RENEWABLE ENERGY AND SWEDEN

An overview of how different regions in Sweden work towards an increase in implementation of renewable energy.

ALFRED SJÖLANDER

JOEL ESPLING

School of Business, Society and Engineering
Course: Degree Project in Sustainable Energy Systems
Course code: ERA401
Credits: 30
Program: Master's programme in Sustainable Energy Systems

Supervisor: Anders Nordstrand
Examinor: Amare Desalegn Fentaye
Date: 2023-06-12
Email:
asr21004@student.mdu.se
jeg21003@student.mdu.se

ABSTRACT

The goal of achieving carbon neutrality for year 2045 puts Sweden on a road towards further implementation of renewable energy into their energy system. The goal of this degree project is to investigate how the implementation of renewable energy in Sweden is worked towards on a regional level but also to explore how this expansion might look for the Norra Småland Region. By conducting several semi-structured interviews with the energy agencies of Sweden as well as creating a model for the potential solar and wind power expansion in the Norra Småland Region, the authors aim to answer the questions of how the current work with expanding the renewable energy share in the Swedish energy system is conducted; what bottlenecks, problems and challenges exist and what tools, data, information and incentives might help further facilitate this work. Through the interviews conducted, this degree project encapsulates the different projects related to the subject of renewable energy which the various regions of Sweden work with. The degree project also provides a compilation of various challenges related to the projects as well as an insight into what tools and incentives are asked for by the regions with the goal of helping facilitate the work conducted. The degree project also provides a projection for how the future expansion of wind power and solar power might look in the Norra Småland Region based on the previous expansion trends, resulting in three individual projections with individual growth rates.

Keywords: Renewable energy, Solar power, Wind power, Sweden, Interview study, Modelling of solar and wind potential, Future energy systems,

PREFACE

Through three years of renewable energy studies at Halmstad University and two years of study at the Master's programme in Sustainable Energy Systems at Mälardalen University the theoretical aspect of everything related to energy has been investigated.

However, the practical aspect of how said work actually is conducted has felt more distant. The aim of this degree work was therefor to bridge the gap between theoretical and practical knowledge related to energy.

We are ever thankful for the cooperation of the participants of the interviews and the time and effort they have provided us. Time and effort which have given us with many years' worth of knowledge and insight into working with energy questions.

Further we would like to thank our supervisor Anders Nordstrand, examinator Amare Desalegn Fentaye and course responsible Eva Thorin for helping us along the way.

Joel Espling Signature: Joel Espling

Mälardalen University, Västerås June 2023

Alfred Sjölander Signature: Alfred Sjölander

Mälardalen University, Västerås June 2023

CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

Abbreviation	Description
SDG	Sustainable Development Goals
RUL	Regional Development Manager
EKR	Energy and Climate Counselling
GIS	Geographic Information System
ERUF	European Regional Development Fund
MSEK	Million SEK
SCB	Statistics Sweden
PV	Photovoltaics
MWp	Mega Watt peak

DEFINITIONS

Definition	Description
Case-by-case	Separate distinct from others of the same kind
The Swedish Energy Agency	Energimyndigheten – Swedish Energy Agency Responsible for energy related policies and legislations
Energy Agencies Sweden	Energikontoren – Swedish network of 16 regional energy agencies.
Vestibular system	The vestibular apparatus is located in the inner ear, the eye, the central nervous system and various nerves, tracts and nuclei connecting them as they relate to proprioception and spatial orientation.

1. INTRODUCTION

1.1 Background

Since Sweden has taken on the goal of being carbon neutral for the year of 2045 (Klimatpolitiska Rådet, 2022), and renewable energy is playing a big role in this transition, the authors of the degree project wanted to “map” how Sweden and more exactly, different municipalities in Sweden work with the implementation of renewable energy.

Solar power generation has increased worldwide throughout the years although it still, compared to wind power generation and other renewable electric power sources only stands for a small amount of the total electricity mix even in locations with the highest penetration levels. In the year 2008, 3.1 MWp grid connected solar power facilities was installed in Sweden. Wind power produced 1.6 TWh the same year. During this time, one support scheme had been granted for solar power installation but there existed no feed-in credits for electricity generation and also, due to high investment costs, solar power was not seen an attractive investment (Widén, 2010). This entailed that Sweden installed more off-grid capacity. However, after 2007, more grid-connected solar power was installed and after 2016, Sweden had about fifteen times more grid-connected capacity than off-grid capacity reaching a total of 200 MWp at the end of the year (Landelius et al., 2018). In the recent years, the expansion of the installed solar power capacity has increased significantly and has reached a number of 1.6 GWp (Energimyndigheten, 2022).

In 1975, a long-term objective was established by the Swedish parliament to convert from exploitation and implementation of non-renewable energy sources such as fossil fuels and uranium to an increased use of renewable energy sources. These objectives were well in line with the European Union’s goal to increase the share of renewable electric power production to 22% in 2010 from the then current 14%. During the 1970s, the price for the import of oil was high, and this spurred the Swedish government to support an increased share renewable energy. In 2005, established goals to phase out nuclear power existed along with benign environmental attributes of renewable energy and in spite of this, wind power, although appearing to be one of the most promising sources of renewable energy, was still considerably modest in terms of implementation in Sweden compared to other countries such as Denmark, Germany and Spain. (Söderholm et al., 2007)

The electricity systems of Denmark, Norway and Sweden are today well-integrated and form a joint electricity market. There exist differences in the legal and economic preconditions for investment in wind power and other renewable energy sources for the various countries. The importance of the choice of policy support schemes are most significant. In Sweden in particular, the support systems have been less stable over time, and this have resulted in weak economic incentives from politicians. The reason for this instability in the support system schemes have historically been a product of the alteration in governmental support. The support schemes were often changed from one year to another and this entailed no guarantee of sustained support over the lifetime of a wind power project for the investors whereas in

Denmark, the support was guaranteed through the implementation of fixed price contracts or fixed feed-in tariffs over a longer duration of time (often 10 years). In 2003, the green certificate system for renewable energy was introduced in Sweden for the purpose of securing a pre-determined market share for renewable electric power sources along with the promotion of a cost-effective competition between various types of renewable energy sources. This system exchanged the previous investment subsidy programs and has been a key to increase the expansion of wind power in the country. (Pettersson et al., 2010)

The government of Sweden fundamentally has three levels. A national level which is represented by the Swedish parliament, a regional level which is represented by Sweden's 21 individual counties with their own regional counties and a local level which is represented by Sweden's 290 individual municipalities. But it is also worth mentioning that since joining the EU in year 1995, Sweden is governed above the national level by decision-making in the European Council, effectively giving Sweden a fourth, European level of government. (Government Offices of Sweden, 2015)

The energy agencies Sweden is a network of 15 individual energy agencies in Sweden whose purpose is to impartially steer Sweden towards a sustainable energy system through implementing, coordinating and facilitating work with energy and environment policies. The 15 regions for the energy agencies of Sweden are based mainly on the administrative borders of the counties of Sweden on the regional government level mention above. However, a combination of Skåne county, Blekinge county, Kronobergs county and Kalmar county make Region Syd. Uppsala county, Västmanland county and Södermanland county make up the Mälardalen region, and Norrbotten county and Västerbotten county make up Region Norr. (Energy Agencies Sweden, n.d.)

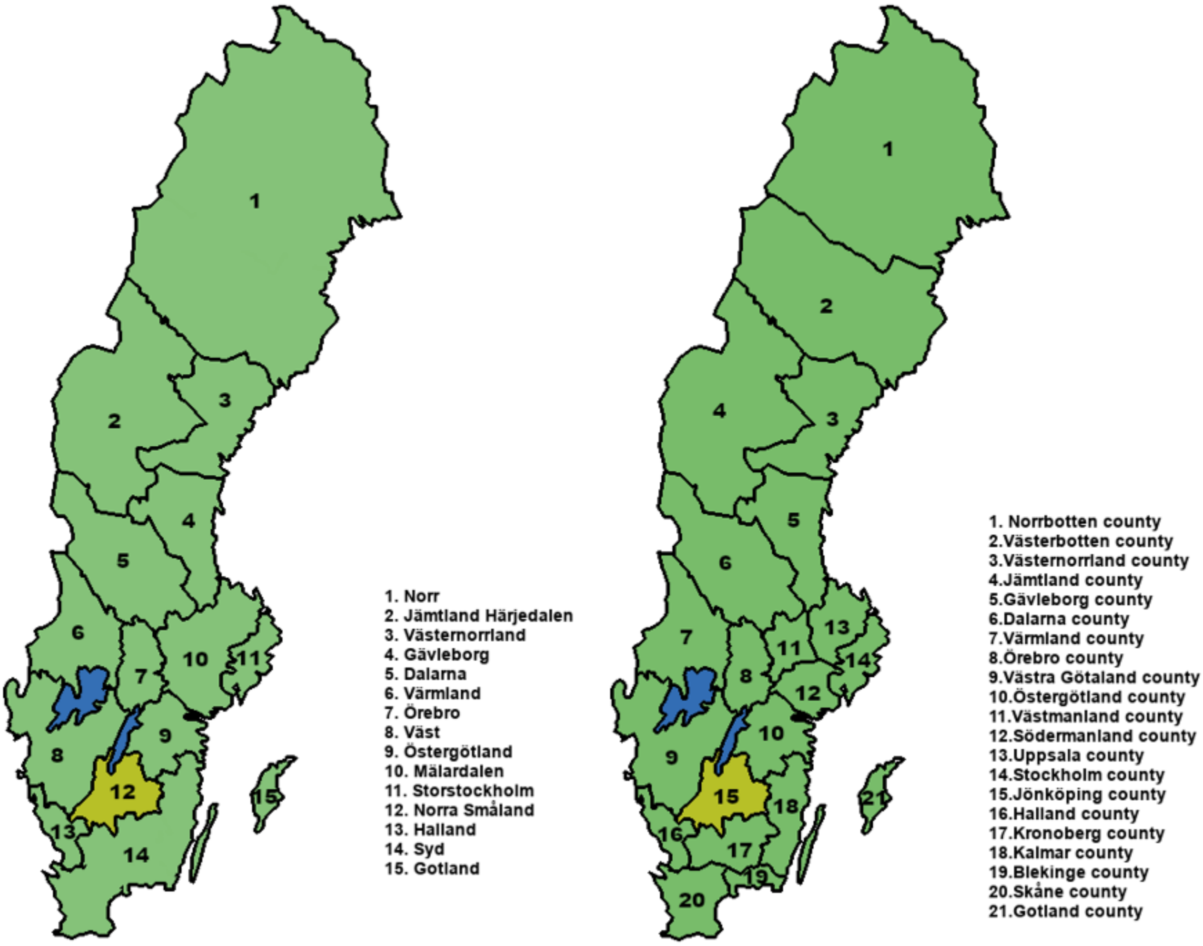

Figure 1: (Left) A map over Sweden's 15 regions corresponding the 15 energy offices of Sweden and with the Norra Småland Region, which was chosen for modelling, colored yellow (Energikontoren Sverige, 2023). (Right) A map over Sweden's 21 counties. Here Jönköping County has been colored yellow (SCB, 2007).

Of note for Figure 1 is that Jönköping County and Region Norra Småland are geographically identical.

1.2 Aim

The aim for this degree project is to evaluate and map how Sweden as a whole works towards an increase in implementation of more renewable energy through researching how each individual region work with questions related to renewable energy. Furthermore, the aim is to create a projection of the future expansion of solar and wind power in the region Norra Småland through investigating the expansion in terms of power output, economy, and roll-out time.

1.3 Research Questions

- How do Sweden's different regions work toward goal 7 of the United Nations' (UN) sustainable development goals?
- What might help the regions in their work towards the implementation of more renewable energy?
    - Which problems or bottlenecks exist?
    - What tools or information might benefit?
    - Which political incentives would be needed?
- In the chosen region, what potential exists for expanding wind power or solar power respectively in terms of economy, power output, and roll-out time?

1.4 Delimitation

For the degree project, the broad perspective on renewable energy and the energy question related as a whole has been considered. However, extra focus has been put specifically on wind and solar power both for the interviews and the modelling part of the degree project. The projections for future expansion of wind power and solar power have been done only for one of Sweden's 15 regions due to the time constraint of the degree project. The Norra Småland Region was chosen on the basis of there not, to the knowledge of the authors being any previous research on the potential of the future wind and solar power expansion in the region. For the interviews, only one person per region has been interviewed.

For the projections for the future expansion the economy calculations will be used only with the current SEK. No consideration was taken to the future inflation on account of the time restrictions of the degree project. Another delimitation for the solar part of the projection was that data for current electricity generation in Jönköping County only existed for one year. The effects that extensive amounts of renewable energy have on the stability of the grid have not been investigated.

2. THEORETICAL FRAMEWORK

2.1 UN's Sustainable Development Goals

In 2015 the members of UN adopted the 17 sustainable development goals (SDG) specified in the report my General Assembly (2015). These are 17 goals with the one goal of solving some of the world's greatest global challenges. Challenges such as, poverty, world hunger and protecting the planet from degradation and more. The 17 goals span everything from goal 1 which has a goal of ending poverty to goal 5 which is to achieve gender equality and empowering women and girls as well as goal 13 which is to combat climate change. Goal 7 of the SDG's which revolves around the topic of energy accessibility and sustainability. (General Assembly, 2015)

For goal 7 of the SDGs the subgoals are as follows:

> 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services
>
> 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix
>
> 7.3 By 2030, double the global rate of improvement in energy efficiency
>
> 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology
>
> 7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support. (General Assembly, 2015, p. 19)

2.2 Semi-Structured Interviews

The semi-structured interview was at its cradle designed to ascertain subjective responses from persons regarding a particular situation or phenomenon they had experienced. It might be implemented in a case when the objective knowledge about a particular experience or phenomenon is deemed to be sufficient, but the subjective knowledge is limited. The participants are free to answer the questions, which are open-ended, as they see fit and the researcher is allowed to probe the responses. The answers of the interview-questions are allowed to be flexible, and this constitutes the semi-structured aspect of the method in question. Apart from other interview methods, the semi-structured interview is recognised due to the provided relevancy it provides the topic simultaneously as the interviewers are remaining responsive to the participant. The data provided by semi-structured interviews cannot be obtained through the use of structured questionnaires, participant observation or analysis of literature. However, semi-structured interviews can be combined with these data collection strategies in order to obtain a more detailed result. Compared to the guided interview, where the structure of the interview is reflected depending on the participant's response to a, so called, grand tour question. Depending on the response, the researcher follows with loosely organized list of questions. The responses are not individually collected, the analysis is not performed case-by-case but rather by categorization. When it comes to the semi-structured interview however, the questions that are asked are in the same order for each participant and all the data that is acquired are analysed in a case-by-case systematic manner (McIntosh & Morse, 2015).

Historically, there has existed diversification in various fields that has implemented semi-structured interviews. The differentiation has been a product of different purposes, the role of the participant(s) in the research, the established knowledge implicit to the interview guide, and the outcome of the research. The semi-structured interviews have thus been divided into four types as can be observed in the bullet-list presented here below:

- Descriptive/confirmative
- Descriptive/corrective
- Descriptive/interpretive
- Descriptive/divergent

The descriptive/confirmative contemporary type of semi-structured interviews has the purpose of obtaining subjective responses to the objective knowledge to test hypothetical conjectures or theoretical frameworks. The responses of the participants are most relevant in this typology to confirm the frame of the research. The descriptive/corrective type of semi-structured interview has the purpose of evaluating the dominant diffuse representation of an experience by the comparison of the actual experience of the participant. The outcome of the research thereby has the purpose to confirm, refute or elaborate upon the conjectures of the frame. The desired outcome of the descriptive/corrective semi-structured interview is that the participant's response will act as a corrective to the framework and in some cases effect political action for change. The descriptive/interpretive type of semi-structured interview has the purpose of discovering the experiential world of the participant within dimensions related to the topic. The intention of the descriptive/interpretive semi-structured interview is to expand the frame of the work by the help of the responses from the participant. The limited knowledge can also be refuted by the participant's perspectives and produce new hypotheses, categories, and themes. The purpose of the descriptive/divergent type of semi-structured interview is to provide contrast to different perspectives and experiences (McIntosh & Morse, 2015).

