contribute to flexibility in the power market in the future?

The aim of this part of the analysis is to investigate how owners of electrical cars can contribute to a more flexible power market. Consumer flexibility by using the electric cars was only briefly focused on in the survey. To strengthen the data and arguments presented, the third research question will place greater focus on relevant studies from existing literature, compared to the other research questions. The possibility of utilizing electric car batteries as a source of consumer flexibility holds considerable promise for the future, making it an important area of investigation.

To answer research question 3, it was evident to collect data about:

- How many of the respondents own one or more electrical cars?
- How many of the respondents who chose to charge their electrical car during periods with low demand on the electricity grid?
- Other research within the topic of “electric cars and consumer flexibility”.

3 Results

This chapter presents the results of the study. The result provides empirical data and results that are generalizable and transferable to all metropolitan areas in Norway.

3.1 Descriptive statistics

This section shows the descriptive statics of the respondents. Figure 3.1 shows an overview of the type of housing the respondents of the survey live in, distributed by region. Table 3.1 shows an overview of the respondent's education level. Table 3.2 shows an overview of the respondent's household's total gross income. Figure 3.2 shows how the respondents tap water is heated, distributed by region.

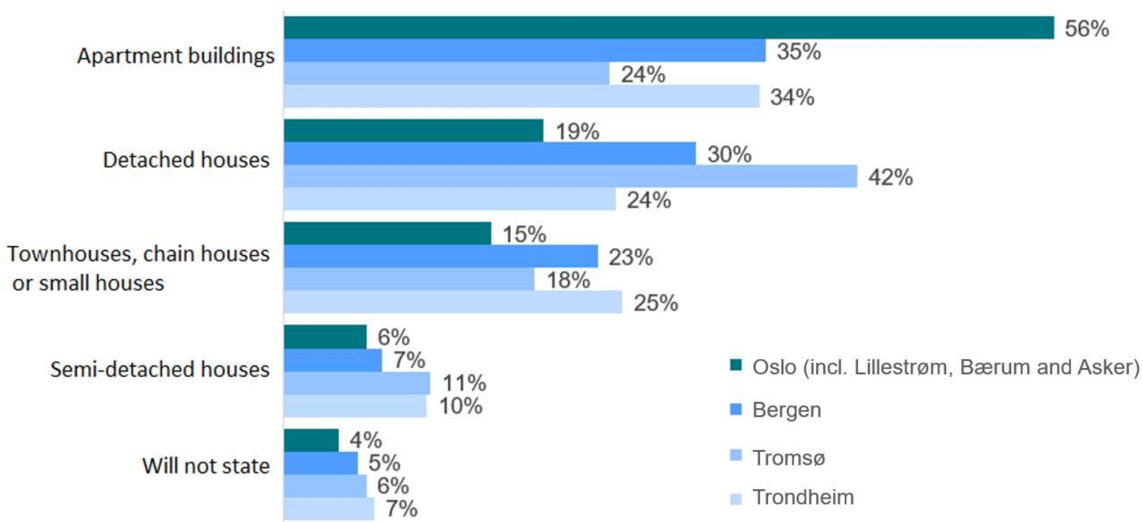

Figure 3.1 Overview of the type of housing the respondents live in, distributed by region.

Table 3.1 Overview of the respondent's education level

Education level	**Percentage of respondents**
Higher degree from university (4 years or more)	43%
Lower degree from university (1 to 3 years)	35%
College	20%
High school	2%

Table 3.2 Overview of total gross income in the respondent's household

Households' total gross income [NOK]	**Percentage of respondents**

Less than 300 000	6%
300 000 – 499 999	11%
500 000 – 799 999	21%
800 000 – 999 999	13%
1 000 000 – 1 499 999	22%
1 500 000 or more	12%
Will not state or do not know	15%

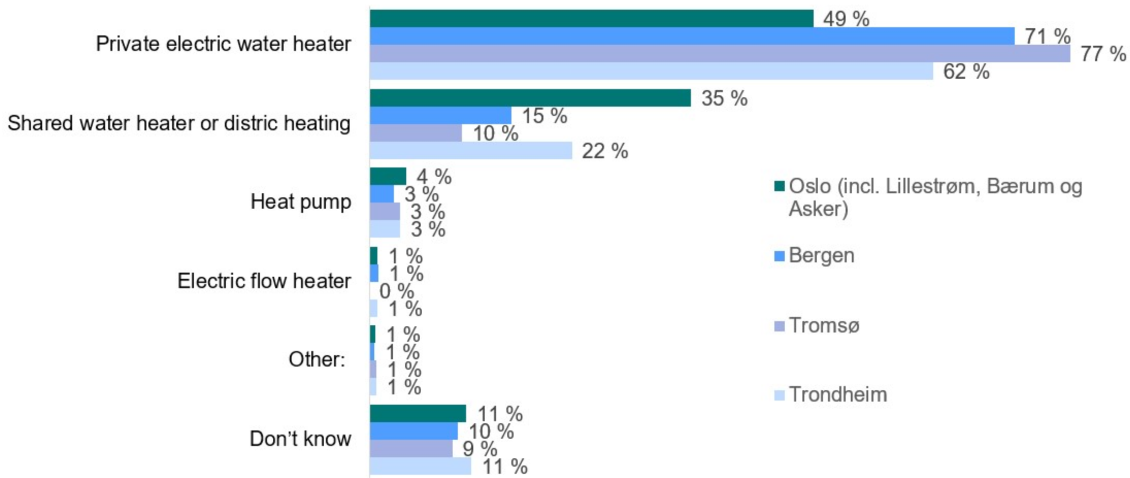

Figure 3.2 Distribution of how tap water is heated.

3.2 Interest in power price and power consumption

It is valuable to uncover the respondents' interest in their own electricity consumption, which encompasses the willingness of consumers to shift their energy consumption to off-peak hours. This information can provide a base for future facilitation of consumer flexibility.

Figure 3.3 shows that over 75% of the respondent's state that they monitor their own electricity consumption, with variation in responses observed across different geographical locations. To the question "Did you monitor your own electricity consumption during the preceding?", 82% of the respondents from Bergen answered "Yes", compared to 68%, 68% and 77% in Trondheim, Tromsø and Oslo, respectively.

