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Techno-economic analysis of onshore wind energy in the ÖMS region

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Abstract

Globally, measures are taken to adapt to and mitigate the climate crisis. CO_2 emissions are continuously high and one measure to reduce emissions is through electrification. In Sweden, the road to electrification is currently focused on nuclear power as the main source and other energy sources are not as relevant. The aim of the thesis is to use the output of a previously performed multi-criteria analysis to conduct a geospatial analysis as input into a techno-economic assessment of wind energy in the ÖMS region. The geospatial analysis is performed in QGIS and the output used input into Python where the techno-economic analysis is conducted. The two technical KPIs in the report are capacity factor (CF) and annual energy yield (AEY), while the economic KPI is levelised cost of electricity (LCOE). The results show the best turbine height is 140 m, both considering AEY and the LCOE. The aggregated values for AEY does not match the LCOE values, since the best performing turbine regarding yearly output, Siemens SG 6.6-170, does not match the turbine with the lowest LCOE, Vestas V150. The best performing regions when analysing the aggregated results of the AEY are Gävleborg and Östergötland, while the best performing regions for the LCOE are Södermanland and Västmanland. When looking closer at specific sites, the best performing turbine measuring the AEY is the Siemens SG 6.6-170, and the lowest LCOE it by the Vestas V150. Analysing the site specific results, it can be observed Södermanland and Östergötland are strong regions with several sites in the top ranking in regard to the AEY. The highest CF can be found in the Vestas V150 at sites in Södermanland and Östergötland. The lowest LCOEs are generated by Vestas V150 where several sites in Södermanland and Östergötland are at the top of the ranking. The Vestas V117 is not recommended as preferred turbine at any site. The average distance to the grid is shorter than to the substations, 1,9 km and 23,2 km respectively. The average distance to a road is 1,1 km.

Keywords

Techno-economic analysis, wind energy, QGIS, Python, geospatial analysis, renewable energy, capacity factor, levelised cost of electricity, annual energy yield.

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Truly, thank you.

Emma Lindvall

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Nomenclature

AEY – Annual energy yield

CAPEX – Capital expenditure

CF – Capacity factor

GWh – Gigawatt hour

IEA – The International Energy Agency

KWh – Kilowatt hour

LCOE – Levelised cost of electricity

MCA – Multi-criteria analysis

OPEX – Operational expenditure

SVK – Svenska Kraftnät

SWEREF 99 TM – The coordinate system used in QGIS and is commonly used in Sweden

QGIS – Quantum Geographic Information System. Programme used as tool for geospatial analysis.

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1 Introduction

Extensive use of fossil fuels releasing carbons into the air is one of the main drivers for the climate change. Because of this, electricity is an important commodity for several sectors, especially the industry and the transport sector. The European Union has several adaptation and mitigation plans in place for different sectors to tackle the climate crisis at large and decarbonisation specifically. The Clean Industrial Deal (2025) from the European Commission is an example of such mitigation plans, where the focus of this agreement is the decarbonisation of the industry while maintaining global competitiveness. One of the pillars in the deal is the acceleration of clean energy to reach the desired electrification goals.

On a national level, fossil-free electrification of society is also the most prioritised area in the Swedish Climate Policy Council's assessment of the current Swedish government's climate policy action plan (2024, p.88). The Government has proposed to meet an electricity demand target of 300 TWh by 2045, where it is stipulated, nuclear energy is projected to meet this demand. According to the Swedish Climate Policy Council "nuclear power" and "reactors" are mentioned over 90 times in the action plan, while "wind power" is mentioned 25 times (Swedish Climate Policy Council, 2024, p.88). The government's plan was released in December 2023 and the Swedish Climate Policy Council's review shows several concerns regarding the measures taken for electrification. The four major issues with the government's proposal were lack of short-term actions for fossil-free electricity generation, limited range and uncertain initiatives for the long-term fossil-free electricity generation, lack of expert and other stakeholders' advice concerning energy policy decisions and skewed emphasis on electricity supply.

Wind power is a crucial technology for the transition towards a decarbonised future. Both for short-term and for long-term electricity generation. The lead time for operational new wind power in Sweden is according to Vattenfall (n.d) around 7-10 years. For nuclear, the time from construction start to operation is approximately 9,5 years and that does not include process time for permits, research, environmental impact assessment nor solutions for final nuclear fuel repository et cetera (VGR, 2024). Furthermore, according to Energiforsk the LCOE for onshore wind energy is on average 32 Swedish öre/kWh, which translates to approximately 0,029 EUR/kWh (Energiforsk, 2021, p.27). For nuclear, the average LCOE is 56 Swedish öre/kWh, approximately 0,052 EUR/kWh (Energiforsk, 2021, p.18). If one-sided focus on nuclear energy persist, cheaper fossil free alternatives are overlooked both for short-term and long-term electricity supply. Additionally, wind energy has a slightly smaller life cycle emission of CO_2, 11 g CO_2/kWh compared to nuclear with 12 g CO_2/kWh (Naturvårdsverket, n.d.). Wind power, along with other intermittent renewable energy sources, could be important to urgently decarbonise fossil heavy sectors and increase electrification.

1.1 Current electricity generation

In Sweden, the electricity production is to a large extent already decarbonised, where the two main sources are hydropower at 40% and nuclear at 29% of total generation in 2023 (IEA, n.d.). In 2023, wind power accounted for 20,5% of the generated electricity and is estimated to grow from 34 TWh in 2023 to 53 TWh in 2027 (Energimyndigheten, 2025b). The growth of renewables, and wind power, is however important also in Sweden since the share of nuclear energy in the energy mix is debated. The issue of how to handle the used nuclear fuel is a complex question to answer, and currently, nuclear fuel repository is the main answer. Another solution could be the 4th generation of nuclear power plants where the fuel is utilised in a more efficient way and with reduced final storage.