2.3 Social Acceptance Towards Solar Power

There are numerous examples of situations where solar power has been implemented into the society with successful results. Just like with wind power in Denmark, the social acceptance has highly depended on the country's energy policy and the means to deal with various entailments of energy related problems. In 2008, Germany led the world market in the use of solar electricity domestically and the manufacturing of photovoltaic cells respectively. One quarter of the total world market for residential solar PV-systems was installed in Germany with a capacity that exceeds 3700 MW. (Sovacool & Lakshmi Ratan, 2012). In 2018, Germany had an installed a capacity of 39 GW. (Gürtler & Paulsen, 2018) The reason for Germany's acceptance towards renewable energy sources is due to its history. In the 1990's, when the country was divided into two blocks, Germany was reliant almost entirely of domestic coal for electricity generation with the objective of self-sufficiency. The commitment to fossil fuels underwent a fundamental shift when the country united, and a more anti-nuclear, pacifist movement and a policy culture of strong governmental intervention took place. Anti-nuclear mainly due to the events that followed the Chernobyl accident since the south part of Germany was affected by the fallout. The German economy was highly regulated and this facilitated acceptance of several measures, feed-in tariffs, subsidies, targets, and other political incentives to promote residential solar panels. (Sovacool & Lakshmi Ratan, 2012)

2.4 Wind Power and the Interests of the Military Power in Sweden

The amount of installed wind power in Sweden has grown quickly in the recent decades but with this increase in wind power comes an increasing problem of land use conflicts. One of the parties clashing in interests with the interest of and expansion of wind power being armed forces of Sweden. The military in Sweden is not against the expansion of wind power in Sweden as a general. However, land area of interest for the military and specifically the military aviation in Sweden and land area of interest for wind power companies in many regions coincide. Open areas with low population density are land areas of interest for both the military aviation and wind power companies. For the military aviation the areas are valuable training grounds for low flying aircrafts at an altitude at which any wind turbines installed would impact the military aviation's ability to be able to operate said aircrafts at high speed and low altitude. Other than this, the height and nature of the rotating blades of the wind turbines is of course a safety hazard to take offs and landings if places in close vicinity to airbases. Another way wind turbines interfere with military interest is by interfering with the accuracy and disturbing instruments for reconnaissance such as radar system. But it can also affect radio communication where bad weather conditions in combination with the disturbance of the spinning wind turbines can render the communication system undependable. (Lindgren et al., 2013)

In their report, Lindgren et al., (2013) look at the military, the wind power industry and relation between them in Sweden, Norway, Denmark, Finland and Germany. Here it is mentioned that the Swedish and Finnish pilots undergo their training at home, while Norway, Denmark and Germany send their pilots abroad for at least parts of their training. Combining this with the tactic of flying low and the fact that Sweden is also less population dense in comparison to countries such as Germany and Denmark, leads these countries having far more extensive restrictions than Sweden when it comes to low flying.

The planning and permitting systems differ for each country. While there is communication with the military related to the planning and permitting of wind power for each country, the communication is conveyed in different stages of the planning and permitting and performed in different ways for the individual countries. For Sweden, the military is only one of the parties which handles the permits for the wind turbines, where the interests of nature conservation is another part taken into consideration for the permits by another party. (Lindgren et al., 2013)

Lindgren et al., (2013) conclude that better communication, improved understanding for the interest of the other party would help the current and future planning of wind power. But also, that a better technical understanding of the interactions between wind turbines of military instruments and wind turbines as well as a possible reforming of the planning and permitting system could have a positive impact on the future expansion of wind power in Sweden.

2.5 Social Opposition of the Expansion of Wind Power

The social opposition of wind power is a subject that occurs in several previous studies where the authors have tried to measure the general public preferences related to the subject of wind power establishments. In a study performed by Ek & Persson, (2014), the general acceptance towards wind power establishments in Sweden was analysed with the help of data from a sample that came from a web panel consisting of 90 000 Swedish citizens. The data covered areas related to specific attributes of interest such as type of landscape, type of ownership, invitations to participate in the planning process, revenue transfer to the society, and monetary cost in terms of an electricity certificate fee. The result of this analysis showed that the choice of preferred wind farm was offshore in general. It also showed that the public did not like the notion of placing wind turbines in mountainous areas. Based on these results Ek & Persson, (2014) argue that in the future, offshore developments could prove to be less in favour of scepticism from the general public. Also, based on the analysis, Ek & Persson, (2014) argue that people's perception of the development of wind turbine establishments in landscape types that people use for recreational purposes is more negative or sceptical. However, the perception of the people seemed to change when the landscape investigated for wind turbine establishment was the types of landscapes where the respondents lived permanently. The analysis also showed that from a consumer perspective, municipally owned wind farms were viewed as better alternatives than private ownership. This finding is also shared by Enevoldsen & Sovacool (2016), who found that social acceptance is higher in regions where the local population are committed directly as stakeholders with ownership than in areas where commitment among locals is less coherent with the wind project developer. In other words, acceptance is dependent on the local inhabitants' sense of ownership towards the wind project.

The past decade has been fortunate in terms of installed wind capacity in Sweden. This was ensured by the renewal of the green certificate schemes in 2003 and 2006 with the implication of additional financial benefit to the market price for green electricity. Many large wind project developers have focused on Swedish market due to this. The result has been an increase in installed capacity from 509 MW in 2005 to 6519 MW in the end of 2016 (Enevoldsen & Permien, 2018).

The most important parameter for the promotion of wind power have historically been the national energy policy. When compared to Denmark, Sweden entered the wind market later because of the fact that Sweden's energy policy did not focus on wind power as a solution to the oil crisis in the 1970's, as mentioned in the background section of this report. This is also the reason why Sweden has multimegawatt wind turbines as standard and the entailment of this that large investment organizations rather than small private local investors have been influencing the Swedish wind energy market (Enevoldsen & Permien, 2018).

Today, Swedish municipalities and local inhabitants have the right to turn down wind projects. In regards to the expropriation act, expropriation with the object of "meeting a public demand for electricity" may be permitted unless the purpose of the expropriation is best met by other means, or if the damages of the expropriation from the viewpoint of the affected public and private interests exceeds its benefits. This means that private property might be expropriated if the purpose is to establish installations that meets the electricity demand if the benefits of the installation in question exceeds the damages associated with the expropriation of the property. Although various energy installations are covered by the expropriation rule, previous research have shown that this rule, most likely, is not applicable when it comes to harness energy from a natural resource, such as wind. (Pettersson, 2008)

The social opposition of wind power shows similarities with the opposition towards hydropower, nuclear and biomass as they were introduced to as energy sources in Sweden (Enevoldsen & Permien, 2018). The protesters against wind power have taken a conservative stance in the political debate concerning energy matters. By definition, the opposers defend the route the Swedish energy policy took up through the implementation of electricity certificates in 2003, and thus, they are becoming supporters of hydro and nuclear power with the claim that those sources of energy are more sustainable (Anshelm & Simon, 2016).

2.6 Environmental Impacts of Wind Power

Based on the results from the study performed by Ek & Persson, (2014), the social opposition towards wind power has been an impediment for wind power development in Sweden. However, when considering wind turbines, there are environmental aspects to consider such as noise, visual impact, and the effects that wind turbines have on the local wildlife (Leung & Yang, 2012).

When it comes to noise, there are two types of noises that wind turbines produce. Mechanical noise and aerodynamic noise. The aerodynamic noise is of low frequency and are considered as the most critical of the two. According to Leung & Yang, (2012) these low frequency noises can cause stress symptoms such as headaches, sleep disturbances and damages to the vestibular system of people living nearby wind turbine establishments.

The visual impact is more complexed since some people have tendencies of thinking that wind turbines are pleasant to look at, even impressive while others tend to disagree with the image of a spinning wind turbine. There exist arguments that wind power establishments are damaging the local tourism because of the visual impact that the wind turbines are imparting (Leung & Yang, 2012).

The effects wind turbine establishments have on the local wildlife can also be a part in the social opposition since wind turbines are allowed to be built in the habitats of various species of birds. In Texas, avian radars are set to protect birds in areas such as these. Once a bird is detected in a potentially dangerous area, the wind turbines are shut off Leung & Yang, (2012). In European countries, there are prohibitions of building in areas that can be associated with environmental claims. These are referred to as "protected areas" such as nature reserves, natural parks, biosphere reserves and fauna-flora habitats. There are also other areas like bird-or bat sanctuaries. Directives from the EU has declared several of these areas in Europe. In Sweden, areas that are defined as environmental constraints in regard to wind power expansion are nature reserves, ecologically sensitive areas, and wetlands (Permien & Enevoldsen, 2019).

2.7 Previous Studies

2.7.1 The Role of Sörmland Region in the Energy Transition of Sweden

Sörmland or Södermanland is one of Sweden's 21 regions and in a pilot study produced by Sweco, for Region Sörmland Ersson et al., (2022) have examined how the projected increase in use of electricity will affect the region as well as how the progression of implementation increased electricity generation specifically from solar, wind as well as biogas use and production might look.

According to Ersson et al., (2022) the electricity use in the region is projected to increase by 1 TWh until 2030, which corresponds to about 30 % of the region's current yearly electricity use. In addition to this increase there has also been noted an increased interest in biogas since SSAB are increasing their efforts and work towards fossil free steel production.

The region stands for about 6 % of Sweden's greenhouse gas emissions while simultaneously being one of the regions with the lowest amount of electricity generation. The region does have 18 small scale water turbines amounting to about 24 GWh of produced electricity, as well as 14 GWh of solar produced and 30 GWh from Wind. The progression of installed solar capacity in Sörmland Region is fast however the progression of wind is facing bigger resistance due to conflicting interests as well as lesser wind conditions.

While there is some resistance to wind power electricity generation in Sörmland Region, resulting in a close to no growth in installed capacity in the region. However, there are still projects in motion in the region, both land-based and offshore. One of the big factors in the progression is the social acceptance of wind power which in the region is very low. As comparison the opinion on solar power in the region is much better. (Ersson et al., 2022)

Various projects for solar power in Sörmland region add up to a total of 74 MW with planned starts from 2022 to 2024, spread through four individual projects in different phases of their development. The potential for solar panels on roofing has been estimated to about 100 TWh.(Ersson et al., 2022)

Ersson et al., (2022) identify the municipal veto as one of the central pieces in the question of wind power installation. Where 78 % of all establishments in 2021 were stopped by the municipal veto. However, a few other key components for the progression of development of renewable energy in the Region are also named as a better planning for local electricity generation for renewable energy, more inclusion of power supply in the planning, integration of solar power in buildings both new and old as well as better work towards a closer cooperation between actors in the region to further support the knowledge and interests needed to further develop solar and wind power in the region. (Ersson et al., 2022)

2.7.2 Future Electricity Generation in Sweden

The energy system of Sweden is already fossil free for the most part. This has improved the country's chances that it will be completely fossil-free in during the time span of 2030-2050. The energy mix will consist of hydropower, biofuels, solar and wind power or new nuclear power. (IVA, 2017)

According to the report *Future Electricity Production* by IVA, The Royal Swedish Academy of Engineering Sciences there exist four main pathways to meet the energy demand in the years 2030-2050. The demand for electricity is expected to be between 140-180 TWh with estimated maximum power capacity of 26-30 GW. The scenarios are listed here below:

- More solar and wind
- More bioenergy
- New nuclear power
- More hydropower

Each of the listed scenarios make up their own individual energy mix but with the main focus being specifically on the energy sources named in the scenario. The scenario for solar and wind power has the ability to generate a lot of energy but one of the limitations with this scenario is that the ability to deliver power or guarantee power is lower. Therefore, this solution would need to have technical supplementary systems in order to deal with the peaks in demand when the electricity consumption is high. In the reverse situation, when there is energy surplus in the system, supplementary systems would also be needed. In the scenario "More bioenergy", Sweden has the potential to become self-sufficient in energy power. The system is based on domestic fuel and electricity production and thus the need for transmission capacity is mitigated. To achieve this, new technological development is needed to improve the efficiency of the plants. The "New nuclear"-solution is the scenario that is most similar to the system implemented in Sweden today. Substantial systems will not be required. The technology for third generation of nuclear plants is most likely to have been developed for implementation by 2030. Expertise in this area will be required to ensure that the country is taking well-informed decisions. The "More hydropower" scenario would involve an expansion located at rivers and streams that are protected by law at this moment. For this scenario to occur, the laws concerning wildlife and water streams would need to be changed. However, like the "More bioenergy” scenario, this scenario has the potential to make Sweden self-sufficient in terms of energy and power. Hydropower is one of the most flexible energy sources since it has the ability to store energy. An amelioration of the transmission grid in the south part of Sweden would be needed ensure the outcome of the scenario since the hydropower capacity is located in the northern part of Sweden. An increased share of energy exchange between countries would also be needed due to the large differences in domestic energy this system would have between dry and wet years respectively in terms of participation. (IVA, 2017)

Concerning the “More solar and wind”-scenario where the capacity for these technologies is being expanded. Today, wind power exists to a large extent in the south part of Sweden and along the coasts. The future expansion of wind power could thereby either occur on land with an increasing number of wind turbines erected in forests. Mainly in the northern part of Sweden. The expansion could also entail more efficient wind turbines replacing older ones in profitable places. Larger offshore wind power parks could also be built. The electricity generation could reach a maximum of 70 TWh. When it comes to solar power, the scenario also suggests that there exists great potential for expanding solar power on roofs and fields in Sweden, even though the bulk of the electricity is generated between March and October one advantage of solar power is that it is possible to forecast electricity generation a few days ahead. (IVA, 2017)

2.7.3 Sweden’s Potential for Electricity Production from Roof Mounted Solar Cells

In study on Sweden’s potential for electricity production from roof mounted solar cells Kamp, (2013) investigates the theoretical, technical and economic potential of roof mounted solar cells in Sweden. Through using data on the amount of built area in Sweden as well as type and tilt of the roof among others, Kamp was able to make an estimation on the potential of roof mounted solar cells (Kamp, 2013).

According to the report, the total roof area to be 319 km^2 and results show that, where only maximum installed power to be considered, a total of 47.9 GW of capacity would be able to be installed, producing a total of 49 TWh of electricity per year. She continues to state that at the date of writing the report, it would not be profitable to install solar panels on the roofs of houses in Sweden. With an investment cost of 20 SEK/Wp and a subsidy of 35% Kamp concludes that the price of electricity needs to substantially increase for the investment to be profitable. (Kamp, 2013)

3. METHOD

This degree project can be divided into mainly two individual parts. An interview with the energy agencies of each region in Sweden, and a model of the potential of solar and wind power for one of said regions. For the purpose of creating a model for a region the authors chose to investigate the potential of the Norra Småland Region, which was chosen because of the apparent lack of any previous studies on the potential of wind and solar power in the region. For the data collected for the models, the data is denoted as Jönköping County. Jönköping County being the geographical area and the Norra Småland Region being the acting region in the same geographical area. Hence, the names Jönköping County and Norra Småland Region will be used interchangeably for the rest of the report.

3.1 Interview Approach

The approach for the interviews was semi-structured and the typology chosen was descriptive/interpretive. This, because of the fact that the framework was elaborated upon by the responses of the participants in the manner of providing the authors with additional information that could widen the scope of the framework for the degree project.

For compilating and summarizing the interviews the methodology was as follows. The interviews were conducted online via zoom where the interviewers (us students) where responsible each for one part of the questions and the interviewees (the energy agencies) answered the questions.

All interviews where recorded and then transcribed. After all the interviews where transcribed the general answers for the questions where compiled / summarized into an excel ark and then converted to a table for easier being able to compare the resulting answers of the individual regions.

3.2 Energy Policy Interviews

For the purpose of answering the research questions of this degree project, interviews were conducted with the responsible energy agencies of each region in Sweden, investigating how the different regions work with the renewable energy. Sweden along with all other member countries have agreed to try to achieve the SDGs. Goal 7 of the SDGs, concerning the access of affordable, reliable, sustainable and modern energy for all is the goal which this degree project mainly revolves.

Through conducting a semi-structured interview, the goal was to collect data for how the different regions work towards implementing specifically renewable energy into the energy system as well as finding out about bottlenecks that each of the different regions can identify as well as tools the regions recognize as needed for future work. The interviews were conducted in Swedish via zoom calls and further transcribed and translated to English for the report.

In order to map the development in the field of implementation of renewable energy of the country as a whole the authors decided to contact the 15 energy agencies of Sweden to set up an interview with each individual agency and corresponding region and investigate how the work towards further implementation of renewable energy in the Swedish energy system is proceeding. Each of the individual energy agencies were willing to accept partaking in the interview. A total of 13 out of the 15 individual energy agencies of Sweden where able to participate for the interviews. Here regions Jämtland Härjedalen and Gävleborg were unable to participate in the interviews and thus excluded from the subsequent answer compilations.

The interview was divided into two parts, where the first part was about the continuation of the work towards implementing more renewable energy into the system. The other part was about what would help with the work. The interview questions are presented here below as follows:

3.2.1 Part I: How does the region work with the implementation of renewable energy?

- Do you have any examples of renewable energy projects that your region is currently working on or have there been any projects in the past related to this topic?
- Do you have any examples of challenges that have emerged or problems that have occurred during these projects that are central to your region?
- How does the region work with these challenges or problems?
- Are there any examples project related to wind or solar energy in your region?