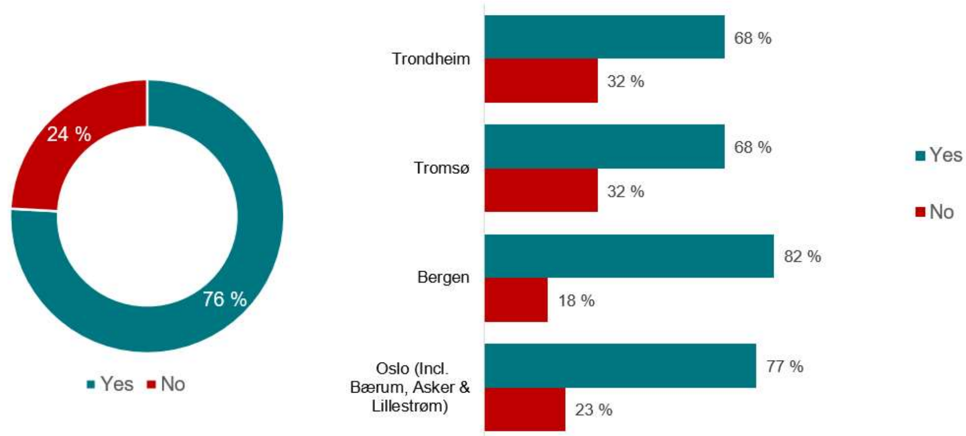

Figure 3.3 Monitoring of electricity consumption.

Those who answered "No" to the question were then asked to explain the reasons for their responses, who indicated a lack of interest in monitoring their own consumption. Figure 3.4 shows the distribution of the respondents' reasons, with several options available for selection. The analysis of the figure indicates that the primary reason for the lack of interest was limited possibilities to alter electricity consumption, and low electricity costs. Figure 3.4 shows the geographical responses, with. 31%, 35% and 40% of the respondents from Oslo, Tromsø and Trondheim, respectively, answered "my electricity costs were not that big", compared to 17% of the respondents from Bergen.

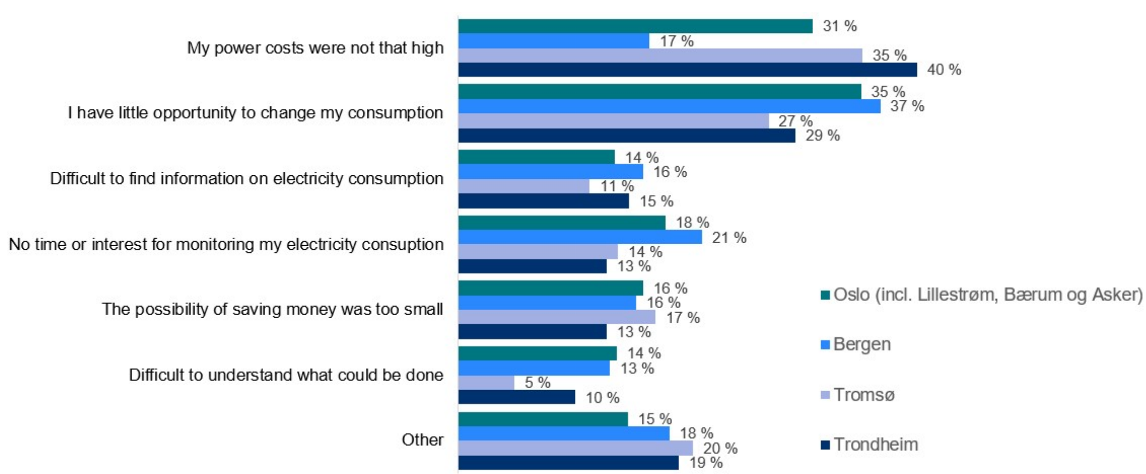

Figure 3.4 Monitoring of electricity consumption distributed by area.

It is useful to reveal how interested respondents are in the variation of electricity prices. The price of electricity is determined by supply and demand and says something about the available amount of production and consumption of power. For the consumers to utilize flexibility it is imperative that they have knowledge and interest about how electricity prices vary.

Figure 3.5 presents the results on the proportion of responds who monitors variations in electricity prices. The analysis indicates that 24% of the respondents from Bergen reported monitoring electricity prices variations every day during the preceding winter, compared to only 8% of the respondents from Tromsø.

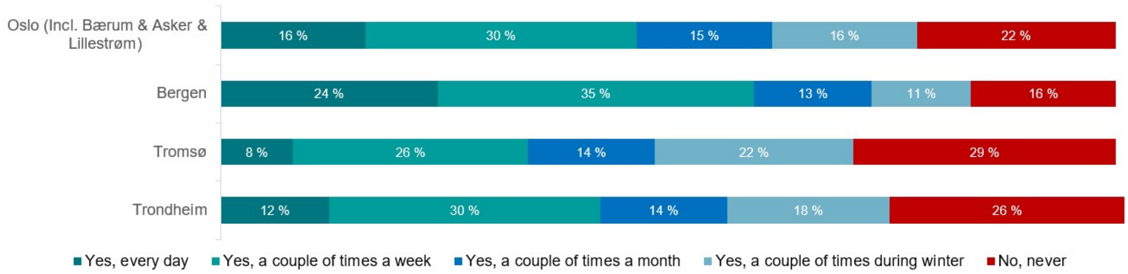

Figure 3.5 Monitoring of electricity prices distributed by area

To identify the respondents who indicated a lack of interest in monitoring variations in electricity prices by answering "No", a further question was conducted to examine the reasons for this. This reveals geographical differences where 34%, 39% and 41% of the respondents from Oslo, Tromsø and Trondheim, respectively, state that electricity costs were not big enough as a reason for not monitoring variations in electricity prices, compared to 21% in Bergen.

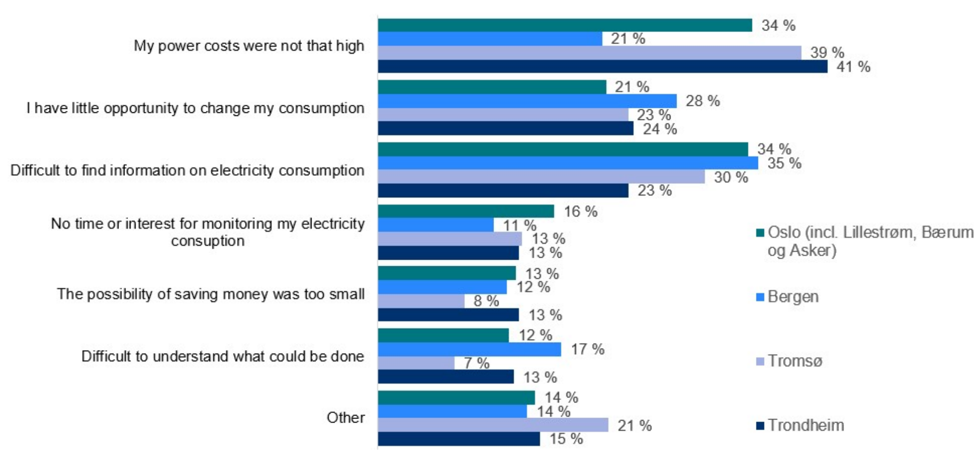

Figure 3.6 Reasons not to monitor variations in electricity prices.

It is useful to investigate whether the respondents took measures to reduce electricity consumption during periods with high electricity prices, and what their motivation was.

Furthermore, understanding why someone did not take any action and identify potential motivators who is crucial to get them motivated.