An issue in Sweden, which has been discussed vigorously, is the capacity and power deficit problems in the transmission grid. Since most electricity production is located in the northern parts of Sweden, and the grid has not followed the expansion rate of the energy generation plants nor the increased demand, issues occur in transmission from north to the south of Sweden, where most electricity is used. A way to curb this trend could be to decentralise production and locate it closer to consumption, which is possible with wind power. Despite the best locations for wind power usually are in remote areas, transmission can still be shorter than for more traditional centralised generation.

2 Background

2.1 The location of study

The study location of this report is the eastern central region of Sweden, called ÖMS region. The regions included in this area are Gävleborgs County, Uppsala County, Stockholms County, Västmanland County, Örebro County, Östergötland County and Södermanlands County. The study area, ÖMS region, can be seen in figure 1 below. Five out of seven counties have a coastline towards the Baltic Sea, while the remaining two counties are inland. The total land area of these seven regions is 6 337 395 hectares or 63 373.95 km^2, compared to the total area of Sweden being ca 410 000 km^2 (SCB, 2022). Sweden is divided into 4 electricity bidding zones, and six out of seven counties lies entirely in bidding zone 3. Only Gävleborg County is divided by the bidding border of zone 2 and zone 3, where the majority lies within zone 2.

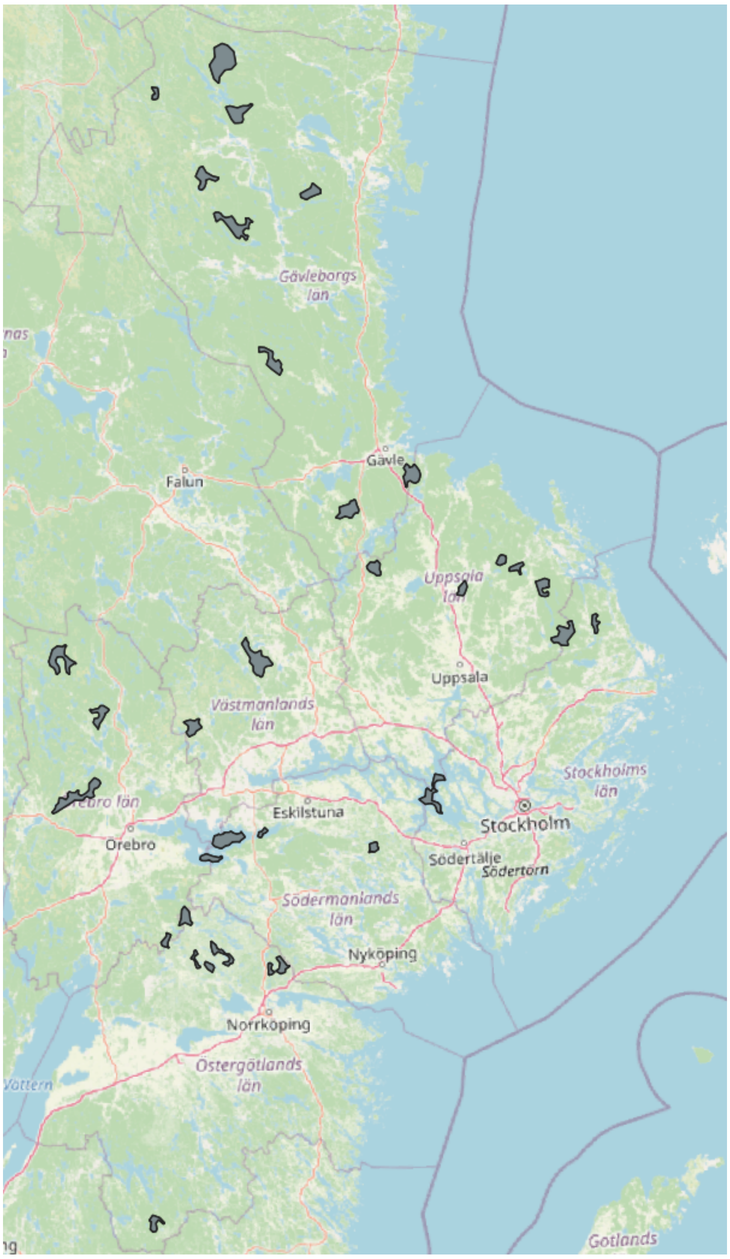


Figure 1. Map of the study area.

County	Number of sites
Gävleborg	8
Stockholm	3
Södermanland	4
Uppsala	6
Västmanland	2
Örebro	3
Östergötland	8

Table 1. Number of sites in each county.

In table 1, a description of how the 34 study sites are allocated across the 7 counties is presented. The number of sites in each county varies depending on factors and decisions made in the pre-study which is discussed in section 5. Figures 2-8 show the sites and their number in each county.