3.2.2 Part II: What would have facilitated the work?

- Have there existed or emerged any bottlenecks or problems with the implementation of these projects?
- In retrospective, what tools, data or additional information would have been necessary or helpful and what tools, data or additional information could be helpful or needed in the future?
- Any examples of political incentives that might be needed or helpful?

3.3 Modelling of Potential for Solar and Wind Energy in the Norra Småland Region

The second part of this degree project is the more engineering centred task of modelling the potential for solar and wind of one of Sweden's regions. For this task the region of Northern Småland was chosen because of its appearing lack of previous studies on the potential of solar and wind energy in the region.

3.3.1 The Potential of Solar Power in the Norra Småland Region

The Swedish Energy Agency provides data for the total solar electricity generation of Sweden as well as total installed capacity. For this purpose, annual data for electricity generation as well as installed capacity yearly was used. The capacity factor for solar power in Sweden could then be generalised through:

$$cf = \frac{E_{Generated}}{P_{Capacity} * 8760}, \tag{1}$$

here, cf is the capacity factor for solar, $E_{Generated}$ is the annual electricity generated and $P_{Capacity}$ is the installed PV capacity. 8760 being the number of hours in a year gives the yearly capacity factor for solar in Sweden.

From SCB, statistics for end-use electricity consumption in Jönköping County. The reason for choosing Jönköping County being that it geographically is the same region as Norra Småland Region meaning that the name Jönköping County and Norra Småland Region is used interchangeably. Hence, the data for Jönköping County is used to represent the Norra Småland Region.

The data was loaded into MATLAB, where the function polyfit was used to produce a first-degree polynomial to estimate the growth rate of the end-use of electricity in Jönköping County. The function polyfit utilizes the least squares method to fit the data given. Giving a function and a prediction for how the future growth of the solar power expansion might look.

The polynomial is constructed as follows:

$$p(x) = p_1x^n + p_2x^{n-1} + \cdots + p_nx + p_{n+1}, \tag{2}$$

where $p(x)$ is the polynomial and p are the coefficients and n corresponds to the degree of the polynomial. The function returns the polynomial with the best fit to the given data. For the electricity function a first-degree polynomial was chosen, giving a linear estimation for how the increase in end-use electricity consumption might look.

Data for solar generation was able be to retrieved from SCB. In Jönköping County however, at the time of writing this report, only data for the year 2023 existed. But this was later be used to validate the estimation for generated solar electricity.

The Swedish Energy Agency also provided data for the amount of and installed capacity for PV systems in Jönköping County.

From this data, the number of installations could be visualized as well as installed capacity and distinguish between systems of size less than 20 kW or small-scale systems, 20 kW – 1000 kW meaning bigger systems or smaller solar parks and finally systems bigger than 1000 kW meaning bigger solar parks.

Data on the number of residencies in Jönköping County was gathered from SCB. This data was then used in conjunction with the data for number of small-scale installations to calculate an approximation for the number of homes which have already installed PV systems as well as letting an estimation be made for which future capacity can be expected for single home systems, since the majority of the systems installed of sized 20 kW or less are single home installations.

An estimation for the maximum capacity being able to be installed on single homes was calculated by taking the number of single homes in Jönköping County and multiplying it by the average size of the smaller systems giving a crude estimation for the maximum capacity able to be installed on single homes in Jönköping County.

$$CapMaxSH = Res_{SingleHome} * P_{Average}, \quad (3)$$

where $CapMaxSH$ is the maximum capacity being able to be installed on single homes in Jönköping County. $Res_{SingleHome}$ is the number of single home residencies in Jönköping County and $P_{Average}$ is the average installed capacity of a solar power system of a size less than 20 kW. The reason for the systems of size smaller than 20 kW being chosen is because the size for single home systems generally is not bigger than 20 kW.

For the data on installed capacity in Jönköping County, the function polyfit was once again used. For the installed capacity however both a first degree and a second-degree polynomial was produced since the curve had quadratic characteristics.

For our data an estimation for both a first and a second-degree polynomial was chosen. In extension to this another linear prediction was made, using the growth rate of the expansion of PV in Jönköping County for the year of 2022.

$$y = k * x + m, \quad (4)$$

for this third prediction the value for k was given the difference in installed capacity of solar power in Jönköping County, between year 2021 and 2022. And where m was calculated since the values are already known for both y, the amount of installed capacity and x, in this case the year of 2022.

This gives three different estimations on how the future growth of the solar power capacity in Jönköping County might look.

Because of the relationship between installed capacity, generated electricity and capacity factor shown in Equation (1) an estimated growth rate of the yearly solar electricity generation could then be obtained through rewriting the equation:

$$E_{Generated} = P_{Capacity} * 8760 * cf, \quad (5)$$

where installed solar PV capacity is $P_{capacity}$ and $E_{Generated}$ is the estimated generated electricity.

An interesting point to put into perspective felt to be the magnitude of the estimated electricity generation. As a reason of this, the generation was then compared to the estimated end-use of electricity consumption to evaluate how big a share of the total end-use, the solar power would make up. Following the formula:

$$E_{Share} = \frac{E_{Generated}}{E_{end-use}}, \quad (6)$$

where E_{Share} is the share the generated electricity makes up of the end-use of electricity, $E_{Generated}$ is the electricity generated by solar power ad $E_{end-use}$ is the end-use of electricity in Jönköping County.

Through taking the latest values for LCOE and global weighted average total installation cost for solar power from (IRENA, 2022) the total investment needed per year can then be calculated with the following formula:

$$Cost_{invest} = Cost_{inst} * P_{Capacity}, \quad (7)$$

where $Cost_{invest}$ is the total yearly investment needed, $Cost_{inst}$ is the global weighted average total installation cost of solar PV and $P_{Capacity}$ is the installed capacity of solar power.

For the global weighted average total installation cost of solar PV, the value for the year of 2021 was used. And the cost was translated from dollar to SEK based on the currency conversion rate for 2023-05-23, 10.62 SEK (XE, 2023).

3.3.2 The Potential of Wind Power in the Norra Småland Region

The approach for the wind model was similar as that of model for solar power.

Data was collected from The Swedish Energy Agency for annual installed capacity for wind power as well as generated electricity from wind power for both Sweden as a whole and Jönköping County.

By using Equation (1) the capacity factors for both Sweden and Jönköping County could then be calculated individually.

Through using the same approach as for the solar model, applying the same method on the wind data using the MATLAB function polyfit, one first degree polynomial model and one second degree polynomial was created as well as a linear model based on the last years rate of increase.

This methodology was applied for both data for the installed capacity of wind power and the data for generated electricity from wind power in Jönköping County.

For a way of validating the models, the generated electricity from wind power, based on the modelled increase of capacity in Jönköping County was made. Where Equation (5) was used to calculate the generated electricity.

For the validation, the capacity factor for wind power in Jönköping County at year 2022 was used. This was done for all three models for installed capacity and then compared to the data from the model for produced electricity.

Finally, the share of generated electricity as compared to the end-use of electricity in Jönköping was calculated. The formula presented in Equation (5) was used but $E_{Generated}$ now being used as the electricity generated from wind power in Jönköping County. Observe that only the modelled date for generated electricity in Jönköping was used for this.

Equation (7) was used to estimate the investment needed for the wind power as well, however here the global weighted average total installation cost of onshore wind power was used instead for the value of $Cost_{inst}$ and $P_{Capacity}$ was taken as the installed capacity for wind power instead of solar power.

The same conversion from dollar to SEK mentioned in the method for the solar model was used.

4. RESULTS AND DISCUSSION

4.1 Energy Policy Interviews

The energy agencies of Sweden varied in size in terms of manpower, some energy agencies have only two persons that were working with projects and questions related to energy. Others have a lot more people working with these questions and projects. There currently exist 15 energy agencies in Sweden and these represent all the various regions of the country. The Swedish energy agencies are part of a so-called umbrella organization. They work throughout the EU and converges to a network that operate towards more sustainable energy solutions but also towards mitigating climate change.

4.1.1 Currently Ongoing Projects Related to Renewable Energy

Table 1: Compilation of the answers given for the question on current ongoing projects related to renewable energy in the individual regions.

Region	Wind Power	Energy Efficiency	Hydrogen	Electricity Grid	Solar power	Transport	Providing Information to Private and public	Bioenergy	Real Estate	Circular economy	EKR / RUL	Energy Mapping
Norr	X	X	X	X	X	X		X				
Dalarna	X	X					X					
Östergötland	X			X	X	X		X	X	X		
Mälardalen	X	X			X		X					X
Storstockholm	X	X	X	X	X		X			X	X	X
Halland	X	X	X	X	X		X				X	X
Gotland	X	X	X				X	X				
Västernorrland	X	X	X		X		X	X	X		X	
Värmland	X			X							X	
Örebro	X			X	X						X	
Väst	X		X									
Norra Småland	X	X		X	X		X		X			
Syd	X	X			X	X	X	X	X	X	X	

When looking into the energy agencies in Sweden and the projects and subjects mention in Table 1 a few topics can be observed to have re-emerged during several of the individual interviews. One thing being that they primary are project dependent. Some of the energy agencies focus mainly on providing energy advice, information about sustainable energy solutions and webinars to citizens, various associations along with small and medium sized companies that are established in the region. Additionally, examples of collaborations with the

Swedish Energy Agency are also mentioned in the interviews for instance, a national project called “Hela Sverige Laddar”, which works as a forum for information about electric vehicles. Some regions focus more on helping people and companies develop their own small facilities that produce sustainable electricity like project planning for installation of solar panels on roofs. The regions work accordingly with various sustainability programs, where goals are set to for example install a certain quantity of solar power in the region that will generate a specific quantity of energy.

The different regions give a range of different answers for what projects they are working on related to renewable energy. When it comes to projects surrounding energy sources the main sources are solar and wind. However, hydrogen as both an energy carrier and a way of storage is mentioned by 6 of the 13 of the interviewed regions. Biofuels, district heating and combined heat and power is also mentioned by 5 out of 13 of the regions as a meaningful part of the current and future energy system.

When it comes to wind power, all regions have had or currently have ongoing projects related to the energy source. Of note is that while every region mentions working with wind power in one capacity or another, region Storstockholm mentions that working with the wind power question in the region is harder partly because of the population density of the region but also because of the number of actors present in the region as well as the question of whose mandate the wind power question is. In region Storstockholm the number of actors present and the fact that the county government and municipal government very much so raise the question and do the work than in other regions the energy agency does creates a very competitive market for the question. However, the impartial aspect of the work that the energy agency does is here raised, whereas many companies working on the wind power question in the region have agendas and products they work towards implementing.

All regions have in common their work with RUL or (regional development manager) which is a post announced by the Swedish Energy Agency and who works for as a coordinator and manager of the specific region’s energy and climate advisor. The RUL and the energy and climate advisors work towards furthering the energy efficiency in the individual regions. Even so, it can be observer that EKR (the energy and climate counselling) only showed up relating to renewable energy projects for 6 out of the 13 interviewed regions. This could be explained partly by the EKR not being a responsibility of the energy agencies of Sweden but instead being a responsibility on the municipal side. However, another reason from the side of the participants were that they didn’t have any projects directly tied to renewable energy.

The energy agencies of Sweden have many different projects in every region. However, most if not all of them are all encompassing or involve multiple different SDG:s. For example, when it comes to the energy agencies work with energy efficiency it typically starts with looking at ways of reducing energy use for starters but then in many cases also includes looking at for example installation of solar PV panels. Another example being the work related to the transport sector where some examples of work are public transportation using biogas, installation of speed chargers for electrical vehicles and in Region Norr, Region Västernorrland and Region Gotland pilot project with electrical roads. While not directly linked to renewable energy, these projects are very closely linked to the energy system of Sweden and its road towards and being fossil free and thus the renewable energy system.

Project related to energy efficiency are another common ground the regions have. Partly since the Swedish Energy Agency has given this assignment to each individual region in Sweden, but also because the vast majority of regions have further projects related to energy efficiency.

As a general there are few projects in the regions related to only one subject. Most of the ongoing projects in the regions have a broader perspective, relating renewable energy sources, energy efficiency and the grid in one project.

The energy agencies of the different regions describe their work as acting to help facilitate the work with renewable energy, energy efficiency, the environment and sustainability. They describe their role as more of a coaching and managing role between the public and the private sector. Bringing the different interested parties to a common ground and helping further knowledge and competence on the energy question to all parties involved.

4.1.2 Challenges or Problems Related to the Projects

Table 2: Compilation of the answers given for the question on challenges and problems related to the projects in the individual regions.

Region	Wind & Ecology	Social Opposition	Electricity Generation	Wind & Military	Land use	Conflicting Interests Wind	Finances	Lack of Competence and staff	Electricity Grid	Municipal veto	Planning and Permitting System for Wind	Uncertainty on mandate for Wind	Fossil free Transport sector
Norr	X	X	X		X	X		X	X	X	X		
Dalarna	X	X		X	X		X	X	X	X	X		
Östergötland		X		X	X	X			X	X	X	X	
Mälardalen							X	X	X		X		
Storstockholm							X		X				X
Halland					X	X						X	
Gotland	X			X	X				X				X
Västernorrland		X					X	X		X			
Värmland			X						X	X			
Örebro					X			X		X		X	
Väst			X	X	X			X	X		X		
Norra Småland													
Syd		X		X		X							X

A recurring challenge that has emerged in conversation with the energy agencies is that of the conflict between expanding wind power in districts that currently is being used by the military. Certain territories within the borders of the country are so-called areas of interest and can be located at sea or inland. In order to erect wind turbines on these areas, consensus with the military is critical.

However, the challenge of conflicting interest is not limited only to the military. Looking at Table 2 it can be seen that military, forestry, environment, tourism and nature are a few examples of different interest that have come up, clashing with the interest of building wind power. When it comes to the interests of ecology vs the interests of wind power which is something that appeared in 3 of the 13 interviews the reasons differ somewhat. The benefit of the wind turbines compared to their direct impact on the ecology of the close vicinity has to be taken into consideration. This varies greatly depending on the placement of the wind turbines and can differ widely from region to region. An example of this is in the Region Norr where consideration to the reindeer population has to be taken into consideration since they roam the forests of the northern parts of Sweden. This is of course a consideration that for example the south of Sweden does not need to take into consideration. For example, in Region Gotland where there is lots of talk about the eagle population and how these are affected by the expansion of wind power.

According to the some of the respondents, consensus with the military can be complicated to accomplish to say the least meaning that it can be difficult to acquire concurrence with the military regarding these areas of interest. Because of the difficulties, the energy agencies have to focus on other problems like, for example, conflicts between landowners and the expansion of wind power are also an imminent challenge that the participants have mentioned on several occasions. When it comes to installation of wind turbines on private property remotely close to the landowner's residence, there exists an opposition in many cases. On the other hand, if the landowner resides somewhere else in the country, the response to receive payment for the use of the land are in most cases positive.

The opposition to wind power has increased during the last couple of years according to 5 out of 13 of the energy agencies, and this is perhaps one of the greater impediments that occurs in the work towards implementing more renewable energy. In comparison with the theoretical framework of this study, the results from the interviews are to a large extent strengthening some of the suggestions mentioned in the previous studies and the theoretical framework. When it comes to social opposition, most of the regions which mention it as a problem mention the term ”not in my backyard” meaning that people are in general positively posed towards wind power, except for when it's close to them. Another reason for social opposition which came up in the interviews was the landscape, mountain areas, and areas for recreational purposes for which a desire to preserve was expressed. Concerning the social opposition of wind power, the study performed by Ek & Persson, (2014) suggested that people tend to dislike the notion of placing wind turbines near places that are used for recreational purposes, mountainous areas etc. The results concerning social opposition are thereby congruent with the results of the study of Ek & Persson, (2014).

Another challenge or problem that all regions seem to share is the veto of the municipality, a law stating that the municipality has the last word of whether a project gets approved or not. This veto creates a problem where a project could be seemingly approved, a lot of investigative and preparatory work can be made, just for the project to be shut down, far into the project where money already has been invested in the project.

Another problem mentioned in all the regions is the legislative work or the lead times being far too long for the approving of the projects. Related to this, problem with the competence and the labour of the agencies responsible for investigating and approving the applications for the projects, stating that more people are needed for this work to continue smoother.

The question of competence and labour force is another subject mentioned in many of the regions. Both a low general competence in the energy question as a whole in the energy question is mentioned as a problem as well as labour force both within the agency and outside.

Capacity of the electricity grid is another challenge or problem which re-emerges in 8 out of 13 of the interviewed regions as can be seen in Table 2. However, the different regions state different problems or challenges related to the grid. Where some regions need an expanded grid to be able to further increase their expansion of renewables, others have new big industries interested in the region or industries working on electrification putting a strain on the existing electricity grid. Where, some of the regions state that they have already reached a point where they have to stop the expanse of renewable electricity generation because of the limiting factors of the grid, while other regions mention having to further plan or slow down the rate of which the expanse is made. One region mentions the considerable expanse the electricity grid is facing and the challenges that this expanse entails.