The respondents were asked to identify the factors that motivated them to reduce electricity consumption during periods of high electricity prices. Figure 3.7 shows that a significant motivation for changing electricity consumption during hours with high electricity prices is a lower electricity bill, which 74% of respondents cited as motivation. About 1/3 of the respondents cited measures that are easy to do manually, measures that happen automatically and measures that do not compromise comfort at home as motivators.

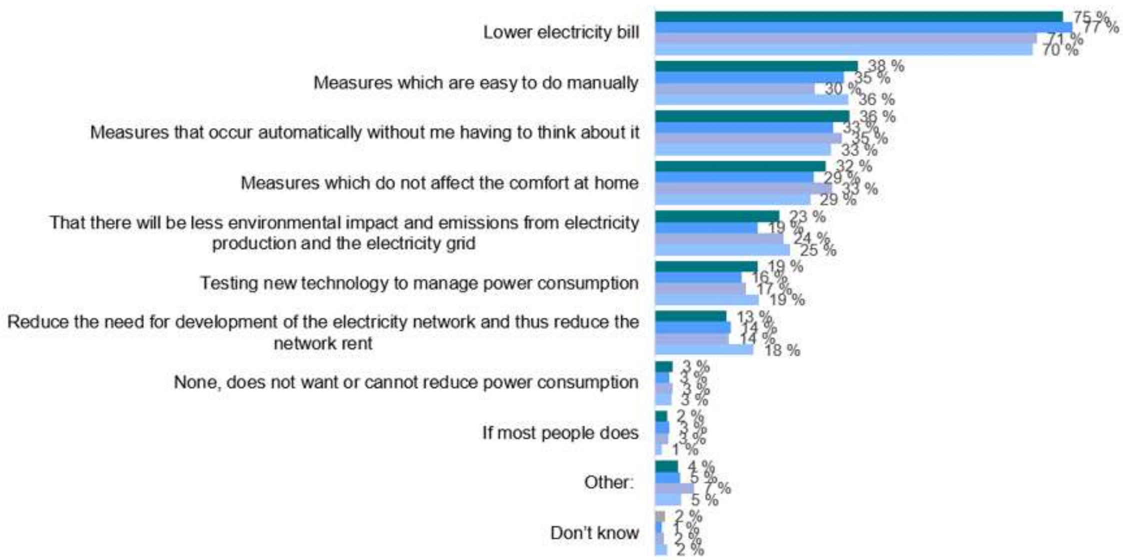

Figure 3.7 Motivation to save energy.

3.3 Level of knowledge of own electricity consumption

Figure 3.8 displays the extent to which the respondents adopted measures to reduce or shift electricity consumption during periods of with high electricity prices during the winter. In total, 74% stated that they had taken some form of action, while 26% answered that they had not taken any actions at all. The results revealed geographical variations, with 18% and 22% of the respondents from Bergen and Oslo, respectively, indicating a lack of action, compared to 39% and 42% in Trondheim and Tromsø, respectively.

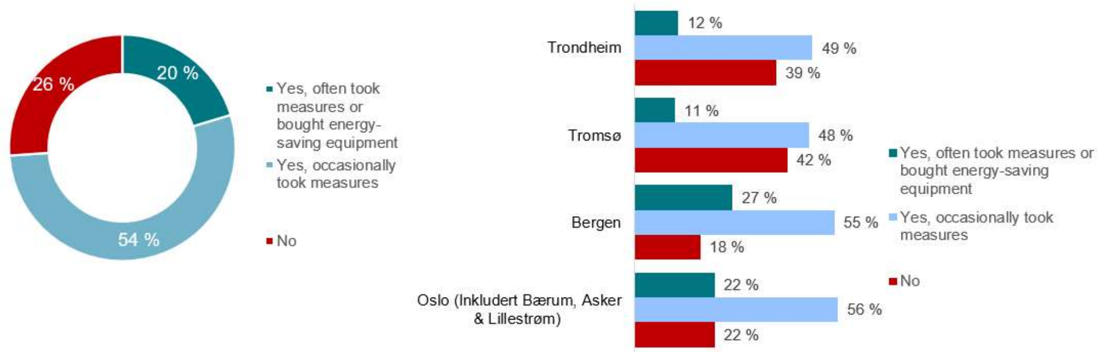

Figure 3.8 Reduction or moving of electricity consumption in hours with higher electricity prices.

The respondents who answered positively, "yes", to the question of whether they took actions or purchased energy-saving equipment to reduce or shift electricity consumption during periods with high electricity prices, where asked to specify the actions they did.

Figure 3.9 shows that more than half of the respondents frequently or occasionally took measures such as shifting use of appliances like the dishwasher, washing machine or dryer to other times, lowering the indoor temperature, turning off lights or other small electronics, turning off electric heating in rooms that are not being used, and reducing shower time or taking fewer baths.

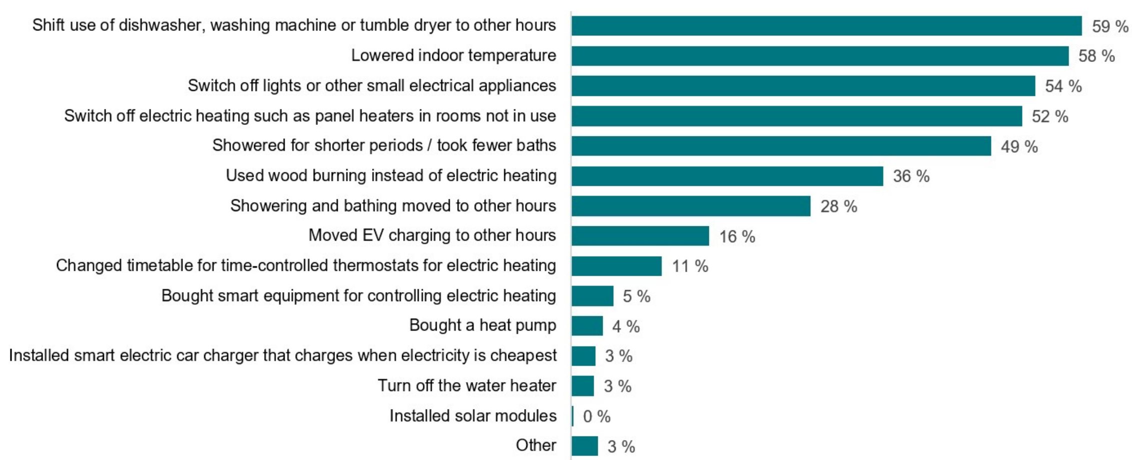

Figure 3.9 Most popular actions to save energy.

The respondents who answered positively, "yes", to the question of whether they took actions or purchased energy-saving equipment to reduce or shift electricity consumption during periods with high electricity prices, where further asked whether they believed the measures they had implemented were worth the savings on the electricity bills. Figure 3.10 shows that 74% answered “Yes”.