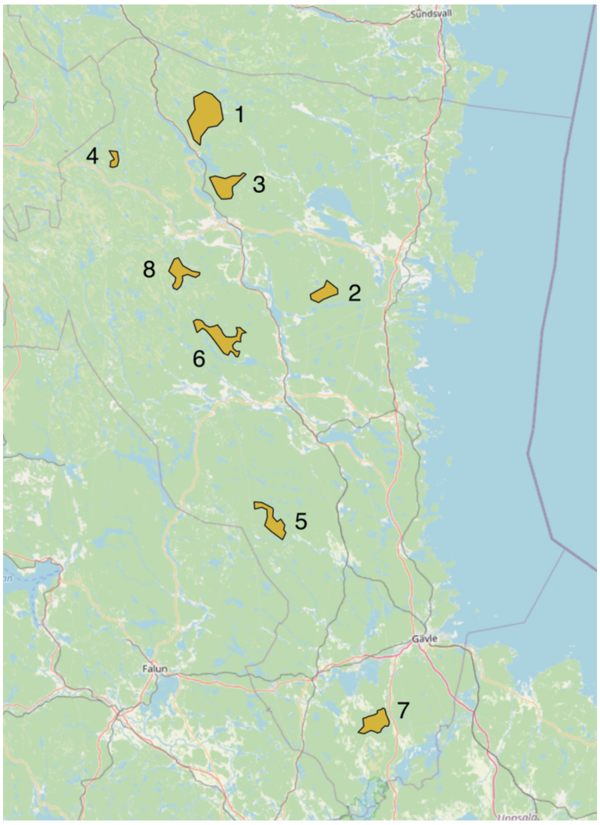


Figure 2. Map of sites in Gävleborg County.

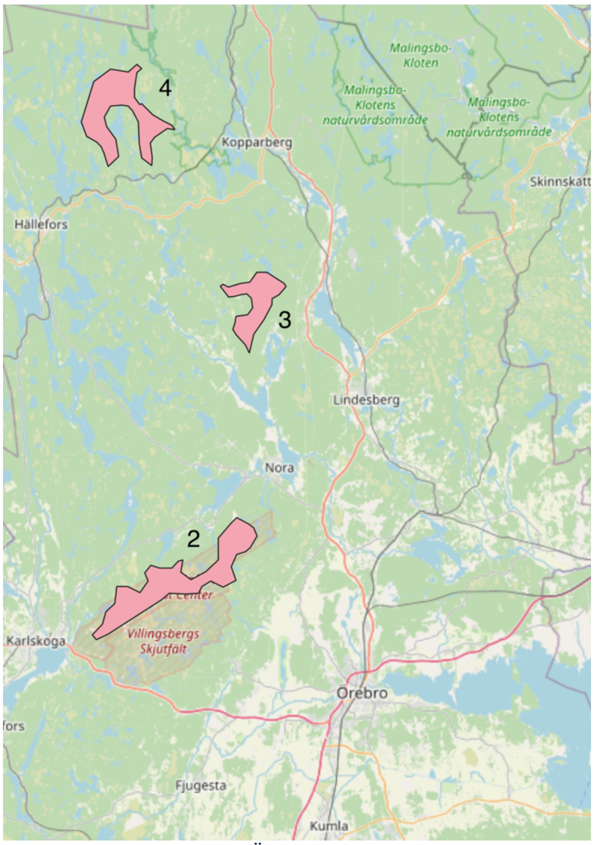


Figure 3. Map of sites in Örebro County.

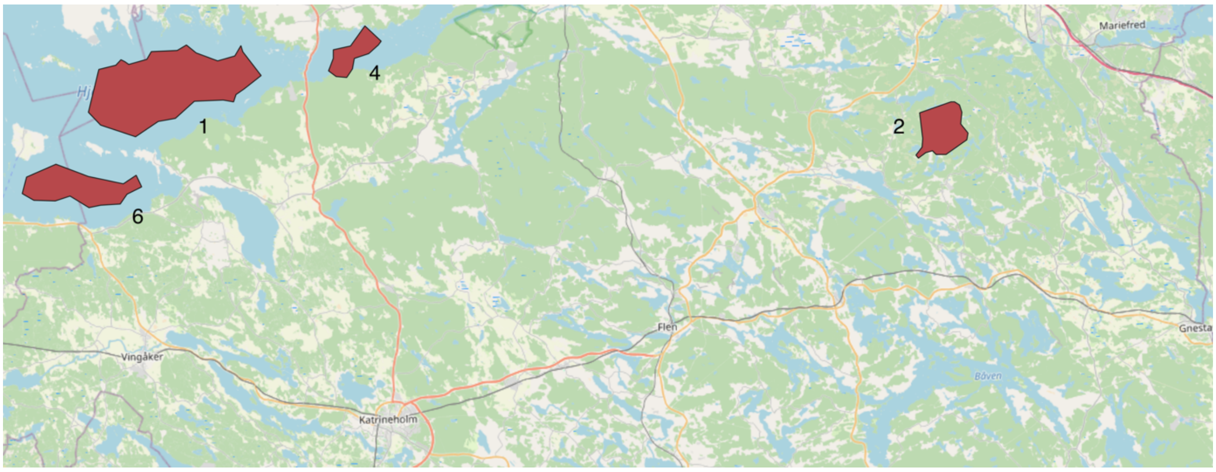


Figure 4. Map of sites in Södermanland County.

Figure 5. Map of sites in Östergötland County.

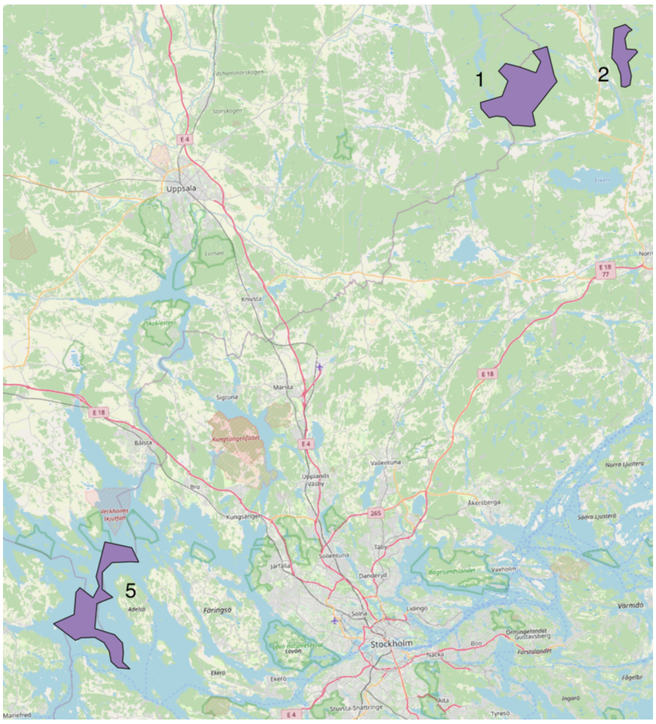


Figure 6. Map of sites in Stockholm County.