For many of the regions a future expansion in terms of new industries, more people and housing are expected, entailing an associated increase in electricity consumption. Even if the goals for advancements in energy efficiency are meant to offset this expanse, the continued electrification of Sweden entails that the electricity use in Sweden will grow in the future. In a report by Energimyndigheten, (2023a) three predictions are presented for Sweden’s future energy use. One for lower electrification, one for higher electrification and one for lower electrification only for the industry sector. In these three scenarios only the higher electrification scenario predicts a significant increase in the energy use. However, all three scenarios predict an increase in electricity use. An increase in electricity use would further strain the electricity grid. For example, the northern regions have many big new industries on the horizon, Northvolt in Skellefteå and the electrification of the steel production in Luleå Hybrit being to examples, giving the northern part of the country an expected increase of electricity consumption that is manifolds bigger than the regions current electricity generation. And the northern regions being one of Sweden’s bigger energy producers, transitioning into an energy consumer poses big challenges in and of itself.

While not part of the compilation of the answers, Region Norra Småland did mention that one challenge right that the region is facing is the fact that the region is not classed as an electricity producer but rather and electricity consumer meaning that all electricity produced in the regions always falls under the consumption of the region. For Region Norra Småland to transition into becoming an electricity producing region with an electricity generation greater than their consumption, work would have to be put into the legislations, knowledge and problems that this transition entails.

4.1.3 Methods for Dealing with Challenges and Problems

Table 3: Compilation of the answers given for the question on methods of dealing with mentioned challenges and problems in the individual regions.

Region	Dissemination of Knowledge	Applying Funds from ERUF	Work with GIS-data	Cross-sectional Mediation Between Actors	Advocacy Work with the EU	Influence Politicians	Achieve an Energy System Perspective	Energy Mapping	Impartial counselling with public and private
Norr								X	
Dalarna			X				X	X	
Östergötland	X			X			X		
Mälardalen	X	X	X		X	X			
Storstockholm	X	X							X
Halland									
Gotland	X					X			X
Västernorrland	X				X			X	
Värmland		X							
Örebro	X								X
Väst	X			X		X			
Norra Småland									
Syd	X								

Table 3 presents a compilation for the answers by the regions for methods of dealing with the, in Table 2 presented challenges or problems. When the question of addressing the issues and challenges was asked 8 of the 13 regions mention that the way they approach the problems and challenges is mainly by providing competency and at a managerial roll, bridging gaps between different parties involved with the specific projects and with knowledge on energy related questions. For both the public and the private sector the regions work towards rising the general competency and knowledge on the energy questions. Through working with both smaller and bigger companies, politicians, and officials on the same, or different sides of the table, the energy agencies work to help come to an understanding and move towards a more sustainable business.

Other examples of addressing challenges or problems with the projects are the achievement of a more stable financial situation concerning the projects by applying funds from ERUF. Concerning the challenges related to land use and the planning for wind power development GIS-data can be implemented for obtaining more information about the area in question.

The work with the implementation of renewable energy in the individual regions involve many different actors. These actors can many times have different views and goals. Table 3 shows that 2 of the 13 energy agencies mentioned that they actively try and mediate between the parties so that they can reach a conclusion of how to proceed with the work. Sometimes this entails influencing politicians which came up in 3 out of 13 of the interviews.

One of the reasons for the variation of the answers regarding the question of dealing with challenges and problems is that while the energy agencies of Sweden have a shared goal of impartially steering Sweden in the direction of more renewable energy, the individual agencies in each region widely differ in size, organisation etc. In short, there is a big individuality for each regional energy agency even if they share the same base framework, leading to the methods for dealing with challenges and problem being distinct from one other.

4.1.4 Examples of Wind or Solar Power Projects in the Region

Table 4: Compilation of the answers given for the question on examples of Wind and solar power projects in the individual regions.

Region	Offshore Wind Power	Onshore Wind Power	PV on Roofs	PV Plants	Sharing distributed solar power generation
Norr	X	X			
Dalarna		X			
Östergötland		X			
Mälardalen		X	X		
Storstockholm					
Halland	X	X		X	
Gotland	X		X	X	X
Västernorrland		X	X		
Värmland		X			
Örebro			X	X	X
Väst	X	X	X	X	
Norra Småland		X	X		
Syd	X		X	X	

Table 4 shows the compiled answers from the different regions on examples of Wind and Solar Power projects in the region. Comparing the answers given in Table 4 to the answers given in Table 1 it can be observed that there is some discrepancy between the number of regions who mention working on projects related to wind and solar respectively. Combining the three solar related answers in Table 4 shows that 8 out of 13 regions mention working with any kind of solar projects. Comparing this to the answers given in Table 1 where 9 out of 13 mentioned solar projects in one way or highlights this discrepancy. Looking at the same comparison for wind power it can be observed that 10 out of 13 regions mentioning on- or offshore wind power in Table 4 while comparably each region mentioned some sort of work involving wind power in Table 1. Reasons for these discrepancies being that regions have projects relating to wind outside the scope of onshore or offshore wind power, regions having previous completed wind project which the participant did not have further knowledge of, or having lower priority on work with the wind question for various reasons. For the discrepancy on project related to solar the main reason is that either the project falls outside the scope of roof PV, PV plants and shared distributed solar. Or that the regions have renewable energy projects related to solar power, while not having a fully blown solar oriented project.

One can observe that the number of regions mentioning projects related to onshore wind power far exceeds the number of regions mentioning projects related to offshore wind power. Of the 5 regions mentioning offshore wind power, it is worth noting that 3 of the regions are positioned along the Swedish west coast, which has the best potential for wind in Sweden on account of having not much more than open seas facing west. Region Gotland is geographically and island which gives the region more potential for offshore wind power since the land use is already relatively restricted. Finally, Region Norr which mentions offshore wind power has a comparably bigger portion landmass than shore and corresponding sea with potential for offshore wind. However, because of its size region Norr still has a substantial coastline compared to many other regions giving it potential for offshore wind on the east coast.

4.1.5 Challenges or Problems Related to Wind or Solar Projects

Table 5: Compilation of the answers given for the question on challenges and problems related to the wind and solar projects in the individual regions.

Region	Electricity grid	Planning and Permitting System	Municipal veto	Land Use	Lack of Competence and staff	Conflicts of interests wind	Politics	Uncertainty for economics	Uncertainty on mandate / the
Norr	X	X	X		X	X		X	
Dalarna	X	X	X	X	X	X	X		
Östergötland		X				X	X		X
Mälardalen	X				X				
Storstockholm	X				X			X	
Halland				X	X	X			
Gotland	X	X	X			X	X		X
Västernorrland					X				
Värmland	X				X		X		
Örebro			X		X				X
Väst		X		X		X			
Norra Småland					X				
Syd						X			X

The challenges or problems related to the wind and solar power projects turned out to be quite vast. In Table 5 a compilation of the most commonly re-appearing answers corresponding the challenges and problems related to solar and wind projects are displayed. 6 of the 13 participants are viewing the shortage of capacity in the electricity grid as a problem. The regions Värmland and Gotland are noteworthy in regard to the electricity grid since both of the regions are not permitted to install more capacity. These regions are different in the terms of various geographical restraints. Since Gotland is an island, they are connected to the grid through a cable, which according to the participant of the region Gotland needs replacement to handle more capacity. Värmland on the other hand, is restrained due to the need for grid expansion in their region and therefore are not permitted to install more capacity.

The permitting system is another challenge that has arisen in 5 of the 13 participants answers, mostly when discussing wind power expansion. Since the time for an area to be investigated for installation of wind power could range from approximately 3 to 8 years, the participants mention that there is a need for acceleration in the planning process of a wind turbine. Related to this is the municipal veto. Even though an area has been cleared for installation of a wind turbine by the county administration, the municipality has the right to turn down the project at any time. The entailment of this is that the work put into the various investigations of an area could be futile in the end, which delays the expansion of wind power to a large extent.

The participants also mention the conflict regarding land use and expansion of renewable energy which is a challenge that occurs when there is uncertainty of whether an area is more profitable for electricity production or agricultural production. 3 out of 13 regions mention this, region Väst, Dalarna and Halland, since the land area for agricultural production is vast in these regions.

The returning issue of the lack of competence and staff also re-appear in 9 of the respondents answers to the question, see Table 5. Another example of challenges or problems that are mentioned for multiple regions when working with projects related to wind and solar power are conflicts of interest and uncertainty of mandate in the question regarding wind power where 7 out of 13 respondents mention that conflicts of interest are a problem or challenge and 4 out of 13 respondents mention the uncertainty around the mandate of the wind power question as a challenge or problem. When it comes to mandate the respondents conveyed that the question of installing wind power is a complex one, with many different components and actors. For smaller solar PV systems, a system can be projected at practically any level of government. But when it comes to wind power an installation is less clearly defined, needing to pass multiple different regulations from different actors, meaning that it can feel overwhelming for the actor wanting to make a wind power installation. As for conflicts of interest, the military, ecology and recreation are mentioned as a few of the different conflicting interests. However, these are mostly the same as presented under Table 2.

4 out of the 13 respondents name politics, in one way or another, as a challenge or problem. Here some examples of answers are that the politics work with the renewable energy question short-term since a new government is chosen every 4 years. Meaning that politics, incentives and legislation surrounding renewable often vary from year to year. Here a more stable and

coherent view on the matter is desired from some of the regions in question. 2 of the 13 respondents also mention an uncertainty when it comes to economics as a challenge or problem, related to the politics since the way the energy agencies of Sweden work, it relates very closely to the government and the EU and the project are many times sponsored by money from ERUF but also governmental agencies such as the Swedish Energy Agency and the Swedish Agency for Economic and Regional Growth.

4.1.6 Tools, Data or Additional Information that Would Help Facilitate the Projects

Table 6: Compilation of the answers given for the question of whether any tools, data or additional information could help facilitate the work towards implementing more renewable energy.

Region	Increase in Educated Staff	More Statistics and Data	Better Communication	Roadmap	Energy Mapping	Climate View	Common Regulations
Norr					X		
Dalarna	X	X					
Östergötland		X	X				
Mälardalen		X				X	
Storstockholm		X			X		
Halland	X	X					X
Gotland		X		X		X	
Västernorrland							
Värmland	X				X		
Örebro		X	X	X			
Väst							
Norra Småland	X						
Syd	X	X					

Like the compilation presented in Table 6 above suggests, 9 of the 13 interviews mention that an increased availability of various statistics and data would help facilitate the work. These data and statistics would work for purposes such as making different prognoses for the grid capacity in particular geographical regions, visualizing statistics to arouse interest among politicians and local population, and to help communicate information related to renewable energy in a more pedagogical manner better. However, accompanying the want for more data and statistics there is also an understanding that it in most cases is a question of finances. More data, pilot projects etc. are costly to perform or research and while many times good it has to be weighted to the costs. A pilot project conducted in the south of Sweden might not result in the same conclusions as a pilot project on the same matter in the north of Sweden. Another aspect of data is that it's not always easy to get a hold on since the many different actors of the region might have data for parts of for example the electricity grid or PV-installations but the whole picture for the region might not be openly available.

6 of the 13 participants responded that an increase in educated staff or simply just more personnel that works with energy-related issues in general at the energy agencies would help with facilitation of the work. The mentioning of various energy mapping tools also occurred during the interviews along with the lack of a road map to help the energy agencies follow the broad guidelines set by the EU to achieve carbon neutrality. 2 of the 13 participants mentioned the software Climate View, which is a visualization tool to help the user to see the energy flow of an entire city and thus help the decision makers with the right choice to mitigate the emissions.

Even though the respondents provided Climate View as an example of a tool that could help facilitate the work, most of the answers as to what might aid the work with the projects were data or information related and very few concrete examples for tools where mentioned. Since specific tools did not come up as something that the regions wanted or needed to help facilitate the work with the projects, an assumption could be made that when it comes to specific tools, the regions are sufficiently satisfied with the already existing and accessible tools. On the other hand, there seems to be a lack of data from pilot projects or statistical data in general and this could be something that might need improvement in the future. To help regions with projects related to renewable energy, a database, accessible to the energy agencies, with examples of various pilot projects related to renewable energy that previously has been performed in the country could perhaps be of use for the purpose of obtaining relevant data.

4.1.7 Political Incentives Needed or Helpful in the Work with the Projects

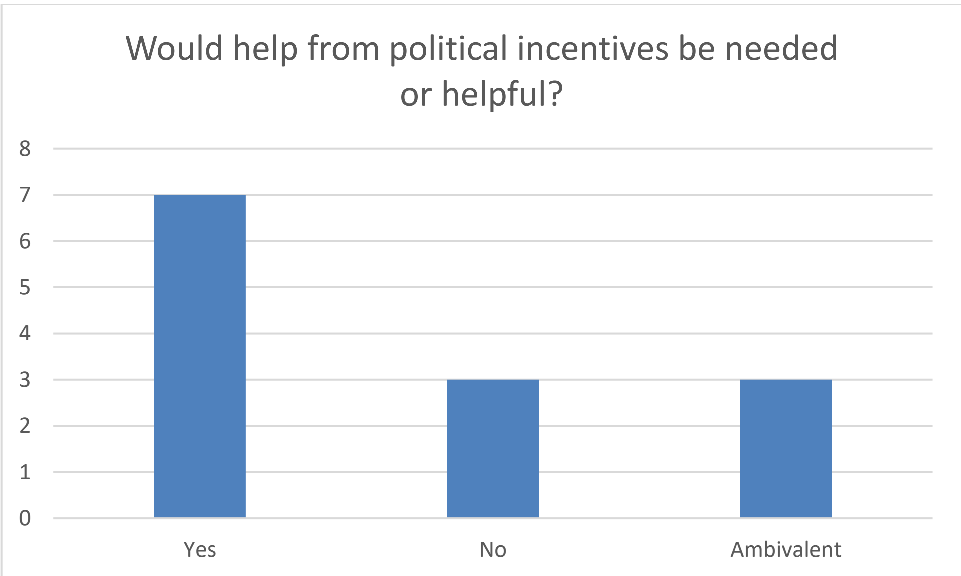

Figure 2: Summary of the answers for whether political incentives would be needed or helpful.

As can be seen in Figure 2 the distribution between regions mentioning they would need help from any form of political incentives, regions mentioning they wouldn't need and regions being ambivalent on the question, 7 regions mention that some sort of political incentive could help in the work. 3 regions mention that no further incentives are needed, and 3 regions were ambivalent in the answer.

Table 7: Compilation of the answers given for the question of whether any political incentives could help facilitate the work towards implementing more renewable energy.

Region	Incentives needed?	Individual answers		
Norr	No	Big engagement already		
Dalarna	Ambivalent	Broader perspective on all levels	Well-functioning market, broad economic incentives	
Östergötland	Yes	More clear definition of the questions on all levels & a clearer mandate on wind question	Long-term decisions	Economic incentives
Mälardalen	Yes	Long-term decisions	Economic incentives for energy efficiency	
Storstockholm	Ambivalent	Economy and informational incentives		
Halland	Yes	Focus on broader and more detailed knowledge	Energy System perspective	
Gotland	Yes	To set a better example	Throttle up	
Västernorrland	Yes	More resources	More clear definition of the questions on all levels	
Värmland	Yes	Long-term decisions	Clearer mandate on wind question	Energy System perspective
Örebro	No	Already good communication with politics		
Väst	No			
Norra Småland	Ambivalent	Economic incentives		
Syd	Yes	Technically neutral incentives	More clear definition of the questions on all levels	Economic incentives

Many of the individual regions do in one way or another collaborate with politicians, on either a regional level, municipal level, national level, EU level or all of the above. This means that the energy agencies many times work very close with the responsible politicians for ruling on incentives and legislations one example being the region of Örebro as can be seen in Table 7. This could be one of the reasons that not all regions have examples for incentives which would help in their work. However, since Energy Agencies Sweden is an umbrella organisation and all individual energy agencies vary in size, organisational structure and responsibilities as well as vicinity to the different political levels. This could also be a reason for the differences in the regions' answers on whether political incentives are helpful, needed or not.

Looking at Figure 2 it is visible that most of the regions seem to wish for political incentives in one way or another. Whereas 6 of the 13 regions answer that further political incentives aren't needed or are ambivalent on the question. The answers broadly differed from region to region as to which specific incentives might be helpful and some of the regions where ambivalent in their answers as well as some regions stating that they couldn't think of or didn't desire any further political incentives.

In the region Norr, the furthest northern region in Sweden the respondent stated that the amount of activity and interested actors make the region a sort of Swedish Klondike, the respondent considered it akin a Swedish goldrush. Therefore, the politics are already very positive to the questions related to renewable energy and the transition to a fossil free future. Region Dalarna, Västernorrland and Syd all mention that they desire a clearer direction or broader perspective view on the wind power question and renewable energy question in general. And that this perspective and direction is to be present on all levels of government. Region Mälardalen, Värmland and Östergötland wish for some form of longer continuity for the renewable energy questions since politicians generally work in shorter terms where they need to be re-elected every 4 years. Meaning the renewable energy question can easily sway often and hard which is why there could be some merit to having someone or in some way having a more long-term view on the question, giving it a smoother continuity.