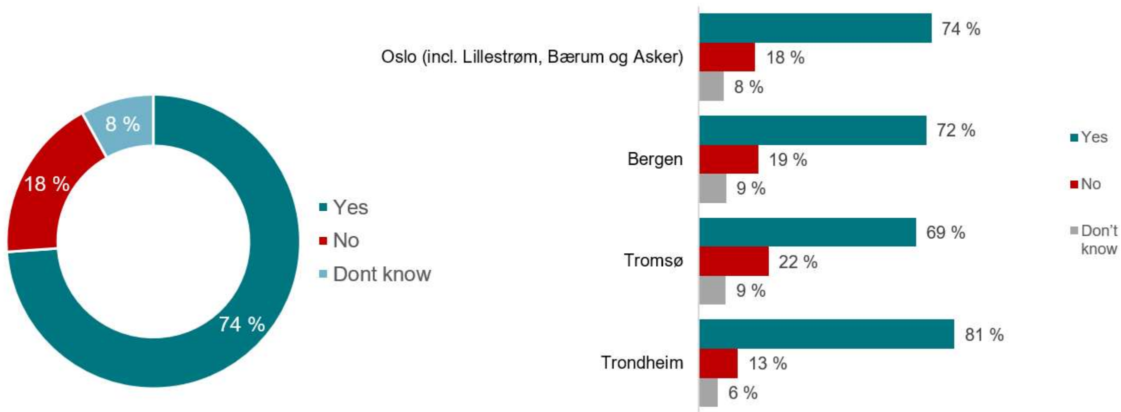

Figure 3.10 Share that think the energy saving actions was worth it.

The respondents who answered positively, “yes”, to the question of whether they took actions or purchased energy-saving equipment to reduce or shift electricity consumption during periods with high electricity prices, were then asked if they know how much money they have saved. Figure 3.11 shows that 85% answered “No”.

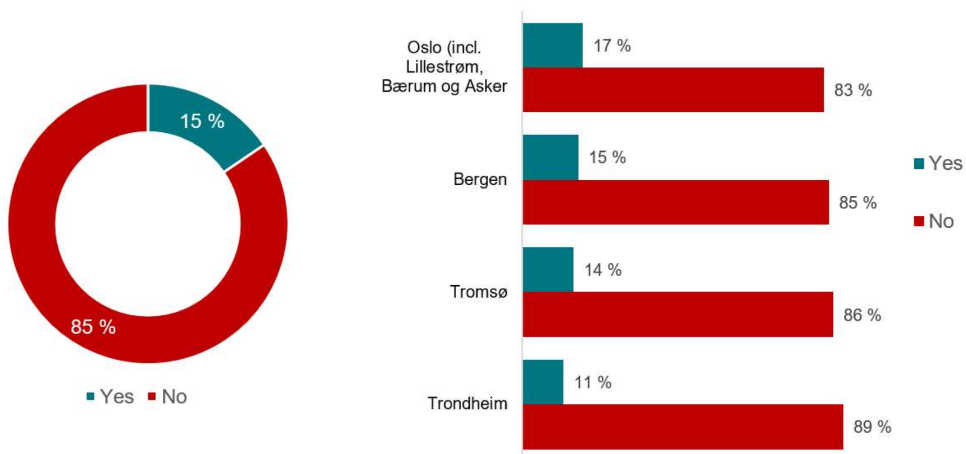

Figure 3.11 Respondents aware of economical savings by reducing energy.

The 26% who stated "No" when asked if they had taken measures to reduce or move their electricity consumption, were asked why they did not take any measures. Figure 3.12 shows that half of the respondents from Tromsø and Trondheim state that "my electricity costs were not that big", compared to only 1/3 of the respondents from Bergen that cited this as a reason.

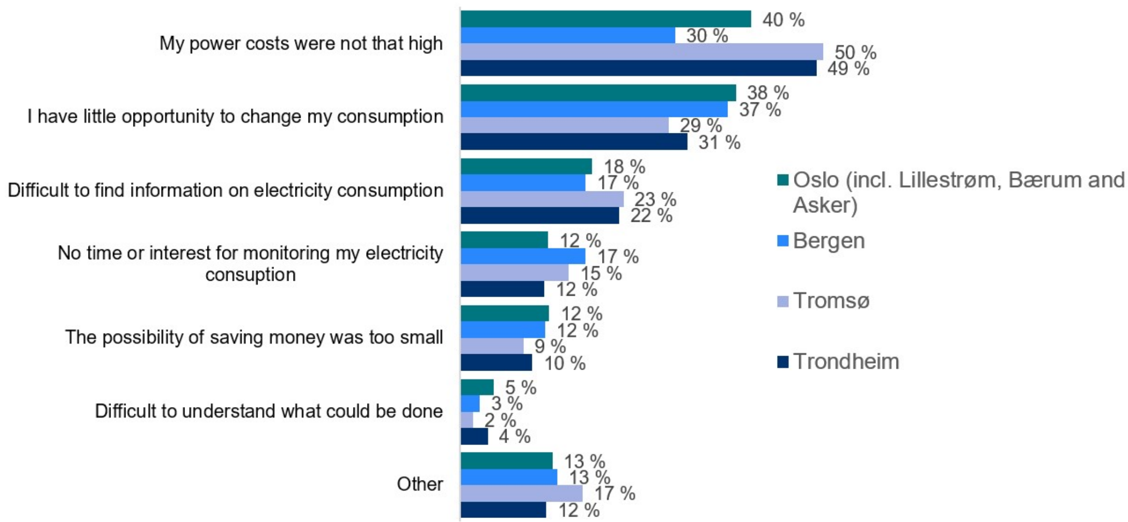

Figure 3.12 Reasons some of the respondents did not do any actions to reduce their energy consumption.

3.4 Private electric cars and flexibility in future power market

It is useful to reveal how many of the respondents who has an electric car that they charge occasionally at home, since charging is a big part of the electricity consumption for households. The transition from fossil to electric car fleet will require a lot from the power grid in the coming years.

Figure 3.13 shows whether the respondents have an electric car who is occasionally charged at home. The figure reveals that 27% of the respondents have an electric car in their household that is occasionally charged at home. However, it does not appear in the survey how many of the respondents who own an electric car which is not charged at home. As a result, the total number of electric vehicle owners among the respondents could possibly be more than the reported 27%.