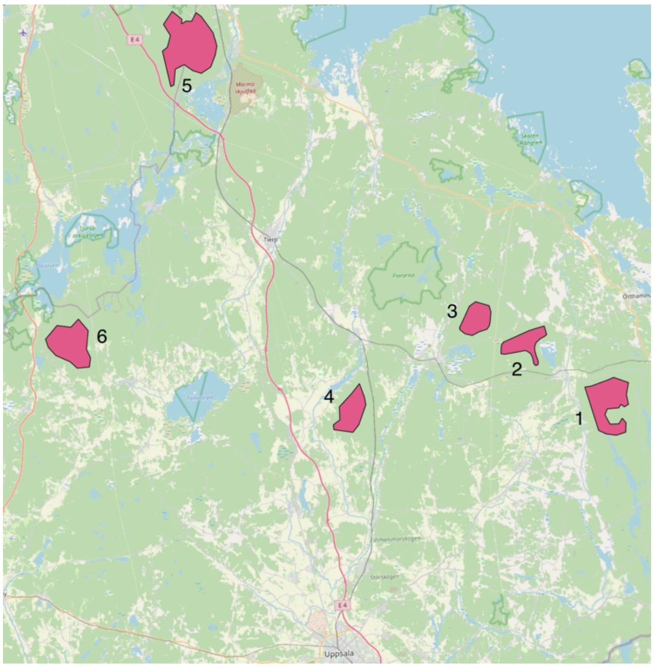


Figure 7. Map of sites in Uppsala County.

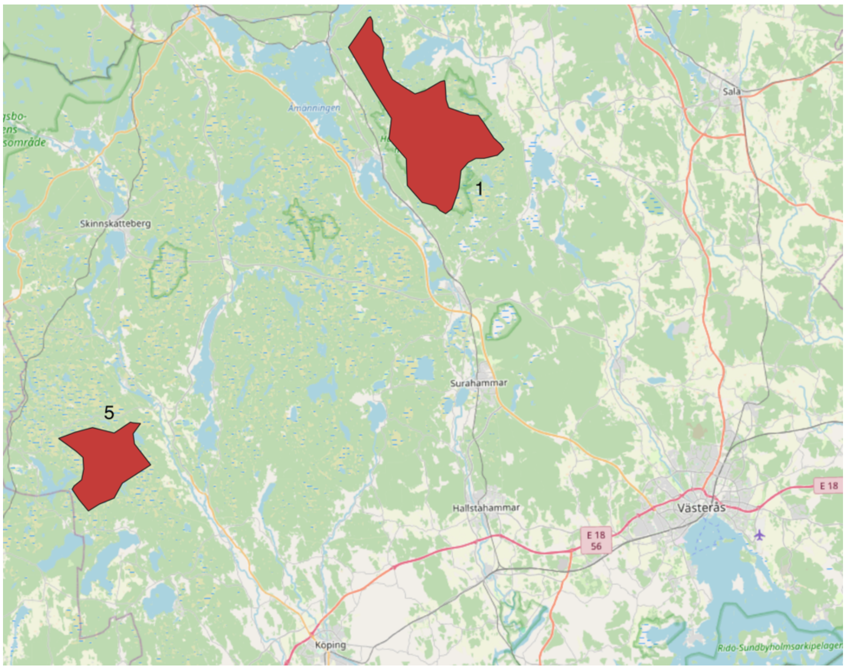


Figure 8. Map of sites in Västmanland County.

The counties studied are some of the highest populated areas in Sweden according to Statistics Sweden (SCB, 2025). This results in different types of infrastructure needed in, or near, residential areas such as transport, waste management and power and energy infrastructure. This can differ significantly between the regions. Besides urban areas, many single-family houses are spread across the counties.

One major issue when planning for wind turbines in an area are opposing interests when it comes to land use. As mentioned previously, these regions are highly populated, which can contribute to the stress on land usage. Agriculture, recreation, forestry, species and habitat protection, cultural heritage sites as well as the military are only some of the different interests competing for the same land area. With many powerful actors, which could impact the entire country's economy as with for example the forest industry, the decision could become increasingly difficult. Conflicts regarding land use could grow bigger with time due to climate change and the increasing effects on energy, water, land and agriculture systems.

The land use of the different counties, as well as their size, is accounted for in table 2. The values come from Statistics Sweden and shows the percentage of the total land the different categories constitute (SCB, 2022). Since Sweden is a major exporter of wood, forest cover the largest share of the counties area. Agriculture is the second largest share of the land use for all but two counties, Gävleborg and Stockholm. Since forest takes up almost 90% of Gävleborg County's surface, agriculture, residential areas and marshes make up a relatively equal share. In Stockholm County, the situation is reversed. Since the capital of Sweden is placed in this region, many actors have an interest to operate in, or in the proximity, of Stockholm city. This means less area for forest as well as agriculture, but increased need for residential areas and other uses as can be seen in the table.