7 out of 13 regions mention economic incentives in one way or another. Where region Östergötland, Syd and Norra Småland mention that more resources would help in their work. Region Dalarna spoke about the importance of broad economic incentives which don't favour a specific energy source and Region Mälardalen wished for further economic incentives for energy efficiency or a rework of the existing ones.

Region Örebro states that the communication with the responsible politicians is already good and Region Gotland wishes the politics would lead the way and set a better example for the private sector and companies. As well as throttling up the tempo with which the work is done.

4.2 Modelling the Solar and Wind Power Potential in Jönköping County

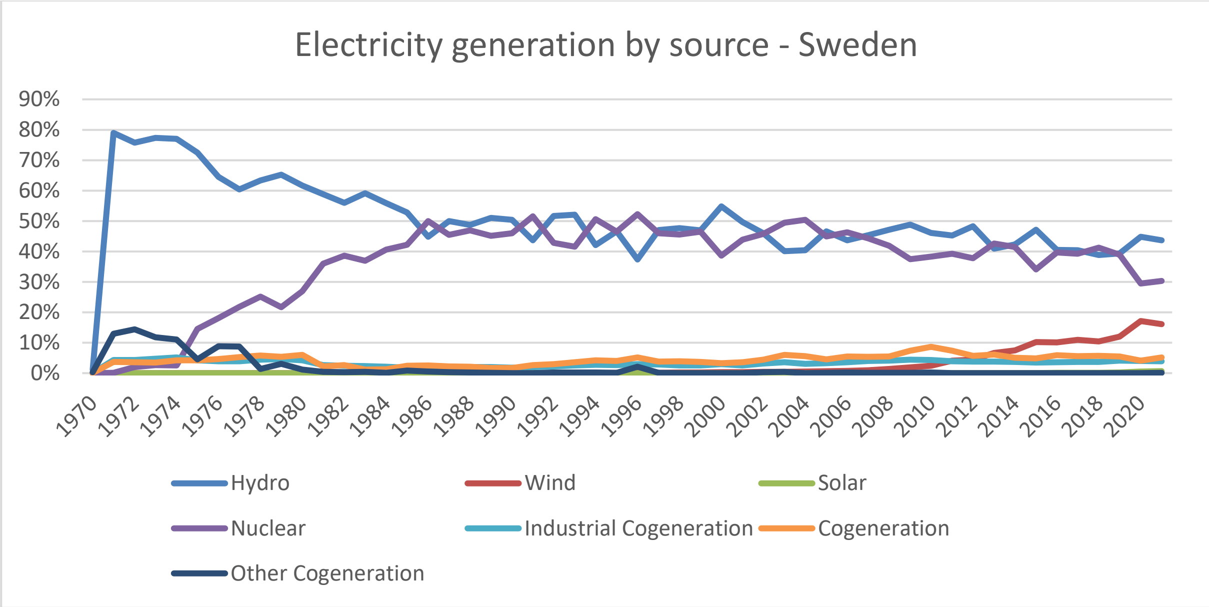

Figure 3: Swedish electricity generation by source from 1970 to 2020 (Energimyndigheten, 2023b).

In Figure 3 one can observe the how the shares of Sweden's energy generations have changed throughout the years. Here it is observed that the hydropower has always made up a substantial part of Sweden's electricity generation. The share for nuclear power greatly grew between 1974 and 1986 but now is more stable and rather slowly declining. During the last few years wind power has greatly grown to now make up one of our major energy sources. However, solar still makes up quite a miniscule part of the Swedish electricity generation.

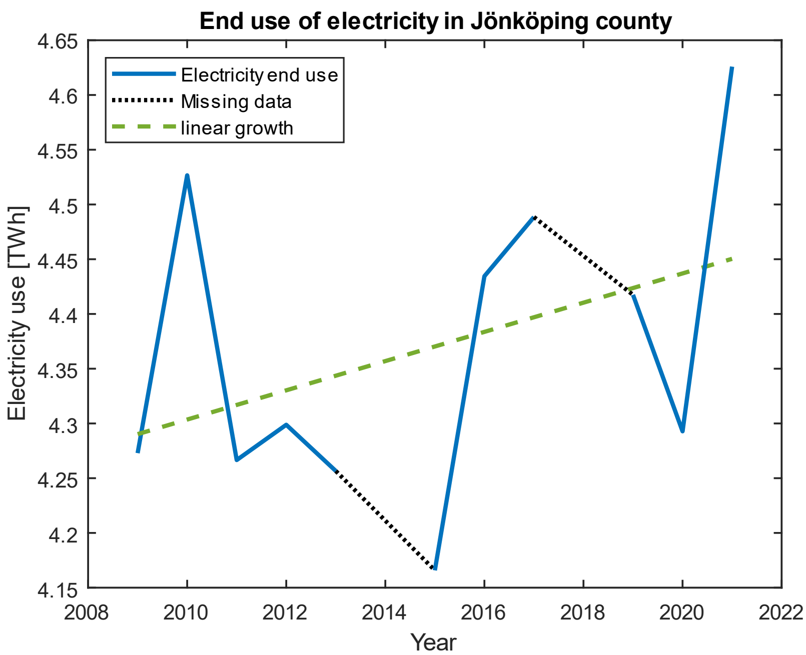

Figure 4: End use of electricity in Jönköping County.

Figure 4 shows the end use of electricity in Jönköping County as well as a linear approximation of the growth rate. The linear approximation gives an estimated annual increase of about 13.3 GWh of end use of electricity for Jönköping County.

4.2.1 The Potential of Solar Power in the Norra Småland Region

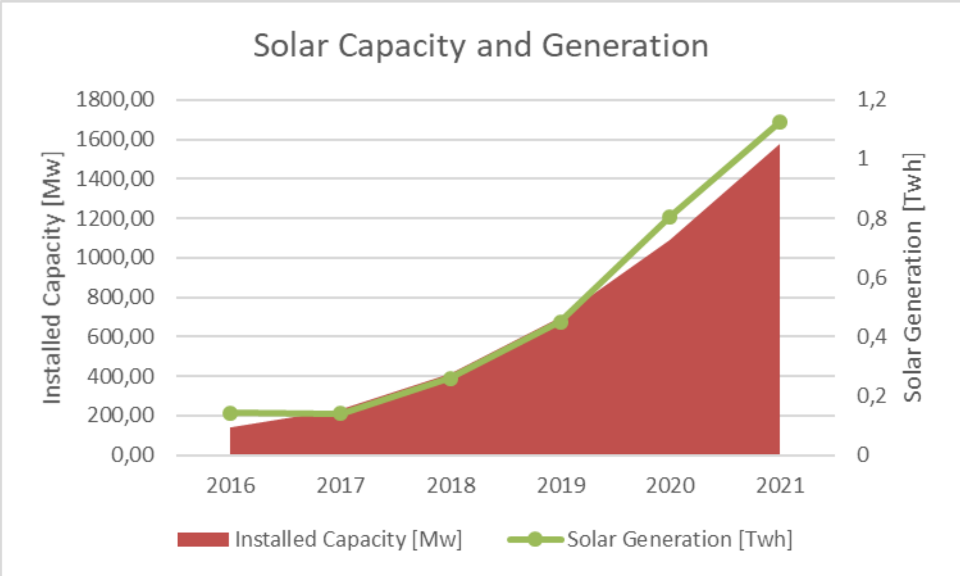

Figure 5: Installed Capacity and Generation of Solar Electricity. Data from (Energimyndigheten, 2023c).

Figure 5 shows how the capacity of solar power and the electricity generations from solar power in Sweden has changed over the most recent years. As can be seen, the rate of which the installed solar capacity has increased over the last few years has quickly risen, meaning a continued increase of rate of growth can reasonably be expected. It can also be observed that the solar generation also follows the curve of the expansion reasonably. The deviations between the increase in capacity and generation can be explained by different levels of solar irradiation between years.

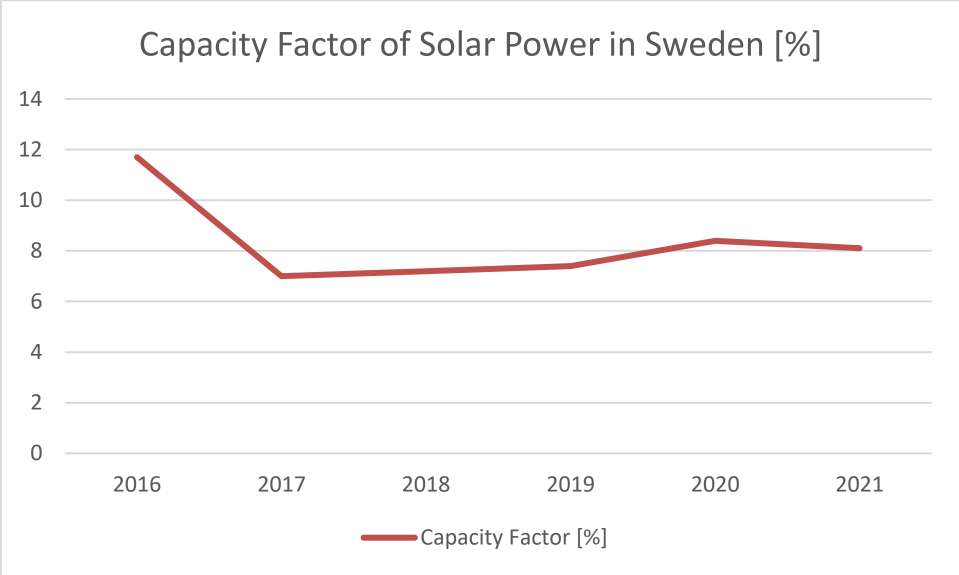

Figure 6: The capacity factor for the installed solar power in Sweden.

Figure 6 shows the capacity factor of the installed solar power in Sweden and how it has varied from 2016 to 2021. It can be observed that the capacity factor for the year of 2016 is higher than the rest of the year but that for the rest of the years the capacity factor for the solar power seems to be moving between 7-8 percent. Since for the years after 2016 the capacity factor seems to be stabilizing around 8 %, for further use in this degree project, this capacity factor was used.

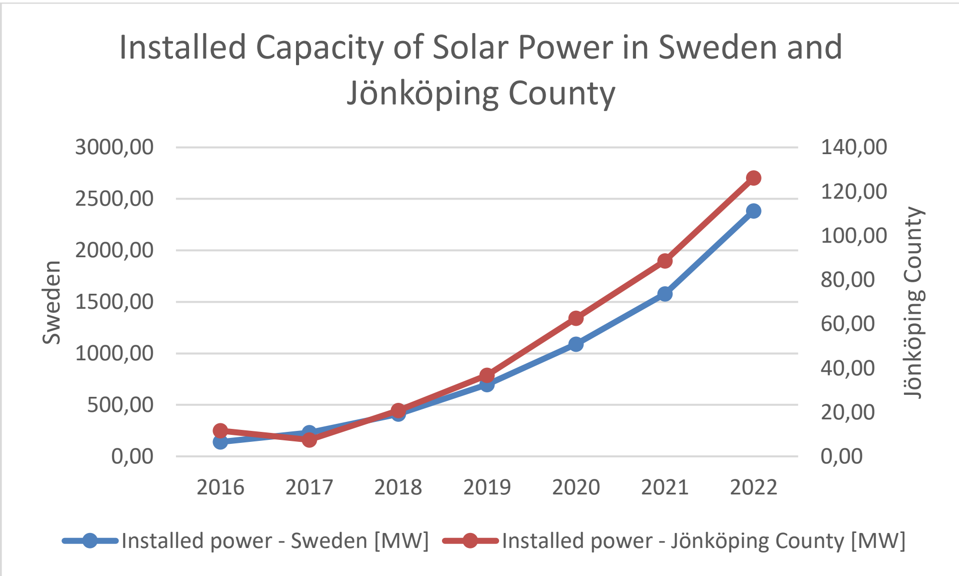

Figure 7: Comparison between installed Solar Power in the whole of Sweden and Jönköping County years 2016 to 2022.

Figure 7 shows installed capacity of solar power in both Sweden and Jönköping County and the difference between them. It can be seen that the rate at which the capacity increases is similar but that Jönköping County seemingly has increased their capacity of solar power at a faster rate than other counties in Sweden since the growth rate is higher than that of Sweden.

At the same time, it can also be observed that Jönköping as of year 2022 has installed about 120 MW of solar power capacity.

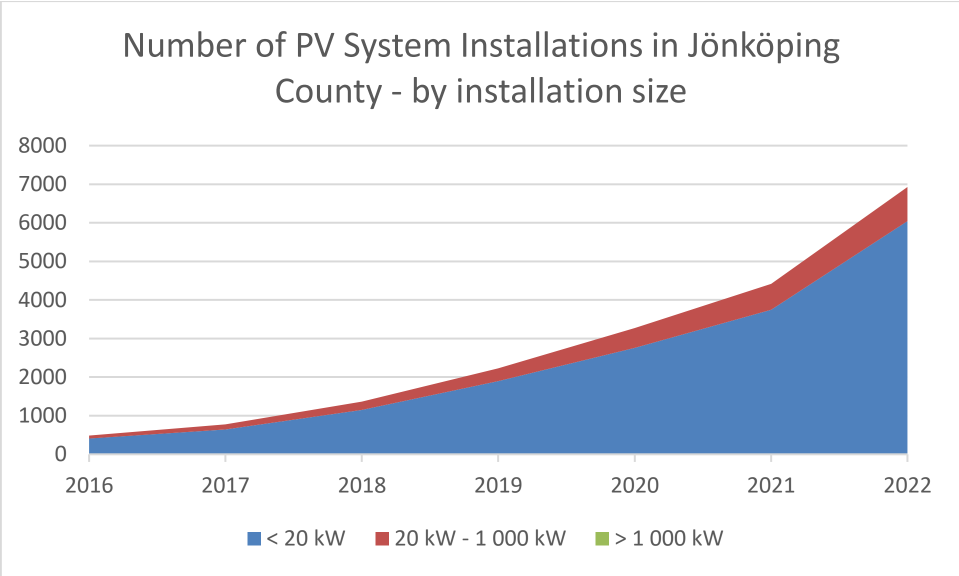

Figure 8: Number of PV installations in Jönköping County by size of installation.

Figure 8 shows the number of PV installations in Jönköping County from 2016 to 2022. Figure 8 shows that the vast majority of the installations are systems with an installed capacity of less than 20 kW, mostly home systems. Where the systems of sizes between 20 and 1000 kW are more of the industrial installations as well as smaller solar parks. And where sizes over 1000 kW are bigger solar parks. As can be seen in Figure 8 there is a noticeable amount of medium sized installations even if the biggest part of the installations in Jönköping is made up of home systems. To note is also that Jönköping 2020 had 2 installations bigger than 1000 kW, and year 2021 got 2 more for a total of 4 installations.

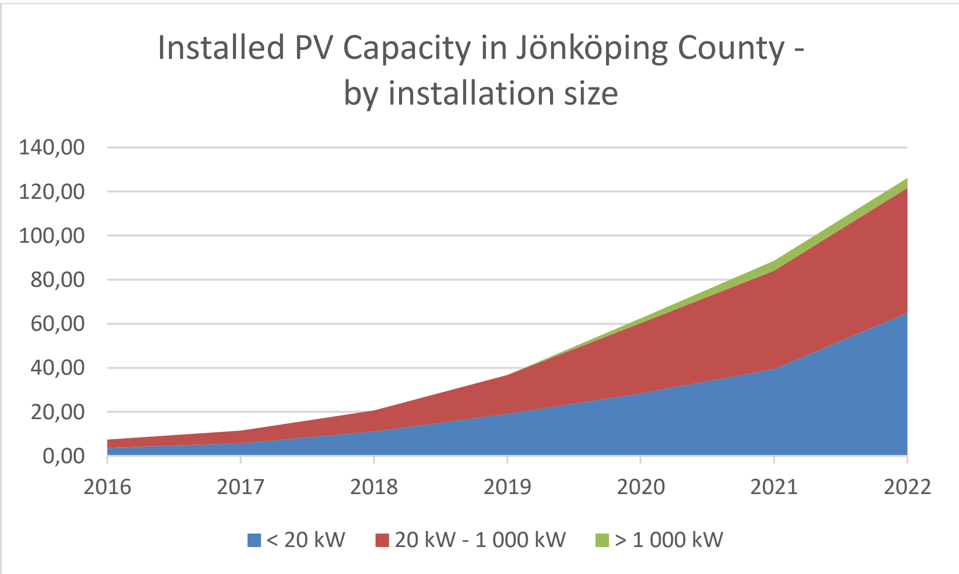

Figure 9: Installed PV capacity in Jönköping County by size of installation.