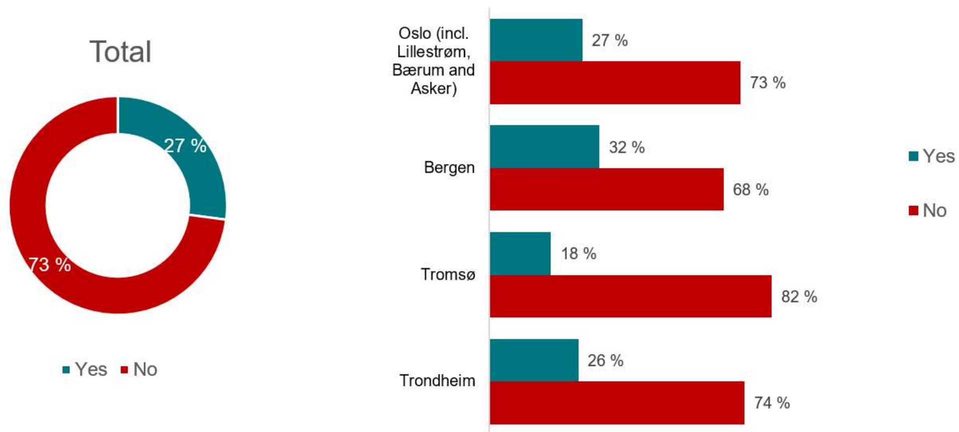

Figure 3.13 Responds that own an electrical car who is occasionally charged at home.

The findings represented in Figure 3.14 indicate that among the respondents who own an electrical car that is occasionally charged at home, manual control of battery charging is the most common method to avoid high demand peaks. There are some geographical differences, 37% and 48% of the respondents from Trondheim Tromsø, respectively, claims that they do not control the charging time due to high demand peaks, compared to 26% and 27% in Oslo and Bergen, respectively.

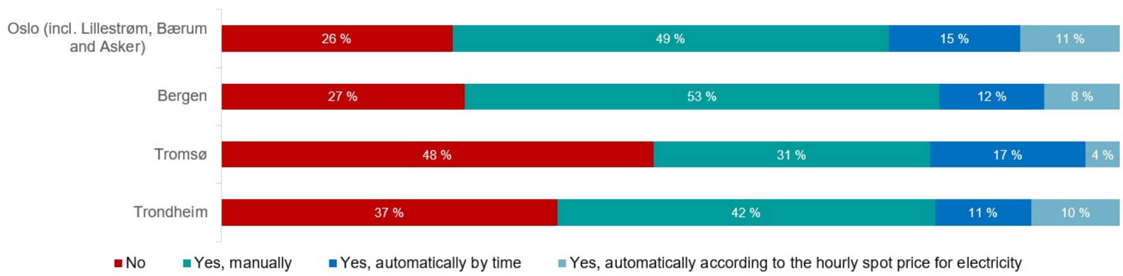

Figure 3.14 Monitoring of charging time to avoid high demand peaks.

4 Discussion

4.1 Research question 1

Are the electricity prices an important factor to facilitate a more flexible power market for private electricity consumers?

Consumer flexibility refers to the practice of modifying electricity consumption in response to variations in electricity prices throughout the day, which can lead to reduced power peak loads and be economically beneficial. Traditionally, electricity prices across the country have remained relatively consistent. However, from the beginning of 2021 increasing price differences have emerged between the northern (NO3 and NO4) and southern regions (NO1, NO2 and NO5), as shown in Figure 4.1. During the autumn of 2021, spot electricity prices in the southern price areas more than quadrupled compared to the preceding winter season. For price area NO1, NO2 and NO5, the average spot price was 345% higher than the year before, while the corresponding regions NO3 and NO4 experienced a decrease of 36%(Dalen, 2022).

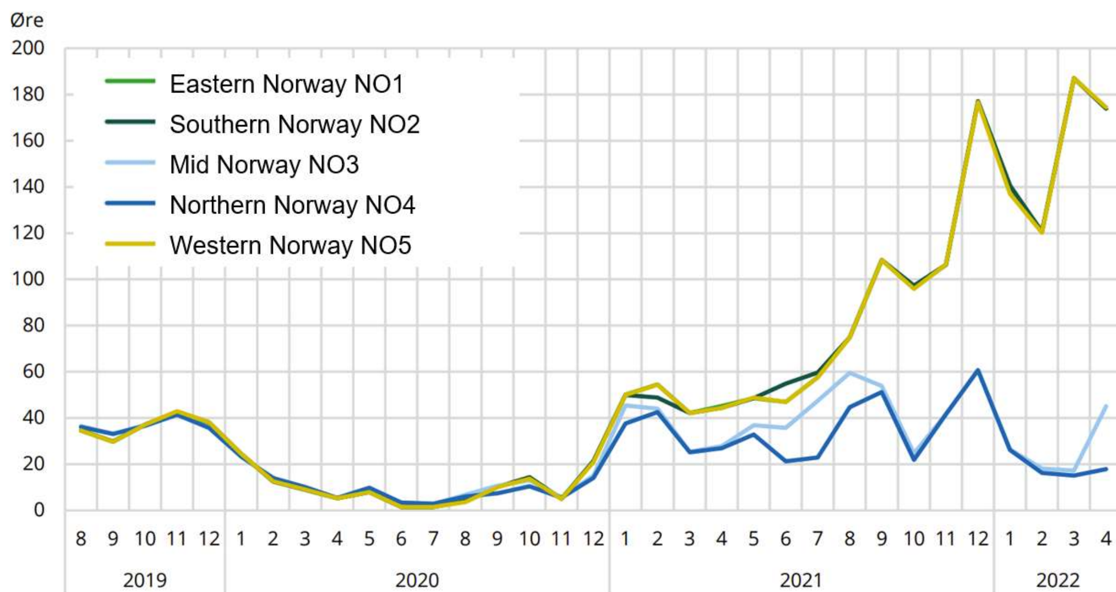

Figure 4.1 Average monthly spot electricity price from august 2019 to April 2022(Dalen, 2022).

These geographical differences in electricity prices appear to have influenced the results of the survey. For respondents who own electric cars, there is a trend that in area NO1 and NO3, where the prices have been highest, there is a significant number of respondents who control charging to avoid hours during the day with the highest electricity prices. This is shown in Figure 3.14, where approximately 75% of the respondents from Oslo and Bergen respond that they actively manage their charging schedule. In comparison, only half of the respondents from Tromsø control their charging. Charging electric cars constitutes a part of a household's electricity consumption. At high electricity prices, charging can account for a big part of the cost of electricity. Oslo and Bergen have experienced higher electricity prices than Trondheim and Tromsø, and the respondents from these areas will have a bigger motivation to avoid charging during peak hours of the day when the electricity prices are highest.

Figure 3.5 show the results of the question “Did you pay attention to how the electricity prices varied from day to day and hour to hour during the preceding winter?”. The survey results indicate that respondents from Oslo and Bergen expressed a greater interest in monitoring daily and hourly variations in electricity prices compared to the respondents from the other regions. 16% of the respondents from Oslo and 25% of the respondents from Bergen answered that they were paying attention to the electricity prices every day. In comparison, only 8% and 12% of the respondents from Trondheim and Tromsø, respectively, answered the same.