County	Agriculture	Forest	Residential	Marsh	Other	Total (Ha)
Gävleborg	4,0%	88,6%	3,1%	4,2%	0,2%	1 820 807
Stockholm	13,7%	54,8%	14,9%	1,5%	15,1%	654 858
Södermanland	23,1%	61,5%	6,1%	1,2%	8,1%	609 879
Västmanland	20,8%	66,3%	5,5%	4,3%	3,0%	514 138
Uppsala	21,6%	65,7%	5,2%	1,3%	6,1%	823 097
Örebro	13,1%	75,4%	5,1%	2,6%	3,8%	854 243
Östergötland	22,8%	65,2%	5,1%	1,4%	5,5%	1 060 373

Table 2. Land use and size in the study regions in 2020 (SCB, 2022).

All these Counties, in 2024, have installed wind power to a varying degree as can be seen in table 3. The table is reproduced based on information from the Energy Agency. Västmanland is the county with the least installed wind turbines of all the study regions, as well as in the entire of Sweden, with only 1 installed wind turbine while Gävleborg has the most wind turbines of the ÖMS region, with 341. The reasons for varying installation numbers are many since the regions differ in their conditions for wind power. With that said, several of the obstacles for wind power establishments found in one county could be found in the other counties as well.

County	Wind turbines	Installed power (MW)	Generated electricity (GWh)
Gävleborg	341	1278,71	3086,46
Stockholm	23	60,87	157,52
Södermanland	13	27,99	72,02
Uppsala	10	11,19	26,98
Västmanland	1	0,06	0,02
Örebro	103	285,65	685,19
Östergötland	159	293,30	583,99

Table 3. Installed turbines, installed power and generated electricity in 2024 in the ÖMS region (Energimyndigheten, 2025a).

It is also important to note if an area has been appointed as an area of national interest for a specific purpose, it does not mean that the area could only be used for that purpose. The national interest areas work as a way to guide the work made on the regional and local level to indicate what is of special value to the nation. Wind energy can still be proposed on these sites.

A study assessing conditions and hinders of wind energy development in Swedish regions and municipalities (Johnsson, 2022) show the most common reason for refusal of wind power installation was the municipal veto at 51%. The second most common reason for refusal was species and nature protection at 24%, a close third and fourth was reindeer husbandry and the "box model" at 12% and 11% respectively. Other reasons for refusal could be protection of landscape, military interest, recreation or disturbances to residential buildings.

The national wind power expansion strategy developed by the Swedish Energy Agency and the Swedish Environmental Protection Agency advice on how the electrification of Sweden could be helped by a sustainable growth of wind power (Energimyndigheten & Naturvårdsverket, 2021:2). This due to the Swedish environmental goal of 100 percent renewable energy production in 2040. The strategy was developed with resolving goal conflicts and differences of interest in mind and aims to guide an even distribution across the country. This due not only to cater to the different land use purposes in each county, but also to for an even electricity supply to reduce straining the transmission grid and security regarding self-sufficiency of electricity. As basis for this strategy, a need for wind power expansion of 100 TWh until 2040 is considered. This development need is distributed across the country with consideration to for example wind speed and land suitability, the region's area, electricity use and population, access to areas with low conflict scores between interests and general factors for a robust energy system (Energimyndigheten & Naturvårdsverket, 2021:2, p.19). Table 4 shows how big the expansion need of wind power in the studied regions is. The table is partially reproduced based on information from the Energy Agency.

County	**Energy allocation (TWh)**	**Estimated number of turbines**	**Requested area for turbines (km^2)**	**Planning area (km^2)**
Gävleborg	7,5	357	338	1013
Stockholm	2	95	90	270
Södermanland	2	95	90	270
Uppsala	2,5	119	113	338
Västmanland	2	95	90	270
Örebro	2,5	119	113	338
Östergötland	2,5	119	113	338

Table 4. Desired wind energy expansion of the ÖMS region from the national strategy (Energimyndigheten & Naturvårdsverket, 2021:2).

As shown in table 4 all counties but one have an equal expectation for projected wind power. Gävleborg stands out with almost four times the wind power development than the allocation for remaining six counties.

Three major factors are expected to affect the future electricity demand according to a report on power supply in the ÖMS region by the Growth and Regional Planning Administration (Tillväxt- och regionplaneförvaltningen, 2019, p.28). Transportation, settlements and industry are projected to be the major causes of increase in the electricity and power demand. Regarding transportation, the main causes for increase in demand is the electricity use of rail and road traffic, the electrification of busses and cars, as well as EV charging infrastructure. The industry aims to digress from the use of fossil fuels by electrification, which means several businesses will have electricity intensive operations, and settlements are predicted an increase of electricity demand, which could be mitigated by energy efficiency measures. It is expected the Stockholm region will need and increase of electricity of around 3000 GWh/year by 2030, while Västmanland, Gävleborg and Södermanland each will need around 600–1000 GWh/year. Örebro, Östergötland and Uppsala regions are each projected to see an increase of 350–450 GWh/year, which is in the lower range of all the study area.

2.2 Literature review

The number of reports covering technical or techno-economic assessments of renewables are plenty. When focusing on wind energy several important factors need addressing to perform such an analysis. All techno-economic evaluations, which are focusing on new wind power, need input data in the form of wind speed. This to be able to assess the wind power potential for the location. Calculating the wind speed probability distribution is an important step in a techno-economic assessment. Several reports use the Weibull probability density function, for example a master thesis work evaluating wind power potential in Sweden by Ossa (2021), and a technical feasibility study in Eritrea by Negash (2021). Others apply the Rayleigh distribution, of which some use it due to data shortage or incorrect types of data available, for example Abdelhady (2017). The most commonly used technical parameters are capacity factor (CF) and annual energy production (AEP). In some of the reports wake loss is also accounted for and discussed, as for example in the report of Ossa. The most used economic parameter used for assessment is levelized cost of electricity (LCOE). Common factors affecting the LCOE are investment costs, CapEx, lifetime of the plant as well as operating and management costs. Other parameters used could be net present value (NPV), net present cost (NPC), or different type of payback time formulas such as simple payback period (SPP) or energy payback period (EPP).