Figure 9 shows instead the installed capacity of PV-systems in Jönköping County. Here its visible that that even if the number of installed systems is vastly dominated by the small-scale home systems, the capacity is quite evenly spread between the smaller ones and the medium sized installations. Figure 9 also shows the contribution that the biggest installed systems give to the total installed capacity in Jönköping County.

Dividing the amount of small-scale installations in Jönköping County by the corresponding installed capacity the average installed capacity for a single PV-System can be estimated to about 10.7 kW.

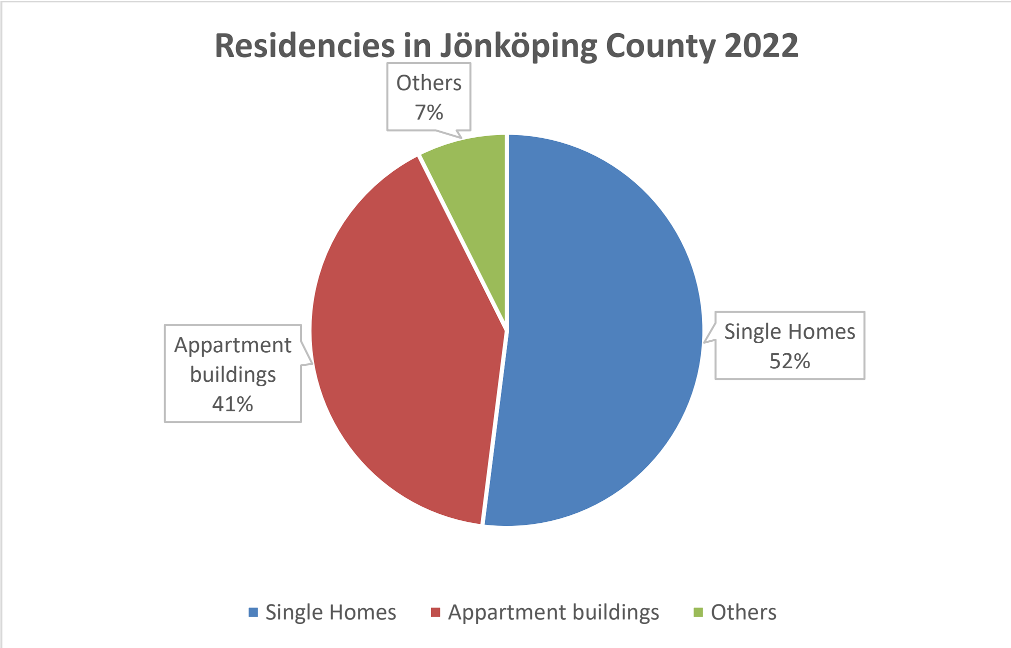

Figure 10: Share of different residencies in Jönköping County.

Figure 10 shows the shares for the different forms of residencies in Jönköping County. It can be seen that 52 % percent of the residencies in Jönköping county are single homes, corresponding to 86 928 individual residencies. Comparing this to the number of small-scale installations in Jönköping County an assumption can be made that there are a lot of single homes which have yet to install PV-systems.

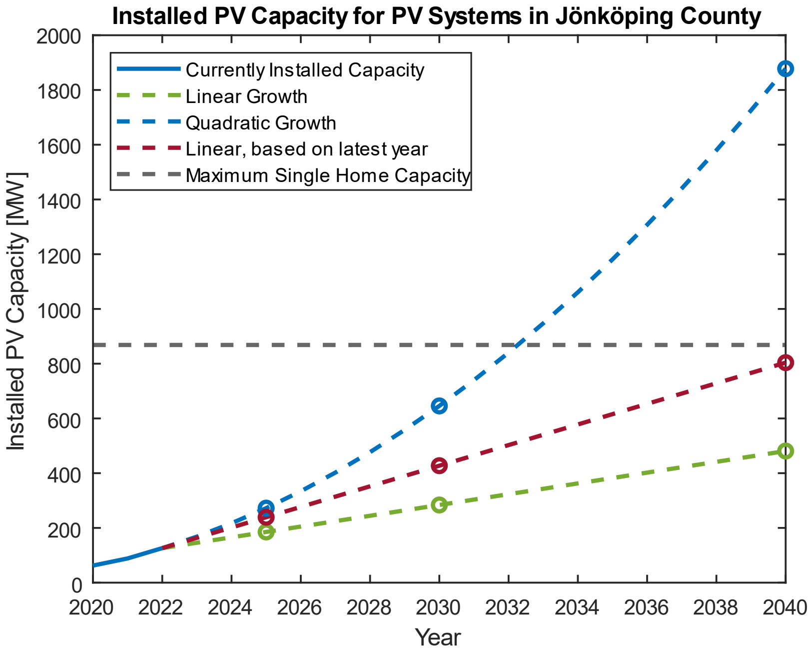

Figure 11: Installed Capacity and predicted growth of PV capacity in Jönköping County.

Figure 11 shows the current installed capacity of PV in Jönköping County from 2020 to 2022 and then continues to show the predicted growth, following three different models. One can also see the estimated maximum capacity that can be installed on single homes. Observing the different predictions, one can observe that if the continued growth is quadratic, then one could install PV on all currently available single homes in Jönköping for year 2032 however if the continued growth is linear, a somewhat lower total installed PV can be expected. The expected annual growth for the linear function based on data from 2016 to 2022 is 19.7 TW while the annual growth rate of the linear function based on the growth rate of year 2022 is 37.65 TW.

The Maximum Single Home Capacity marked by a black dashed line shows the maximum potential for installed capacity on single homes in Jönköping County. As can be seen in Figure 11 it just above 800 TW.

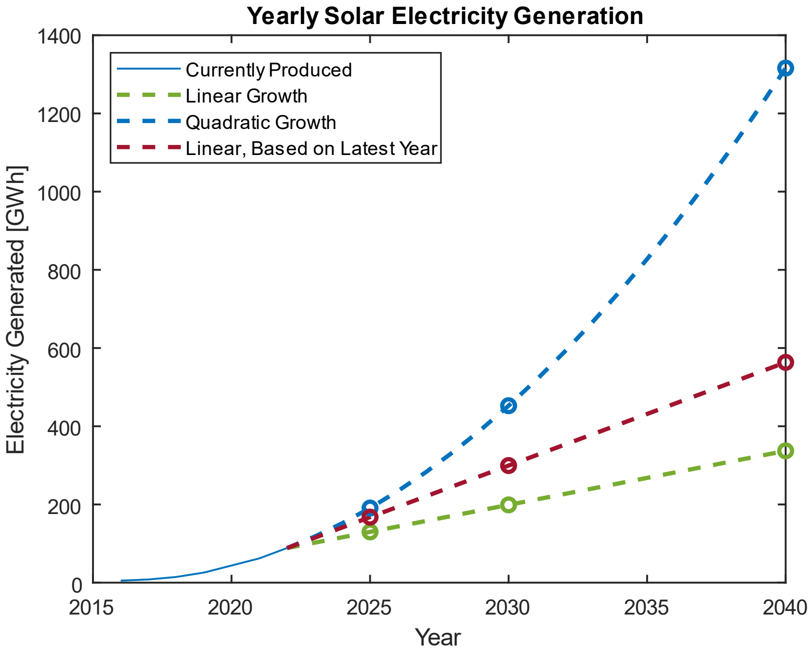

Figure 12: The estimated solar electricity generation in Jönköping County from 2016 to 2022 as well as three models for the predicted growth from year 2022 to 2040.

Following the predictions in Figure 12 it can be observed that the expected electricity generation for year 2025 can be expected to reach 200 GWh or just under, with a smaller spread, while for year 2040 the different growth rates give vastly different predicted electricity generations. Following the quadratic growth rate an annual solar electricity generation of about 1300 GWh is reached for the year 2040. The linear prediction modeled after data from 2016 to 2022 gives a final annual solar electricity generation of about 350 GWh and an annual increase of generation of 13.8 GWh. Finally, the estimation for the growth of the generated solar electricity based on the linear growth from year 2022 gives an annual solar generation of just shy of 600 GWh and an annual increase of about 26.4 GWh.

Table 8: Comparison between actual and estimated electricity generation from PV in Jönköping County for the year 2022.

PV Electricity generation [GWh]	Estimated PV Electricity generation [GWh]	Absolute Error [GWh]	Relative Error [%]
62.9	62.0	0.9	1.4

Comparing the actual electricity generation and the estimated electricity generation from solar power shown in Table 8 shows that there is only a relative error of about 1.4 percent which is acceptable given that for the calculations the solar capacity factor for the whole of Sweden has been used.

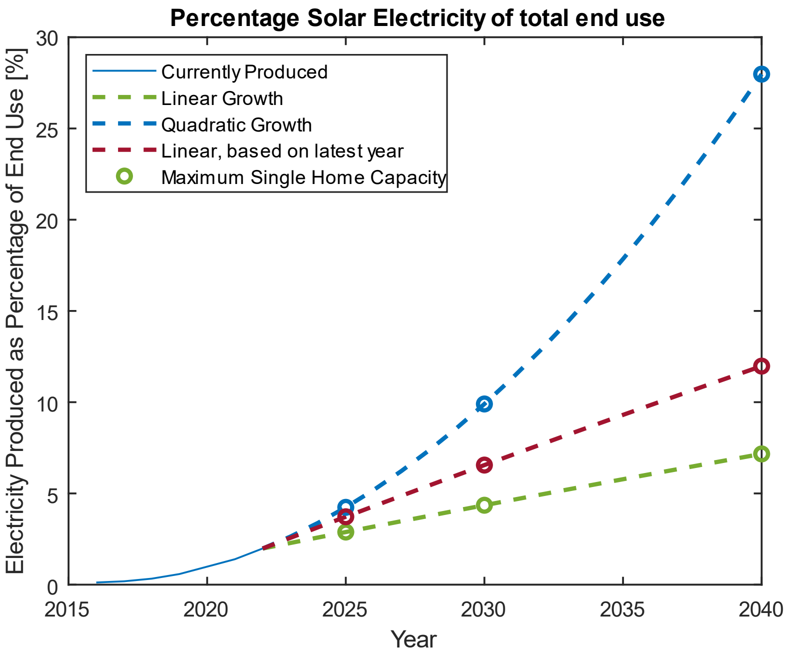

Figure 13: Produced solar Electricity as a percentage of electricity end use in Jönköping County.

Figure 13 shows the produced solar electricity presented as a percentage of the end use of electricity in Jönköping County, presented in Figure 3. The graph shows that Jönköping County as of 2022 has produced solar electricity corresponding to about 2 % of their end use. This is of course only a prediction since a lot more can happen for the electricity generation and use of electricity in Jönköping moving forward. The prediction does not take into consideration the potential addition of large-scale producers or consumers in Jönköping County.

Table 9: Table of total investment needed for solar power in Jönköping County until years 2025, 2030 and 2050 as well as the yearly investment needed according to the different models.

Year	2025	2030	2040	Yearly Investment	Unit
First-Degree Polynomial	538	1535	3228	179	MSEK
Linear Model	1028	2741	6168	343	MSEK
Second-Degree Polynomial	1333	4732	15946	385-1387	MSEK

Table 9 shows the economic result of the solar models. It shows what total investment is needed from years 2022 until years 2025, 2030 and 2050 respectively. As well as showing the annual investment needed according to each model.

As can be seen the first-degree polynomial model estimates that an investment of 179 million SEK is needed for solar PV each year while the linear model, based on the rate of increase in installations from year 2021 to 2022 estimates an investment of 343 million SEK per year and finally the second-degree polynomial model estimates and investment of between 385 and

1387 million SEK needed per year. Comparing the different models, it can be observed that the second-degree polynomial model estimates the greatest investment cost needed each year. Here the lower part of 385 million SEK of investment belongs to year 2023 where it increases each year until it hits the investment needed of 1387 million SEK between year 2039 and year 2040.

One can see that the yearly investment cost is highest for the second-degree model. This is to be expected since it predicts the fastest increase of the installed power of solar PV. One could also compare the different investment costs needed until years 2025, 2030 and 2040 in Table 9. It can be observed that for all years, the second-degree polynomial gives the highest estimated installation cost since this model expects the biggest expansion of solar power.

While the rate of expansion for solar, so far seems to have followed an exponential path, it is not very likely that the expansion will continue following the same curve. Partly because of the extensive investments needed for later years if the rate were to increase. But also, because the rate often slows down. Many different reasons exist for this slowdown e.g., the number of available roofs for installations will gradually decline, slowing down the market. For their report on the future energy system of Sweden Energimyndigheten, (2023a) predict linear increases for their lower electrification scenarios but an exponential increase in installed solar power for the higher electrification scenario where they expect the generated electricity of solar to grow to 32 TWh for the year of 2050.

A challenge that came up in the interviews with the regions was the electricity grid. For many of the regions of Sweden, upgrading or expanding the grid is essential for the continued expanse of renewable electricity production.

4.2.2 The Potential of Wind Power in the Norra Småland Region

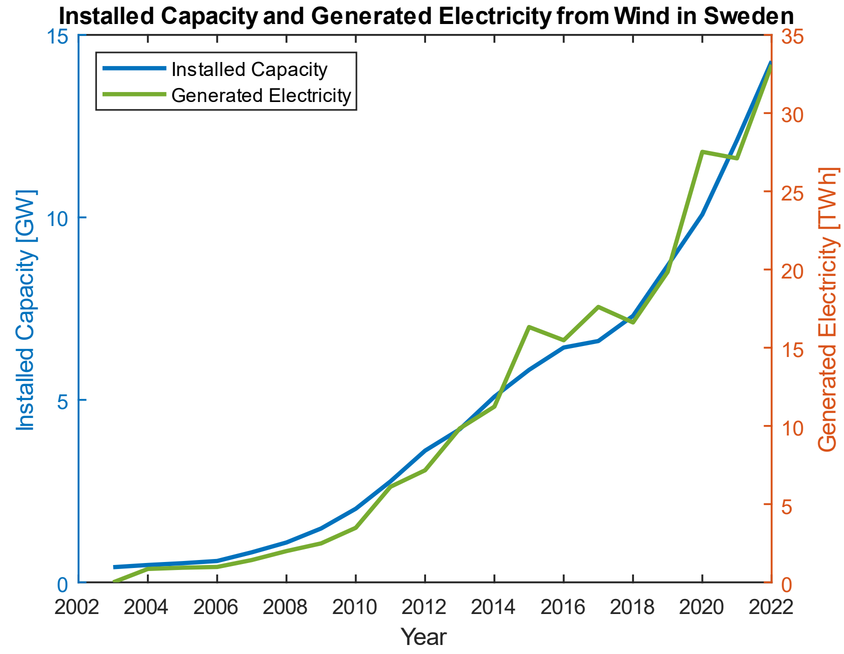

Figure 14: Installed capacity of wind power as well as produced electricity from wind in Sweden from 2003 to 2022.

Figure 14 shows how the wind power capacity has developed in Sweden from 2003 to 2022 as well as the produced electricity from wind power during the same time span.

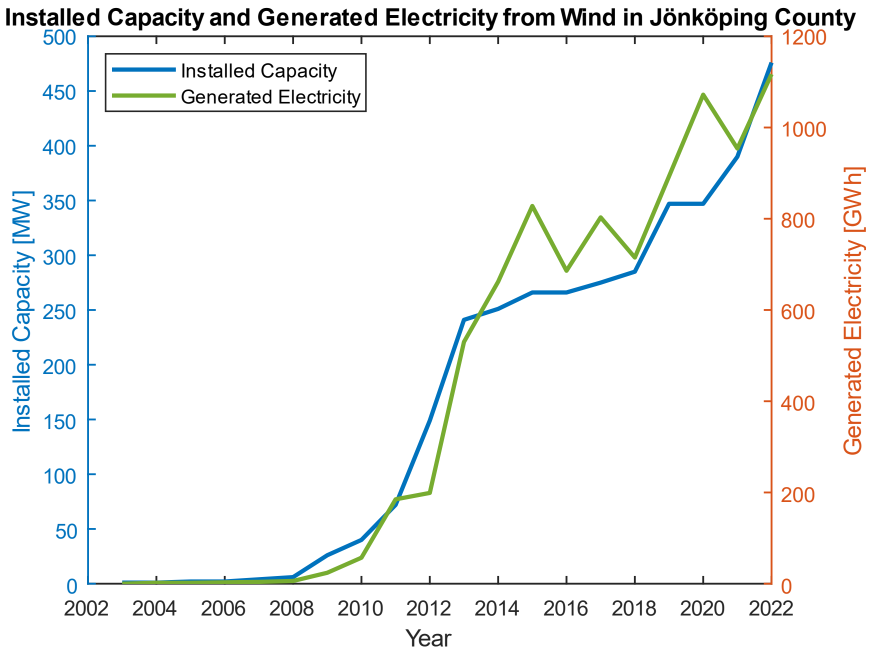

Figure 15: Installed capacity of wind power as well as produced electricity from wind in Jönköping County from 2003 to 2022.