For those who answered "No, never" to the question, the biggest difference in response was between Tromsø and Bergen. Only 16% of the respondents from Bergen answered in the negative, indicating that a majority of the respondents from Bergen were aware of and paid attentions to variation in electricity prices. In comparison, 29% of the respondents from Tromsø answered “No, never”, indicating a higher proportion of consumers in Tromsø who were less aware of or less likely to monitor variations in electricity prices.

The respondents who answered "No, never" were further asked why they did not monitor variation in electricity prices. The data reveals notable regional disparities in the responses. Figure 3.6 shows that 41% of the respondents from Trondheim answered, "my electricity costs were not that big", compared to 21% in Bergen who provided the same reason. These responses correspond with the differences in spot electricity prices observed in the different regions during the period under investigation, with Central and Northern Norway experiencing lower electricity prices compared to Southern areas Norway.

A noteworthy finding in this regard, shown in Figure 3.6, is that 34% of the respondents from Oslo who answered "my electricity costs were not that big", which is significantly higher than the respondents from Bergen, even though the electricity prices in these areas has been at the same level. This may be related to the fact that more respondents from Oslo than Bergen live in apartments, shown in Figure 3.1, which typically have a lower electricity consumption compared to other type of dwellings. Another explanation for this could be the fact that 35% of respondents from Oslo have heating of tap water from a shared water heater or district heating, compared to only 15% in Bergen, shown in Figure 3.2. With a bigger share of respondents in Oslo with small apartments and less electricity consumption from electrical heating, their total cost of electricity will be lower.

Figure 3.8 shows the distribution on the question “Did you take any actions in the household to reduce or shift consumption from hours with high electricity prices during the day, the preceding winter?”. There are some significant geographical differences, and the biggest difference is between Tromsø and Bergen, where more than 75% of the people in Bergen have answered "Yes", compared to only half of the respondents from Tromsø.

Those who answered "yes" were further asked "What motivates you to reduce electricity consumption during hours with high electricity prices?". Here, the respondents generally agree in all regions. Almost ¾ of everyone have answered "Lower electricity bill". However, the motivation is a couple of percentage points higher in Oslo and Bergen than in Tromsø and Trondheim. For those who answered "No" to the question were further asked why they did not take any action. Here the results are shown in Figure 3.12, where half of the respondents from Trondheim and Tromsø answered "My electricity costs were not that big". In comparison, only 1/3 of the respondents from Bergen answered the same. The results show that there are many indications that electricity prices are an important factor for consumer flexibility in the power market. A trend in the results is that respondents who are from Oslo and Bergen, price areas NO1 and NO5, are more concerned with electricity prices and energy savings than the respondents from Trondheim and Tromsø, which are in price areas NO3 and NO4. This also fits well with how electricity prices have developed since the start of 2021, where Oslo and Bergen have experienced a far higher electricity price than Trondheim and Tromsø. When electricity prices are high, consumption goes down, and when electricity prices are low, consumption goes up. A weakness of the results is that they do not show the respondents' actual consumption during the winter of 2021, so it is not clear whether the respondents' consumption really has decreased or not due to higher electricity prices.

Additional sources that support the significance of electricity prices a determinant of consumer flexibility can be found in data from Statistics Norway (SSB). During the winter of

2021/2022, when electricity prices reached their highest levels on record, electricity consumption for households, service industries and manufacturing decreased by 8.2% compared to the winter of 2020/2021. This was the lowest level of electricity consumption since 2014(Dalen, 2022). Many Norwegian households heat their homes by electricity, causing electricity consumption to increase on cold winter days when heat demand is high. In the winter of 2020/2021 temperatures were at record lows, which will also have an impact on why consumption declined in the winter during 2021/2022. However, if the consumption level from winter of 2020/2021 to the winter of 2021/2022 is compared where outdoor temperature is taken into account, there will still be a decline in consumption for the price areas NO1, NO2 and NO5 where prices were high, see Table 4.1 Table 4.1 Changes in power consumption for the five price areas in Norway with and without temperature correction (Isachsen, 2022).

Table 4.1 Changes in power consumption for the five price areas in Norway with and without temperature correction (Isachsen, 2022)

Area	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**
Change in power consumption from winter 20/21 to winter 21/22	- 7,9%	- 4%	+ 0,7%	+ 5,8%	- 4,2%
Change in temperature corrected power consumption from winter 20/21 to winter 21/22	- 9,3%	- 4,5%	+ 0,0%	+ 3,9%	- 4,3%

High power prices coincide with high consumption, due to increasing underlying demand. Norway has a high proportion of electric heating, which make the electricity demand increase when it’s cold outside. Consumers can respond to high electricity prices by lowering indoor temperatures throughout the building or in some rooms, or by increasing the use of alternative energy sources if possible. Flexibility for private electricity consumers today essentially means money saved in the form of moving or reducing consumption during hours of high electricity prices. Consumers need to see the value of adapting their consumption(Buvik, 2022). High prices also seem to result in increased investments in energy efficiency measures and alternative forms of energy such as heat pumps and solar cells, which affects power peaks and can make consumption more flexible in the short term(Fiksen, 2022).

4.2 Research question 2

To what extent do consumers have knowledge about their own electricity consumption?

In a well-functioning market that ensures competition and efficient utilization of resources, market participants will have incentives to reduce costs and increase revenues. Important for well-functioning competition are products that appear to be equal, so the competition will be determined by price(Grønland, 2021). In the power marked it is important that the consumers have good information and knowledge about the different electricity companies and how the electricity prices vary during the day, to be able to monitor and control the electricity consumption.

Figure 3.3 shows the results of the question "Did you monitor your own electricity consumption during the preceding winter?". The results shows that 75% of the respondents answered "Yes'" to this question. Additionally, the respondents were asked whether they had taken measures in the household to reduce or shift their electricity consumption from hours with high electricity prices during the winter. The results of this question are presented in Figure 3.8, which shows that 75% of the respondents also answered "Yes" to this question.

The respondents who stated they had done measures to reduce or move their electricity consumption during periods with lower high electricity prices, were further asked to specify the type of measures they had done. The most common measures, shown in Figure 3.9, included moving the use of dishwashing machine, washing machine or dryer to other times, lowering indoor temperature, turning off lights or other small electrics, turning off electric heating in rooms that are not being used, and showering shorter for shorter periods or taking fewer baths. 50-60% of all the respondents stated that they had taken one or more of these measures.

Approximately 60% of the electricity consumption in Norwegian households is attributed to heating, and lowering the indoor temperature is the most effective way to save energy. Decreasing the temperature by one degree can lead to 5% less energy use. Additionally, 15-20% of electricity consumption goes to heating of tap water, which means that taking less showers is a good measure to reduce the energy consumption. Electricity for lighting, on the other hand, only accounts for 10% of an average consumption and won't have as much impact on the electricity bill(Elvia, 2022).