The deployment of wind power could more efficiently implemented if choosing to use a geospatial method, such as geographic information system (GIS), to find optimal locations for installation. When looking at Sweden specifically, there have been some studies made for geospatial modelling for wind power installation potential. S. H. Siyal et al. in (2015), covering the potential of entire Sweden, which is a published report in *Energy*, while 3 others found have been master thesis projects: Marcianò (2017) in Kiruna municipality, Kandy (2018) performing a study in Västernorrland county and Andersson (2021) in Ragunda municipality and Västernorrland county. All reports are based on a multi-criteria analysis (MCA) or multi-criteria decision analysis (MCDA), since the problem is conflicting factors and restraints for choosing best location. Either the analytic hierarchy process (AHP) has been used, or a fuzzy function have been added to the different reports. One of the most important data sets used as input for evaluation in the GIS programme is wind speed data. This is true for all reports evaluating either the technical and economic aspects of wind power, or its most suitable locations. Other important restraints and factors have been the distance to national roads, railways, electrical grid and other infrastructure. Lakes, shorelines, urban areas and residential houses are also important restraints. Further, all reports had several environmental factors under consideration: protected areas, areas of national interest for culture, nature and recreational values. Other often used parameters in these reports were areas of protected habitats and biotopes, slope areas, military zones and reindeer husbandry, the last one due to the areas researched being further north in the country.

Kandy et al. have previously produced a method to simplify the planning and decision-making process around wind power installation for municipalities and regions to aid growth. The framework is called REWIND and builds on a spatial multi-criteria analysis (SMCA) where scoping, designing and evaluation stages are in focus. A goal with the framework was also to design a conflict score to alleviate goal conflict management which can occur when weighting the different factors and restraints. In this report the analytical hierarchy process (AHP) has been used combined with a weighted linear combination (WLC). The three stages of this developed method are, as mentioned previously, scoping, design and evaluation. During the scoping phase the different criteria and factors are identified and structured. The constraints are set to the Boolean reasoning while the factors are assessed by a scale which is then standardised between 0 and 1, this to make comparison possible. The 0 in this case stands for totally unsuitable while 1 is completely suitable. The most suitable sites for wind power are located during the design phase. The sites were found through applying three filters. First the constraints map, secondly the factor map, and lastly the conflict map where high conflict areas was discarded. In the last stage, the evaluation, different sites are chosen based on necessary size needed as well as high suitability and low conflict values. These sites are then compared to each other considering values such as factor, mean suitability and conflict scores. This aims to create a qualified ranking for the sites where a concluding decision can be made around which sites to pursue.

Previous reports performing a techno-economic assessment of wind power using a geospatial analysis have been executed in numerous places across the globe, with different methods and parameters. One such assessment was performed by Mentis et al. in 2016 in India and published in the scientific journal Renewable Energy. Their analysis was a techno-economic potential analysis of onshore wind power, where they used evaluation and restriction criteria to implement a geospatial estimation method as basis for their research. A shortage of similar reports was the motive behind it. The authors used GIS for the geospatial analysis, and selected grid cells with a capacity factor greater than 20% för continued assessment. The Rayleigh probability distribution was applied, and as technical parameters was the annual energy production (AEP), and capacity factor used. They are a commonly used indicators of the wind turbines technical performance. In this report the authors also accounted for wake losses in the wind farm layout. As economic indicators NPV and LCOE was used, where the latter included investment costs, O&M costs as well as fuel expenditures. The report concluded that several places are economically feasible compared to current cost of electricity generation in India, and the location with the lowest cost was attained in the state of Gujarat.

One recent study in South Korea in 2019 by Ali & Jang executed a techno-economic evaluation based on a GIS-MCDM method. The authors estimated the wind potential on ten different onshore locations which had been the best suitable locations in an earlier study. The main aim of the report was to find the most suitable wind turbine for each site. This turbine choice was based on comprehensive wind speed data with information about extreme wind speed and turbulence intensity. The technical indicators in this report were capacity factor (CF) and annual energy production (AEP) for each turbine, which are commonly used. The economic indicators estimated at each site were net present value (NPV) and levelized cost of electricity (LCOE). The study shows that all de chosen sites was technically and economically feasible for wind power generation.

In Egypt, a geospatial analysis of both wind and solar power was performed to find the ultimate technical and economic feasible locations for electricity generation in 2022 by Elkadeem et al. The authors compiled a list of recent reports using GIS technology and multi-criterion decision-making (MCDM) methodology for location identification of suitable places for renewable energy technology installation. This list displays for instance country, type of renewable technology, and the type of multi-criterion decision-making method that was used in the report. The most used method was the analytic hierarchy process. For their own report a hybrid model where GIS and ordinal priority approach (OPA) for the MCDM method was applied. The AEP and capacity factor was estimated as technical parameters for this report, while the main economic indicator was LCOE which contained for example CapEx and OpEx. The results show that over haft of the area of Egypt could be apt for solar PV and wind power turbine installations, as well as cover 32% and 50% respectively of the country's demand using the best locations. The report also shows that the best economic potential for wind power can be found in the northeastern part of Egypt.