Figure 15 shows the installed capacity of wind power in Jönköping County and how it has changed from 2003 to 2023 as well as the produced electricity from wind power in Jönköping County.

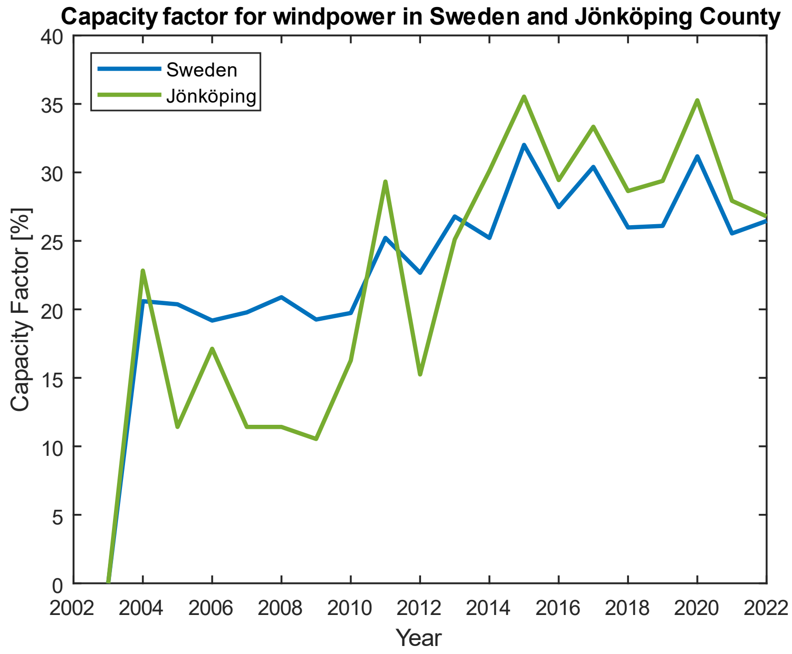

Figure 16: The Capacity factor for wind power in Sweden and Jönköping County.

Figure 16 shows the capacity factors for wind power in both Jönköping County and Sweden. It can be seen that both curves somewhat similarly develop, especially from 2014 and forward where the two factors seem to very closely follow the same movement pattern. The reason for the discrepancy in the earlier years could be the smaller number turbines, giving the installed wind turbines with different individual capacity factors a bigger effect on the general capacity factor for wind power in Sweden and Jönköping County as a whole. While for the years 2014 and forward, more wind turbines had been installed making the capacity factor more stable.

Looking at the curves in Figure 14 and Figure 15 one can see that the amount of installed capacity for wind power had greatly increased from 2012 and before. Another reason for the difference between the wind factor in Sweden compared to Jönköping County could be that the wind conditions vary for different locations meaning that the same general conditions don't apply from one region to another or comparing Sweden as a whole to Jönköping County. This could for example explain why the capacity factor increased from 2021 to 2022 for Sweden while it decreased for Jönköping County at this same time interval. This while the two capacity factors generally seem to follow the same patterns 2014 and forwards.

Since the wind is everchanging as well as the technology surrounding wind power being ever evolving, wind power has a yet undecided future. And while the rate of increase of wind power in Jönköping County seems positive so far it is hard to know if the rate is to continue growing or slow down further in the future. For all three of their future scenarios Energimyndigheten, (2023a) predicts a linear increase in installed capacity of wind power for Sweden.

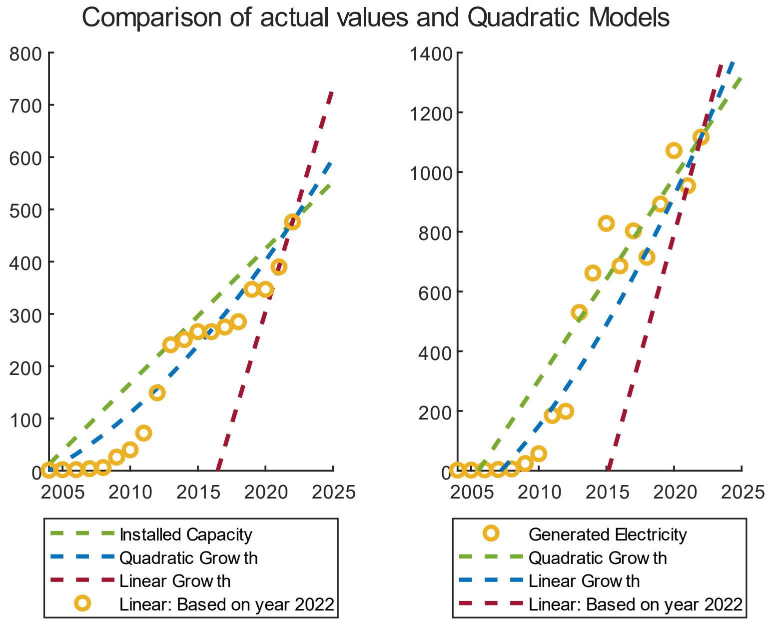

Figure 17: A comparison between the different models and the actual values for years 2004 to 2022.

Figure 17 shows the different values for installed capacity and generated electricity for the years 2004 to 2022 as well as the values for the models. Observe that the models have been adjusted to adopt the actual value for installed capacity and generated electricity respectively for the year 2022, since the increase from the year 2022 and onwards is of interest.

Figure 17 shows that the quadratic model best fits the actual values while the linear model based on year 2022, as described only follows the last years increase and therefor does not fit the actual values leading up to year 2022 very well.

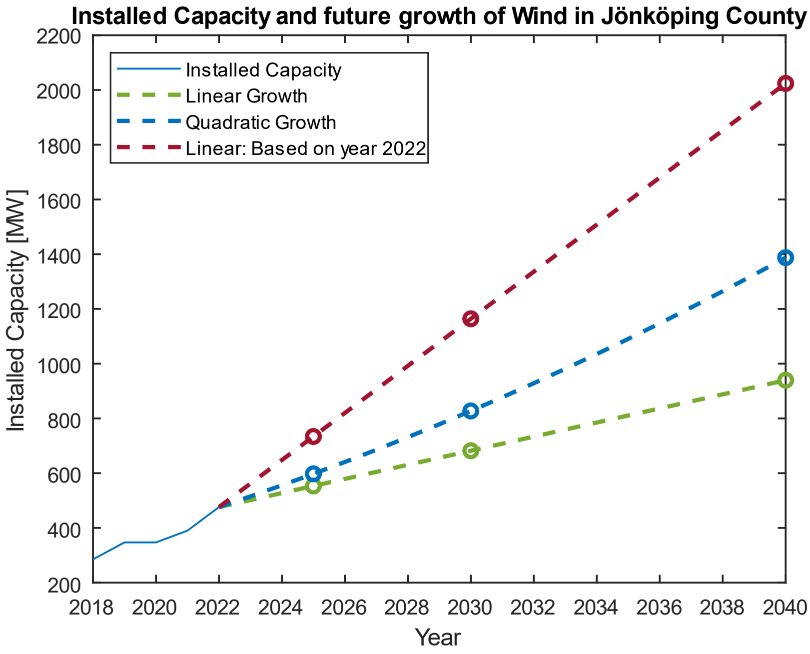

Figure 18: Installed capacity of wind power in Jönköping County from 2018 to 2022 as well as models for future growth of installed capacity.

Figure 18 shows the installed wind power capacity in Jönköping County from 2004 to 2022 as well as three individual models for the future growth. For the quadratic growth, marked by the yellow dotted lines, the growth from 2004 to 2022 was fitted as a second-degree polynomial, giving a quadratic rate of growth. The Linear Growth model is based on the same set of data as the quadratic growth one but now fitted as a first-degree polynomial, giving a linear increase. The last model, Linear: Based on year 2022 is as the name entails a model based on the rate of growth from year 2021 to 2022. Where the continued growth is expected to continue at the same rate as in year 2022 Jönköping County could have about 2 GW of installed wind power for year 2040.

It is however very hard to precisely estimate the future expansion of any energy source in any region. It is important to take into consideration that the models project the future potential of wind based on recorded growth so far. The models do not take into consideration the many variables that have to be taken into consideration when planning for wind power. For this reason, the values could be very risky to take at face value for the years further in the future. But for the close future say until year 2025 the model might give quite an accurate picture of where Jönköping County is headed.

Also, as one can see in all figures the expansion of wind is much more volatile than solar with more peaks and less of a steady increase. Which can be argued might be due to the harder to navigate landscape that is necessary for installing wind power. As point which has come up in the interviews performed.

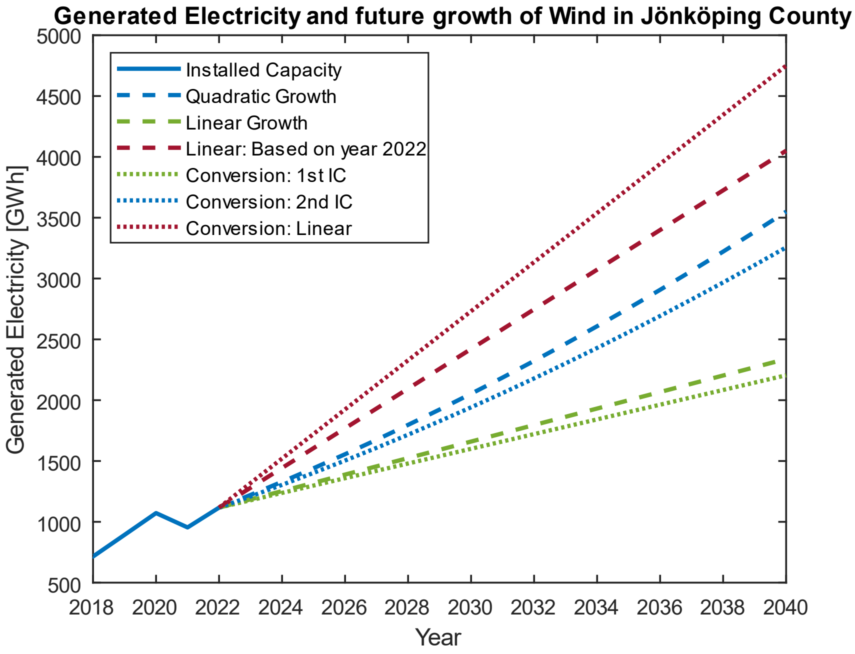

Figure 19: The Generated Electricity from wind power in Jönköping from year 2018 to 2022 and all models for the future growth.

In Figure 19 all three variants of models from Figure 18 are present. However, beyond this, three more models are present. These three models are calculations based on the increase in installation of seen in Figure 18. Through calculating the generated electricity using the installed capacity and the capacity factor 26.8 given from the capacity factor for year 2022 in Jönköping County and the installed capacities given from the models in Figure 18.

One can observe that the calculated values for generated electricity slightly varies from the modeled values for generated electricity based on the 2003 – 2022 data from the Energy Agency. One reason for this could be that the weather and the amount of wind, can vary heavily from year to year, creating a discrepancy on wind capacity from year to year, since different wind turbines perform differently at different wind speeds as well as a difference in production from one year to another even if the installed capacity where the same.

Table 10: Growth rates for the linear models for the installed capacity and generated electricity in Jönköping County as well as a conversion from increased capacity to electricity generation.

Variable	First Degree Polynomial	Linear	Unit
Capacity	25.7	86	MW
Generation	67.8	163	GWh
Calculated Generation	60.4	201.8	GWh

Table 10 shows growth rates estimated for the two linear models. Here, First Degree Polynomial, denotes the model based on the data from 2004 to 2022 and linear denotes the growth rate based on 2022 rate of growth.

Calculated Generation denotes the rate of growth measure for calculating the estimated electricity generation using the model for installed capacity. The discrepancy between the rate of growth for the modelled electricity generation and the calculated electricity generation can be explained by the fact that the rate of increase of capacity seems to differ from the rate of increase of electricity generation. However, the rate of growth in generated electricity depends heavily on the wind. Making the numbers much more unreliable than the rate of growth for the installed capacity.

That being said, many outside factors might come into play when it comes to installed capacity as well.

Table 11: Maximum and Minimum rate of growth for the quadratic models.

Variable	Max	Min	Unit
Capacity	62	39	MW
Generation	166	104	GWh
Calculated Generation	146	92	GWh

In Table 11 the maximum and minimum growth rate of the quadratic models are shown. It shows that the installed capacity increase between 39 and 62 MW per year, where the increase of 39 MW annually is the rate of growth at year 2022 and where the rate increases each year until it reaches 62 MW per year at 2040.

For electricity generated the same pattern applies where the rate of growth is 104 GWh at year 2022 and 166 GWh at 2040. For the calculated electricity generated based on installed capacity denotes as Calculated Generation it can be observed that it is somewhat lower than that of the model for generated electricity.

Comparing the rate of growth of the second-degree polynomials to the first degree / linear models, one can see that the rate of growth for the quadratic model moves in-between the faster rates of growth of the linear model and the slower rates from the first-degree polynomial.

Comparing this to the relationship for the first-degree polynomial model for electricity generated and the validation data calculated based on the installed capacity data in Table 10. For these values it can be seen that both the first-degree polynomial and second-degree polynomial models. Give a lower rate of increase for the calculated generated electricity as compared to the modelled generated electricity. Seemingly indicating that the increase in capacity seems to increase at a faster pace than the generated electricity. Another explanation for the discrepancy between the calculated generated electricity and the modelled generated electricity is that the capacity factor as well as the wind changes from year to year. Meaning that while the calculated generated electricity only takes into consideration the installed capacity, the model for the generated electricity is based on the real data which deals with both changing capacity factors and changing wind conditions from year to year.

While it is more logical to assume that the future rate of growth is quadratic, based on the trend of the growth so far, it is very likely that the rate of growth will slow down in the future depending on a few outside variables such as using up all the most potent sites, approaching the maximum generated electricity that the grid, or the county of Jönköping can handle etc. In their report on the future energy system of Sweden, Energimyndigheten (2023a) has developed three individual scenarios for the future energy use in Sweden. For all three scenarios the increase is linear although the predicted values for future years vary between the scenarios. 102 TWh of generated electricity from wind power is predicted for the lower electrification scenario and the year 2040. 140 TWh for the same year but with the higher electrification scenario and 85 TWh for the same year but the lower electrification scenario for the industry sector.

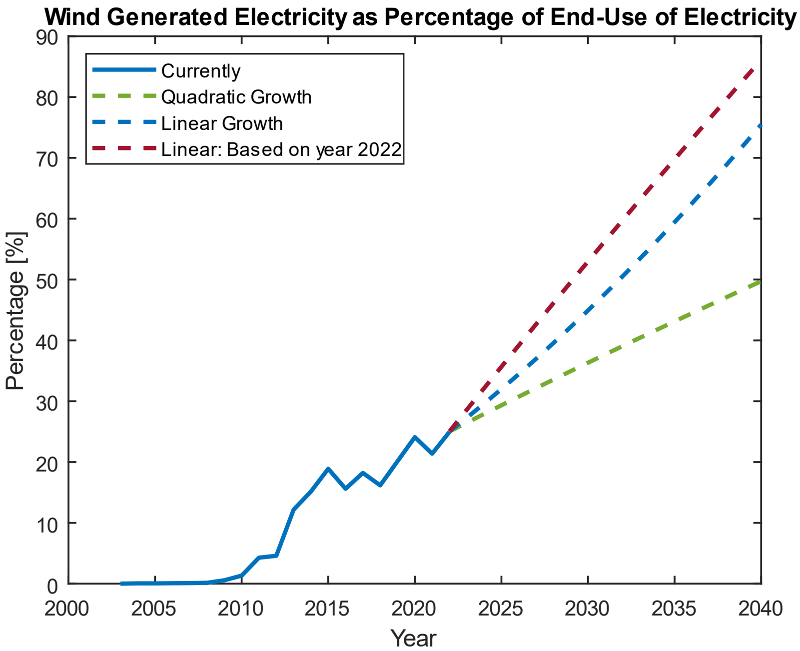

Figure 20: Wind generated Electricity as a Percentage of end-use of electricity in Jönköping County.

It can be observed in Figure 20 that wind power already stands for an impressive amount of around 25 % of Jönköping's end-use of electricity. Meaning that following the modeled increased in generation and capacity of wind power, this share can increase further, putting Jönköping County on the track of reaching between a share of between 50 % and 85 %.

Once again, it is dangerous to take the values of predictions far into the future at face value. However, they could be a good indicator on the direction of Jönköping County as whole and a pointer on the pace of the progression.

Table 12: Table of total investment needed for wind power in Jönköping County until years 2025, 2030 and 2050 as well as the yearly investment needed according to the different models.