The survey results in Figure 3.9 can indicate that the respondents have varying levels of knowledge about which type of consumption are cost intensive. 58% of the respondents stated that they had lowered their indoor temperature as a measure to save energy, which indicate that they have knowledge of cost saving measures. However, it is unclear whether the remaining 42% are aware of the cost saving or if they chose to maintain higher indoor temperatures for comfort reasons. Furthermore, 54% of the respondents stated they had turned off lights or other small electrics to save energy. This may indicate that many think turning off lights or small electrics is an effective way of saving electricity. As stated earlier, electricity stands for only 10% of the electricity consumption, and will therefore have small impact on the electricity bill. However, it is important to emphasize that the respondents were not asked what they think are good measures to save electricity, but what measures they had taken. Turning off lights and small electricity is a simple measure for consumers that will have small impact on the indoor comfort, making it a measure many find easy to do.

The respondents who indicated that they had taken measures to reduce their energy consumption, were further asked whether they believed the actions taken were worth the saving achieved on the electricity bills. Figure 3.10 shows that 74% of the respondents answered “yes” to this question. Furthermore, the respondents were asked whether they know how much their households had saved on their electricity bills because of the measures taken. The results in Figure 3.11 shows that as many as 85% answered "No" to this question.

The finding that a high percentage of the respondents reported taking measures to reduce their electricity bills and even considering them worth the savings, despite the lacking knowledge of the actual savings, highlights the limited level of knowledge consumers have regarding their own electricity consumption. This lack of knowledge can reduce the consumers ability to make informed choices about energy saving. Possible reasons may include automatic payment of electricity invoices through online banking which can result in less awareness off monthly electricity costs, and inadequate invoice design requirements. Although invoices are required to include information about power price and volume, there is no obligation to provide clear indications on the power suppliers mark-up. As a result, it can be difficult to for the consumers to determine how much they pay for electricity, and how much they pay in mark-ups(Løvseth, 2021).

The fact that electricity consumers have limited knowledge about products and prices in the electricity market is also shown in a study conducted by the Norwegian Water Resources and Energy Directorate (NVE) in 2021 "*Measures for an efficient end-user market for electricity"(Grønland, 2021).* The study revealed that there is asymmetric information on electricity bills, indicating various electricity suppliers have different models for calculating prices, making it challenging for customers to compare the actual electricity cost against the electricity suppliers' mark-ups.

The initiative to install automated manufacturing systems, AMS, was intended to increase the electricity consumers knowledge of their own electricity consumption and provide them means to monitor their consumption patterns. To maximize the potential benefits of AMS, it is essential to utilize price information and management options. Emphasizing prices and power consumption can enhance consumer's awareness of their own consumption, and encourage to shift their consumption from peak load hours (Kringstad, 2018). AMS can be a step toward increased knowledge, but expert guidance is required to interpret the power data and put it into a system. The information collected from AMS only holds value if a third-party, such as an energy advisor, can provide customized recommendations and targeted energy advice based on the consumers individual consumption patterns. Access to AMS metering values goes through Elhub, which is a national database for information and communication between the customer, grid company and power supplier. Elhub requires that a third party must enter into a legal agreement with the end customer to gain access to metering values. The requirement to enter into a separate agreement with multiple platforms during the onboarding process results in many customers dropping out(Öberg, 2021).

To facilitate better knowledge for private electricity consumers, opportunities for monitoring must be facilitated and made simple. This is also consistent with the responses from the results in the survey. Figure 3.7 shows the results to the question 'What motivates you to reduce electricity consumption during hours with high electricity prices?". 1/3 of the respondents answered, "Measures that are easy to do manually" and 1/3 answered "measures that take place automatically without me having to think about it". Less than 1/5 answered "test new technology to control electricity consumption". These results shows that many value measures that are simple, and that many won't go into technical details to test new technology. Facilitating simple actions that happen automatically can be an important resource for facilitating consumer flexibility in the future.

4.3 Research question 3

Can private electric cars contribute to flexibility in the power market in the future?

The electrification of the car fleet in Norway is progressing at rapid pace, with electric cars accounting for 73% of all new car sales in 2022. By 2030, it is anticipated that charging of electrical passenger cars will result in electricity consumption ranging from 3 TWh to 4 TWh(Bråthen, 2022). An increasing number of electrical vehicles on the road can cause a capacity issue for the power grid, and it is essential that electric vehicles are not charged during periods of high peak demand. The challenge is not the total increase in electricity consumption, but rather the capacity gap that arises if all electric vehicles are charged simultaneously (Sæle, 2021).

Despite the potential to challenge grid capacity, electrical cars offer a degree of flexibility due to their nature as mobile batteries. The ability to store energy present several advantages. One advantage is that electric cars are not in use when they are charged, enabling much of the charging to occur outside peak grid usage period by using smart control systems. As long as the car is sufficiently charged when needed, it will not impact the consumer how charging is controlled(Horne, 2020).

Figure 3.13 displays that 27% of the respondents own their own electric car who is usually charged at home, which is a higher proportion than reported by Statistics Norway. This is because the survey is conducted on people living in cities, where the proportion of electric cars is higher than the national average(Dokka, 2017). Figure 3.14 shows that 75% of the respondents in Oslo and Bergen control the charging of their electric cars to avoid hours of high electricity prices, which makes a potential for vehicle-to-grid (V2G). With facilitation there is a potential for consumer flexibility where private consumers can contribute to the power market during their charging activities, particularly in urban areas where the proportion of electrical car owners is known to be higher. Moreover, the high population density in urban areas could facilitate more cost-effective and efficient solutions for V2G. By facilitating smart charging strategies, the majority of charging activities can be scheduled outside consumption peaks hours, which can contribute to increased utilization of the power grid. Explicit consumer flexibility, where consumers actively participate in spot or balancing markets via third-party aggregators, could become an important method of exploiting consumer flexibility for private electrical car owners. Calculations from the Norwegian Water Resources and Energy Directorate, NVE, show that the total battery capacity associated with electric cars in Norway could reach up to 100 GWh by 2030, representing an energy reserve that can be utilized to reduce consumption peaks, depending on the number of connected electric cars(Horne, 2020).

The current market structure in Norway restricts participation to power producers who can offer a minimum bid size of 5 MW in price area NO1 and 10 MW in the others. To promote a more flexible power marked who includes private consumers, there is a need for new methods. In 2020, a pilot project named eFlex was initiated by Statnett in collaboration with Tibber and Entelios to explore the potential of utilizing flexibility from smaller consumers. Aggregators were used to consolidate flexible consumption from various consumers. In the pilot, the minimum bid size requirement was lowered in NO1 from 5 MW to 1 MW. Tibber offered 1 MW from panel heaters and electric cars, while Entelios offered 4 MW from industrial companies and 1 MW from commercial buildings(Statnett, 2021b). In this project, innovation was prioritized over volume of power, but nevertheless the pilot parties had a total of 12 MW activated in the regulating power market, of which 7.95 MW was delivered as agreed. The pilot showed that successful integration with Statnett's electronic bid ordering requires testing of flexibility providers, especially related to bidding and activation of bids. But the project has also shown that flexibility down to the end user in the future can be made available to the balancing markets.