Techno-economic assessments based on a geospatial analysis in Sweden are scarce. The first one performed, to the authors knowledge, is by Siyal et al. in 2015 and 2016 where the technical and economic potential of wind power was assessed. The study area was all of Sweden and not just a region or municipality. These two reports were a part of a doctoral thesis consisting of 4 reports in total and published in 2019. Programmes such as GIS and Homer were used for the geospatial and systems analysis. The Rayleigh probability distribution was used for the evaluation of wind speed frequency occurrence. Grid cells with less than 20% capacity factor (CF) or wind speeds below 4.8 m/s at the hub height of chosen wind turbines, was excluded from the analysis due to insufficient wind energy potential for commercial turbines. In the technical valuation, two scenarios were formed where 3 of the restrictions differed from each other. In the first scenario there were no restrictions for wind power installation in or near protected areas, areas of interest for nature, culture and recreational values, or less than 500 m from single residential houses and churches. From this, the annual energy production (AEP) was calculated as a technical factor while for the economic factors the cost of wind electricity (COE), net present cost (NPC), net present value (NPV), annual saving (AS), and simple payback period (SPP). The author was successful in delivering a map of Sweden based on restrictions and technical criteria where the southern parts of Sweden offers lower costs of electricity.

When summarising the constraints and evaluation factors used in the combined studies, there are several common input data used. The wind speed and the borders of the study area are requirements for any study of this kind. Other factors used by these reports are distance to protected areas, roads, railways, waterbodies and shorelines, urban areas, the grid as well as slope areas. Furthermore, factors such as elevation and distance to airports was also used by some of the reports. Due to the specific nature in the different study areas, there are several restriction and evaluation factors not discussed here. Some factors are not applicable to all locations, why a general overview to find common aspects not to oversight relevant features is important. Reindeer husbandry is an example of such factor which is not applicable in this study but used in some other Swedish reports of similar contents.

2.3 Research gaps

Oftentimes, studies in Sweden cover either a GIS-MCDM method to find the best sites for wind power generation or perform a technical or techno-economic analysis of specific locations. Finding several reports which combines a GIS analysis with a techno-economic evaluation has been proven difficult.

Since the number of reports considering a techno-economic assessment using a spatial analysis method are few in Sweden, this work is aiming to bridge this gap. Also performing such an analysis in the ÖMS region has, to the authors knowledge, not been done before.

3 Aim & research question

A geospatial evaluation of the ÖMS region will be carried out based on site specific data and predefined locations as input. Further a techno-economic analysis will be performed where key performance indicators (KPIs) such as annual energy yield (AEY), capacity factor (CF) and levelized cost of electricity (LCOE) are used to reach the main objective.

The main objective of this report is thus to identify the most suitable regions, locations and turbines for onshore wind power generation within the ÖMS region based on technical and economic analysis performed.

The research questions are:

- Which region, or regions, within the ÖMS performs the best in relation to AEY and LCOE?
- Which turbine is the most technologically and economically feasible for wind power generation at the selected sites in the ÖMS region?

4 Limitations and delimitations

One of the limitations of this study is the specific region of which to find the most suitable place for wind power installation. This study will be focusing on 34 sites in 7 regions, the ÖMS regions, which consist of Gävleborg, Stockholm, Södermanland, Uppsala, Västmanland, Örebro and Östergötland.

Financial assumptions such as inflation, interest rates, subsidies et cetera, are factors which can be object of change during or after this project is completed. Each factor is dynamic and influenced by several aspects such as economic growth, increased production costs, demand and supply of money or credit as well as fiscal and monetary policies. This would of course affect the economic analysis. The assumptions made in this report are based on historical data and current regulations to make an as accurate economic analysis as possible.

Another limiting factor for this study could be regulatory uncertainty. Policies, laws, incentives and restrictions are subject to change depending on the party in power and their ideology and outlook for their administrative period. Changes can be made at any time, and implemented at different rate, depending on how important the subject is seen. Therefore, changes in policies and incentives, and consequently funding, will have impact beyond this study.

Technology changes could also be a limiting factor. In this report, the Siemens SG 6.6-170, Vestas V150 and Vestas V117 turbine has been used. The use of other turbines will change the results of both the technical and economic assessment. Technical aspects that could change are for example rated power, cut-in and cut-out wind speed and power curve, which will alter the yearly energy yield. Change in financial factors such as CAPEX and OPEX will ultimately also affect LCOE which is an important KPI of this report.

Data availability can be a limiting factor for this report as well, where data needed could be either difficult to find or be incomplete. Data that is not available at all, incomplete, or incorrect can affect the report in such a way that essential parts could not be done, reliability is reduced or bias distorting the result could occur. The range of time of the available data is also a restriction which could affect the result. If the data, such as wind speed and electricity prices, is only available with dates or time series which are a bit too old it would possibly cause the calculations to be invalid or outdated.

Areas such as capacity analysis of the grid and constraints of transmission are topics beyond the scope and will not be considered due to the time restrictions imposed. The same is considered for any electricity market analysis where for example price forecasting modelling or optimal dispatch is not taken into consideration.

A comparison between wind power farms located in other parts of Sweden will not be performed during the study. A comparison with wind farms in other regions or with farms within the same region will not be possible to execute during the time frame of the study, though possibly interesting. Also, no comparison to other types of energy generation sources will be made. The time frame of this report is another boundary which limits the content and extent of this report.

5 Method

Based on the literature review, the proposed method for this report is an initial geospatial analysis which will be performed using the tool QGIS. When all essential data has been modelled in QGIS, relevant information will be extracted and used as input into Python using GeoPandas. This to be able to perform the techno-economic segment of the assessment. Schematics of the method is presented in figure 9. Moreover, a stakeholder meeting was conducted during the course of the report where valuable input was gained. Actors from some of the counties participated, as well as from KTH and Vattenfall.