Year	2025	2030	2040	Yearly Investment	Unit
First-Degree Polynomial	1087	2899	6522	362	MSEK
Linear Model	3630	9681	21783	1210	MSEK
Second-Degree Polynomial	1712	4943	12826	552-873	MSEK

The economic results for the models in Table 12 show an estimated yearly investment needed of 362 million SEK for the first-degree polynomial model, 1210 million SEK for the linear model based on the rate of growth of year 2022 and between 552 and 873 million SEK for the second-degree polynomial model.

Here one can observe that the linear model gives the highest yearly investment needed, far bigger than the second- and first-degree polynomial models. Comparing these results to the results for the solar power in Jönköping County in Table 9 it can be concluded that different models result in the outlying minimum and maximum yearly investments.

For both the solar power and wind power the first-degree polynomial predicts the slowest rate of increase for future installations. However, for wind the linear model predicts the largest increase while for solar the largest increase.

se in installed capacity, generated electricity, and yearly investment results from the second-degree polynomial model. Looking at Figure 14 and Figure 7 it can be observed that the curves for previous years seem to be mostly exponential. However, it can also be seen that for year 2016 the rate of increase for the wind power temporarily slowed down, before speeding up again which could be one of the reasons for the lower relative rate of increase for the second-degree polynomial model for the wind power expansion in Jönköping County.

Comparing the estimated expansion of both solar and wind it can see observed that the estimated wind expansion always is bigger than that of the solar expansion unless comparing the fastest, solar power expansion of the second-degree polynomial model for the solar, to the slower first- and second-degree polynomial models for the wind. Meaning that unless substantial change is made the solar power will not overtake the wind power as the main source of renewable energy for the future energy system.

4.3 General Discussion

Important to note is that since the interviews are conducted with a sole person per region, the results do not necessary need to entirely coincide with the actual work conducted in the region since individuals can differ in views, work and knowledgeability of the subject at hand. Combined with the fact that the way the individual energy agencies of Sweden work, differs greatly from region to region makes it hard for the answers to 100 % represent how the individual regions work with the questions. One person might have answers for one puzzle piece of the answers for the region but to get the complete answer for each region, many different actors in said region need to be interviewed. The work with the implementation of renewable energy in the different regions involves many different actors, who do not necessarily share the same view on the work, challenges and problems as well as tool and data needed. And this degree project through its interviews gives insight to one of these actors and how they might view the questions.

While the energy agencies of Sweden have a shared goal of impartially steering Sweden in the direction of more renewable energy, the individual agencies in each region widely differ in size, organisation etc. Which is one of the reasons for the variation of the answers for the various questions. The regions each have their very individual basis both from an organisational standpoint and a regional standpoint where the regions, geographically also differ widely from each other. Collaboration between the different regions came up in the interviews for some of the projects. However, mostly mentioned as a few projects with the neighbouring regions. The basis for the framework with which the individual regions work with is essentially the same and even if the regions and their work differ from one another it could be argued that there exists potential for further collaboration between the regions.

Since the interviews were conducted in semi-structured methodology. The answers given and therefor the results, of the interviews are naturally more open-ended and subjective responses as explained by McIntosh & Morse (2015). Comparing this choice of methodology to for example the use of a survey, where the questions are much more structured, the results are much more structured. For this reason, it can be argued that a survey would give more reliable results. However, with surveys, the questions are much more boxed in and leave much less room for more generalised and broad answers. A quality which was sought after for this degree project. The subjective and open-ended nature of the answers is here both the strength and the weakness of the degree project since it does not necessarily answer on the difference of how different regions work with the renewable energy questions, but rather how the specific organisation and people in this organisation work with this question. The strength here being that a difference is being highlighted here for how the questions are approached which can give insight into other views, insights and ways of working with the questions that maybe hadn't been considered before.

This degree project therefor gives a broad introduction to how different regions work with the renewable energy, as well as more specifically wind power and solar power. While also bringing insight as to what sort of challenges, tools, and political incitements are present as well as wished for, for future work. In doing so the work also gives an insight into the individuality of the different regions and the differences present in the different regions and the work they perform.

For the models, two different methods were used to create three individual models for the increase in installed capacity and produced electricity from solar and wind power. The first method used, the polyfit function from in MATLAB as a way of approximating the curve and giving a model for how the future expansion might look. The second method just extends the latest rate of expansion into the future, giving a model of "where the expansion to continue at last year's tempo".

Because of the chosen methodology for the models and the time constraint of the work, the accuracy of the models is somewhat disputable. The models are purely based on previous data and the accuracy thereof. Hence, nothing outside of the scope of previous data is considered for the model of the future solar and wind expansion in the Norra Småland Region. Since the models do nothing as to predict future changes of growth rates for the expansion of the wind and solar power respectively. A case could however be made that the models already take into consideration the various bottlenecks, challenges and problems connected to the expansion of wind and solar power, for example, the environmental and military constraints, since the systems which have already been built today, have navigated these. Therefore, the results from Table 2 and Table 5 have arguably been considered for the model. However, this is only true for challenges, problems and bottlenecks which were present when work was conducted with the solar and wind projects which today are completed. Newer problems and challenges which are surfacing first now have hence not be considered for the model and it can only be speculated as to how they might affect the future expansion of renewable energy in the region.

One example of this would be the Corona pandemic and the war in Ukraine which greatly affected the electricity price of Sweden and Europe as a whole. However, the full effect of this on how the expansion of renewable energy in Sweden continues moving forwards is yet to be fully realised.

5. CONCLUSIONS

Through conducting semi-structured interviews with the energy agencies of Sweden and modelling the expected growth trends of solar and wind power in the Norra Småland Region, a broad overview was given for how the work with renewable energy is conducted in Sweden.

The respondents' answers to the interview questions detail many different forms of projects on a wide area of subjects related to renewable energy. The work of the regions takes on many different forms and with many different actors in the individual regions. The work towards further implementation of renewable energy is conducted at different levels where the approach on the regional level is only one of the levels at which Sweden operates.

Generally, many of the various projects and topics are recurring in multiple individual regions for instance on and offshore wind power, energy efficiency, and hydrogen production which are mentioned in several of the interviewed regions. Simultaneously, there also exist challenges and projects that are unique to each individual region as well as projects and challenges that are present in many different regions but at the same time have local components that set them apart from other regions. One example being the question of wind power and ecology where the Region Norr mentions the need for regard in respect to reindeer and seal population while the Region Gotland mention have to take into consideration the population of the eagle.

Some examples of the most recurring bottlenecks and problem for the different regions are, the electricity grid, conflicting interests concerning wind power, and lack of labour resources but also the permitting and planning system for wind power as well as the municipal veto. The approach for dealing with the respective bottlenecks and challenges vary greatly between the individual regions. Given the various geographical constraints, the variation of size and organizational structure of the individual energy agencies as well as the variety of actors involved in the individual regions it is expected that the approach of dealing with the bottlenecks and challenges will vary. There seems to be potential for further exchange of knowledge between the regions for approaches on dealing with bottlenecks and problems as well as projects of interest.

More data is recurrently mentioned in the interviews as one of the keys in the regions' work towards further implementation of more renewable energy. However, it is also coupled with economics where more data is always helpful, but has to be balanced to the cost of attaining such data. More labour resources, more extensive communications with regional actors, energy mapping, roadmaps and various tools or software programmes are here mentioned as examples of tools helpful for further work.

The number of regions inquiring for further political incentives and the regions more ambivalent or not interested in further political incentives are pretty evenly distributed, where 7 regions expressed a need for some kind of political incentives. 3 regions where ambivalent and 3 regions where not interested in any further political incentives.

Some mentioned examples of incentives are economic incentives, a cleared directive in the question on renewable energy, long-term decisions and a cleared mandate on the wind power question. Given the closeness of the work the agencies and further the regions conduct, to the work of the government, one reason for the ambivalence could be that the energy agencies already feel that they sufficiently can influence the politics and the incentives given.

The number of solar power installations in the Norra Småland Region is vastly dominated by systems with an installed capacity of less than 20 kW, the actual installed capacity of solar power is more evenly distributed by the smaller systems and larger ones, between 20 kW and 1000 kW of installed capacity. More than half of the residencies in the Norra Småland Region consists of single homes meaning that even though the Norra Småland Region already has a lot of installation on single homes, there is still a big potential for further expansion. The models show that the future expansion of solar could net the Norra Småland Region a total installed capacity of solar power in the ranges of between 500 and 1800 TW. A future generation of between 300 and 1300 GWh and a share of solar power ranging from 7 to 27 percentage.

The economic models estimate that the annual investment needed for solar power ranges from around 200 to 1400 MSEK depending on model. With an estimated investment needed of between 500 and 1300 MSEK for year 2025 and between 1500 and 4800 MSEK for year 2030.

The models show that the future expansion of wind could net the Norra Småland Region a total installed capacity of wind power in the ranges of between 900 and 2000 MW. A future generation of between 2000 and 4700 GWh of electricity from wind and a share of wind power ranging from 50 to 80 percentage. For wind, the annual investment needed is estimated to between 360 and 1200 MSEK. With future wind power needing a total investment of between 1100 and 3600 MSEK for year 2025 and ranging between 2900 and 9700 MSEK for year 2030.

While the estimations for the year of 2040, for both solar and wind models are very uncertain, it is very plausible that the actual values land somewhere in the ranges of the models. As well as the models being a good indicator of where the Norra Småland Region is in their work towards an increased implementation of renewable energy and where they are headed.

6. SUGGESTIONS FOR FURTHER WORK

In this degree project, there are several topics that could be elaborated upon. Since the time was limited, there emerged thoughts on how to expand the knowledge on the field of the implementation of renewable energy:

- The effects of large shares of renewables on a regional electricity grid.
- Continued work could be investigated for the same research questions but on a different level, e.g., local, national, or European level.
- The potential for wind and solar power could be investigated for the other regions in Sweden, but also for the various municipalities in Jönköping County and Sweden as a whole.
- Further investigation into the specific bottlenecks and problems resulting of the answers given in the semi-structured interviews.

REFERENCES

Anshelm, J., & Simon, H. (2016). Power production and environmental opinions - Environmentally motivated resistance to wind power in Sweden. In *Renewable and Sustainable Energy Reviews* (Vol. 57, pp. 1545–1555). Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.12.211

Ek, K., & Persson, L. (2014a). Wind farms — Where and how to place them? A choice experiment approach to measure consumer preferences for characteristics of wind farm establishments in Sweden. *Ecological Economics*, *105*, 193–203. https://doi.org/10.1016/J.ECOLECON.2014.06.001

Ek, K., & Persson, L. (2014b). Wind farms — Where and how to place them? A choice experiment approach to measure consumer preferences for characteristics of wind farm establishments in Sweden. *Ecological Economics*, *105*, 193–203. https://doi.org/10.1016/J.ECOLECON.2014.06.001

Energikontoren Sverige. (2023). *Energikontoren Sverige - Om oss*. https://www.energikontorensverige.se/om-oss/

Energimyndigheten. (2022). *Kraftig ökning av installerade solcellsanläggningar*. https://www.energimyndigheten.se/nyhetsarkiv/2022/kraftig-okning-av-installerade-solcellsanlaggningar/

Energimyndigheten. (2023a). *Scenarier över Sveriges energisystem 2023 - ER 2023:07*. https://energimyndigheten.a-w2m.se/Home.mvc/View?view=c&folderId=51637&siteId=733&pageSize=25&offset=0

Energimyndigheten. (2023b). *Årliga energibalanser - Elproduktion (nettoproduktion) per kraftslag fr.o.m. 1970, TWh*. https://app.powerbi.com/view?r=eyJrIjoiNjk1YzgwOWQtMTNiZS00ZjE2LTkyZGUtMjhmM2M3OWEyNzdiIiwidCI6IjVjMTk0OGIzLWE5ODYtNDg1MC04M2YyLTQ2NTk2NWMzNmNhMSIsImMiOjh9&pageName=ReportSection

Energimyndigheten. (2023c). *Solstatistik - Statistik över antal nätanslutna solcellsanläggningar och sammanlagd installerad effekt*. https://www.energimyndigheten.se/statistik/solstatistik/

Energy Agencies Sweden. (n.d.). *Energy Agencies Sweden - About us*. Retrieved May 26, 2023, from https://www.energikontorensverige.se/om-oss/

Enevoldsen, P., & Permien, F.-H. (2018). Mapping the Wind Energy Potential of Sweden: A Sociotechnical Wind Atlas. *Journal of Renewable Energy*, *2018*, 1–11. https://doi.org/10.1155/2018/1650794

Enevoldsen, P., & Sovacool, B. K. (2016). Examining the social acceptance of wind energy: Practical guidelines for onshore wind project development in France. In *Renewable and*

Sustainable Energy Reviews (Vol. 53, pp. 178–184). Elsevier Ltd. https://doi.org/10.1016/j.rser.2015.08.041

Ersson, L., Rundqvist Yeomans, G., Schumacher, L., & Edfeldt, E. (2022). *Förstudie om Region Sörmlands arbete och roll i energiomställningen*. https://utvecklasormland.se/publikationer/forstudie-om-region-sormlands-arbete-och-roll-i-energiomstallningen/

General Assembly. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*. https://documents-dds-ny.un.org/doc/UNDOC/GEN/N15/291/89/PDF/N1529189.pdf?OpenElement

Government Offices of Sweden. (2015). *The Swedish model of government administration*. https://www.government.se/how-sweden-is-governed/the-swedish-model-of-government-administration/

Gürtler, M., & Paulsen, T. (2018). The effect of wind and solar power forecasts on day-ahead and intraday electricity prices in Germany. *Energy Economics*, *75*, 150–162. https://doi.org/10.1016/j.eneco.2018.07.006

IRENA. (2022). *Renewable power generation costs in 2021*. International Renewable Energy Agency. www.irena.org

IVA. (2017). *Future Electricity Production in Sweden - A Project Report*. The Royal Swedish Academy of Engineering Sciences (IVA). www.iva.se

Kamp, S. (2013). *Sveriges potential för elproduktion från takmonterade solceller Teoretisk, teknisk och ekonomisk analys*. https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2023/04/sou-202318/

Klimatpolitiska Rådet. (2022). *Klimatpolitiska rådets rapport 2022*.

Landelius, T., Lindskog, M., Körnich, H., & Andersson, S. (2018). Short-range solar radiation forecasts over Sweden. *Advances in Science and Research*, *15*, 39–44. https://doi.org/10.5194/asr-15-39-2018

Leung, D. Y. C., & Yang, Y. (2012). Wind energy development and its environmental impact: A review. In *Renewable and Sustainable Energy Reviews* (Vol. 16, Issue 1, pp. 1031–1039). https://doi.org/10.1016/j.rser.2011.09.024

Lindgren, F., Johansson, B., Malmlöf, T., & Lindvall, F. (2013). Siting conflicts between wind power and military aviation-Problems and potential solutions. *Land Use Policy*, *34*, 104–111. https://doi.org/10.1016/j.landusepol.2013.02.006

McIntosh, M. J., & Morse, J. M. (2015). Situating and constructing diversity in semi-structured interviews. *Global Qualitative Nursing Research*, *2*. https://doi.org/10.1177/2333393615597674

Permien, F. H., & Enevoldsen, P. (2019). Socio-technical constraints in German wind power planning: An example of the failed interdisciplinary challenge for academia. *Energy Research and Social Science*, *55*, 122–133. https://doi.org/10.1016/j.erss.2019.04.021

Pettersson, M. (n.d.). *Renewable Energy Development and the Function of Law*.

Pettersson, M., Ek, K., Söderholm, K., & Söderholm, P. (2010). Wind power planning and permitting: Comparative perspectives from the Nordic countries. In *Renewable and Sustainable Energy Reviews* (Vol. 14, Issue 9). Elsevier Ltd. https://doi.org/10.1016/j.rser.2010.07.008

SCB. (2007). *Karta över länsindelningen i Sverige. Giltig fr.o.m. 2007-01-01*. https://www.scb.se/contentassets/1e02934987424259b730c5e9a82f7e74/lanskarta_20221103.pdf

Söderholm, P., Ek, K., & Pettersson, M. (2007). Wind power development in Sweden: Global policies and local obstacles. In *Renewable and Sustainable Energy Reviews* (Vol. 11, Issue 3, pp. 365–400). https://doi.org/10.1016/j.rser.2005.03.001

Sovacool, B. K., & Lakshmi Ratan, P. (2012). Conceptualizing the acceptance of wind and solar electricity. In *Renewable and Sustainable Energy Reviews* (Vol. 16, Issue 7, pp. 5268–5279). https://doi.org/10.1016/j.rser.2012.04.048

Widén, J. (2010). *Correlations between future wind and solar power generation in Sweden*.

XE. (2023). *XE Valutaomvandlare*. https://www.xe.com/sv/currencyconverter/convert/?Amount=1&From=USD&To=SEK