Despite a theoretical potential for participation of private electricity consumers in the balancing market, it is imperative that the consumers are motivated and can provide a guarantee of flexibility for it for be a viable approach. Figure *3.7* from show that for 1/3 of the respondents, measures that work automatically and without requiring active though are some of the factors that provide most motivation to reduce electricity consumption for the respondents. This can indicate that the provision of automated solutions is important for private consumers, and something that should be facilitated if they are to effectively contribute to the balancing market.

In 2018, SINTEF collaborated with the Norwegian electric car association, Elbilforeningen, in a project called ModFlex. The aim of the project was to identify the potential for flexibility in charging times for private owner of electrical cars, by using a survey.(Sæle, 2018) A total of 12665 respondents responded to the survey. The respondents were asked about their willingness to move charging from afternoon to night. The result indicated that if the new charging schedule had no negative consequences for the user, 90% were willing to delay the charging time. However, when milage for the following day was reduced to 80%, the proportion of positively respondents decreased to 56,5%. The findings of the survey suggest that predictability to drive with fully charged battery is an important factor for owners of private electrical cars.

Energy storage systems, in conjunction with other measures, can contribute to more flexibility in the power market. Growth of lithium-ion batteries is expected due to high flexibility, continuous technology development and low cost. When demand for power increases in the grid, energy can be extracted from the battery and sold to the grid. In this way, fluctuations in power prices can be managed while at the same time adding flexibility to the system. (DNV, 2020; Nelfo, 2021).

Although consumer flexibility allows for better utilisation of the power grid, it is still an immature solution that requires more research. Today, only large industries can offer consumer flexibility in the balancing markets, and there is uncertain how much flexibility that can be available from private consumers in the future. Even though the technology for V2G is available, the systems are complicated and still at a development stage(Buvik, 2022). Effective implementation of V2G requires optimalization so both the car owner, service provider and the power grid benefit from the technology. (Buvik, 2022; Horne, 2019). Consumer flexibility is not currently considered to be a reliable resource. Implicit demand response can be difficult to estimate, and explicit demand response is not widespread. When grid facilities are developed, it is almost certain that the components function properly. For consumer flexibility to become a credible resource, additional testing is required. (Buvik, 2022).

5 Conclusion and recommendations

5.1 Conclusion

Based on the survey results, it appears that the cost of electricity price is an important factor for consumers' willingness to be flexible. Respondents living in regions that have witnessed high electricity prices tend to be more flexible than those living in areas with lower prices. Respondents from Oslo and Bergen, who experienced high electricity prices during the winter of 2021/2022, monitored variations in the electricity prices and took more measures to conserve energy, compared to respondents from Tromsø and Trondheim, where prices remained relatively low. Statistics Norway's data on electricity consumption by private consumers corroborates these findings, indicating residents in Oslo and Bergen reduced their electricity consumption during the winter of 2021/2022, while consumption levels in Tromsø increased. These observations can indicate that the electricity price is an important factor to facilitate a more flexible power market for private electricity consumers.

The extent to which the respondents have knowledge about their own electricity consumption varies. What many respondents, 54%, stated as a measure they had done to save energy during the winter of 2021/2022, was turning off lights and other small electrics, despite this having only a minor impact in saving energy. However, 58% of the respondents reported reducing the indoor temperature as a measure they had done during the same period. Reducing indoor temperature holds a significant potential for reducing electricity consumption. The results indicates that many of the respondents seem to know what saves energy, but there are also many who should prioritize their actions differently. However, the results only indicate which actions they took, not which actions they think are the most energy-saving.

It appears that there exists a notable knowledge gap among the majority of the respondents in the survey regarding the precise financial benefits associated with each respective action. Among the respondents who stated they had taken actions to reduce their energy consumption, as many as 85% stated they did not know how much they had saved with their actions. A key factor that could improve the consumers knowledge and increase their motivation to conserve energy is the ability to observe the direct financial impact of each measure more clearly. This can be solved with Advanced measurement systems (AMS), providing consumers with more precise information about their consumption patterns.

Energy storage systems, such as private electric vehicles, have potential to improve flexibility in the power market. Lithium-ion batteries are known for great depth of discharge, high cycle life, technical advancements, low cost, and is likely to further drive the growth of electrical vehicles. Batteries in combination with vehicle-to-grid(V2G) technology is expected to be an important method for private electric car owners to participate in power market in the future. By 2030, it is assumed that such technology can provide an energy reserve up to 100 GWh. However, it is important to note than consumer flexibility is currently not a reliable resource, and additional testing in required to establish its credibility.

Consumer flexibility is an important area of investigation due to increasing power demand and rising electricity prices. Utilization of consumer flexibility is in theory an easy and socio-economically beneficial way to reduce power consumption, but in practice it requires facilitation and increased information about the electricity consumers. By increasing knowledge about the consumers habits and needs, it is possible to facilitate consumer flexibility, which can help reduce power demand, reduce grid investment, and save society large costs.

5.2 Policy recommendations

To develop a market for flexibility, I have listed specific measures which policy makers should act upon.

1. Consumers knowledge about their power consumption may encourage them to shift their consumption from peak load hours. AMS can contribute to this, but the complex processes lead to a high number of customers dropping out. Improving the workflow of gaining access to metering values could be a step in right direction.

2. Provide attractive tariffs for flexibility-services. Making grid-stabilization through flexibility trading an attractive business case could interest entrepreneurs and businesses to develop technology and collaboration more rapidly. Furthermore, include consumers in flexibility and making it economically profitable could open for new business models and improve the grid.

5.3 Limitations of this study

A quantitative analyze makes it possible to obtain and systematize information from large groups, but the disadvantage is that information can be missed since the survey only provide the respondents to answer questions explicitly asked in the survey, and hence, fail to uncover underlying reasons behind the respondents' answers.

The survey has been conducted among residents in urban areas, rendering it non-nationally representative. Furthermore, the sample consist of a larger proportion of individuals with higher education and income, which may affect the results of the results(Fredborg, 2023).

5.4 Further studies

Consumer flexibility has great potential to be relevant in the future, but it demands more research, knowledge, and facilitation to make it a safe source of flexibility. Consumer flexibility is a research area that should be prioritized as it can contribute to a more flexible power system in a time of energy shortages.

Statnett is planning for new quantitative surveys about consumer flexibility, and it would be interesting to compare the results in this master's thesis with new results. Comparing two similar surveys from two different time periods provides an interesting insight into how consumers are affected by variations in electricity prices, especially now that the energy prices has remained high over a longer period.

V2G appears to have the highest potential of future consumer flexibility and further studies should focus in depth on vehicles and consumers' willingness to add their car to the flexibility marked.

Overall, it is essential to prioritize research into consumer flexibility and related technologies to create a more flexible power system that can meet the demands of the future.

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