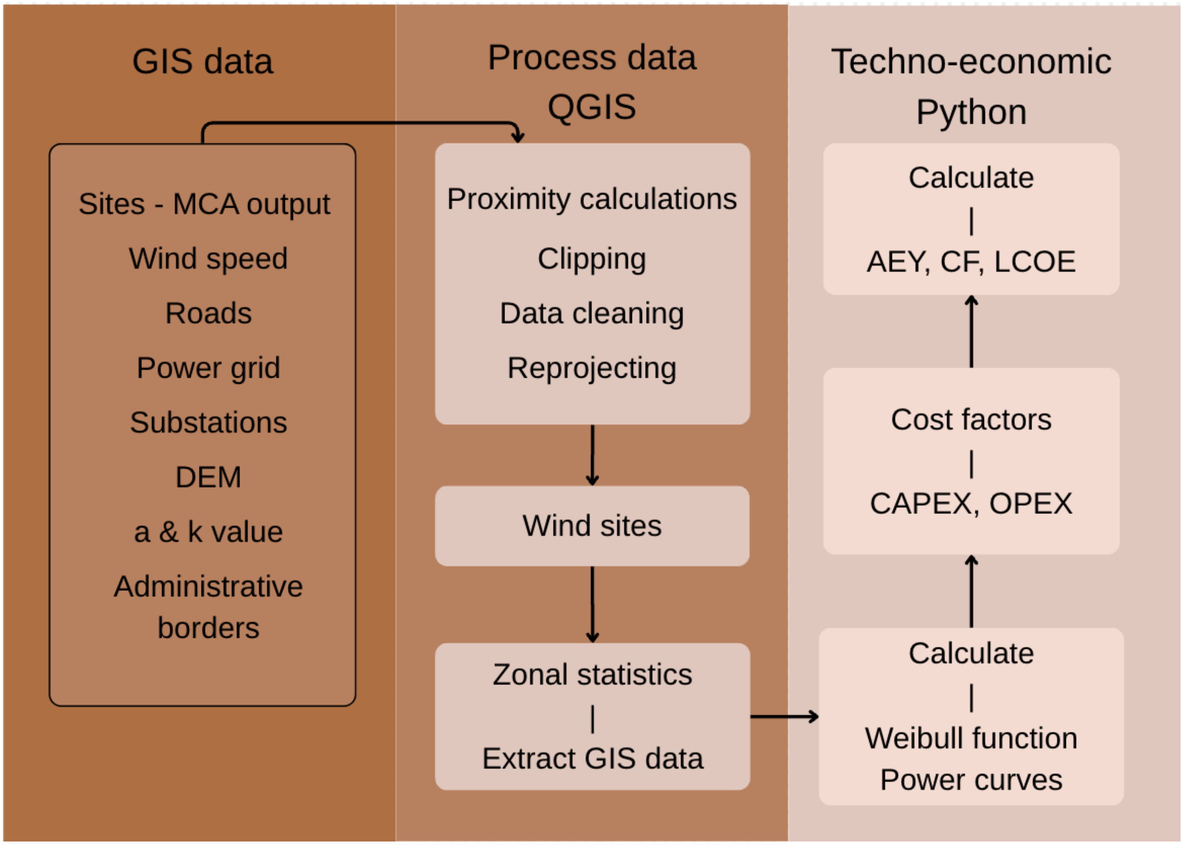


Figure 9. Schematics of the method.

The two first sections of figure 9, the collection of data and the processing of data, is part of the geospatial analysis. The geospatial analysis is performed in QGIS and is described in detail in section 5.1 in this report. The last section of the figure roughly shows the steps of the techno-economic evaluation executed in Python. Section 5.2 describes the parameters needed for the technical analysis while section 5.3 describes the parameters needed for the economic analysis, and these sections build up to the description of the modelling. To describe the modelling, and furthermore the contents of the last section of figure 9 in detail, section 5.4 of the report is referred to.

5.1 Geospatial analysis

Geospatial analysis is performed through applying several types of data about different locations. When combining for example maps and other spatial information as well as GIS and methods for analysing patterns and relationships, it is possible to extract more information than by only applying one layer or technique. This is very useful for complex problem solving when several factors need to be taken into consideration and is a way to inform and aid policy makers in decision making.

5.1.1 GIS

GIS is a program to gather, structure, analyse, and map different types of geospatial data to integrate it into one comprehensive layer for visualisation. It is a step-by-step process tool for multi-criteria decision making while analysing the land suitability of various kind. In this report it is used for land suitability for wind power installation.

The first step of using GIS is to identify the problem of which needs solving. This makes for understanding which data need to be used as input. The second step will then be to find the data to build the map in GIS, which requires as accurate and current input as possible to get the best analysis. The different types of data used as layers in the programme could be transportation networks such as roads and rail, topography, protected nature areas, energy production or urban areas. This information is then layered on top of each other in GIS for visualisation of numerous decision factors simultaneously. This way, data can be analysed together for comprehension of patterns or relationships which would otherwise go unknown. GIS could help with finding the best suited locations, routes or efficient systems management since detailed maps can be built.

Working with data means categorising them into constraints and factors to achieve the end result. The constraints are classified according to Boolean logic which mean they are 0 or 1, to express the either-or relationship, while the factors are classified on a scale depending on expert knowledge, policy and regulation. The value they get classified as is tied to suitability, for example the distance from road infrastructure. This is liked to regulation and laws in the Swedish planning process for wind power.

For this project, using QGIS is a way to combine geospatial data to assess the technical and economic circumstances for onshore wind power turbines in the ÖMS region. Using QGIS instead of ArcGIS, or another form of a geographic information system, was a choice based on availability. QGIS is a programme free of charge to use, which would make any replication of this report much easier to facilitate.

5.1.2 Input data – suitable locations in ÖMS area

The data used comes from different sources. In the ÖMS region, the most suitable locations for wind power have been researched by Deepa Kandy as a step prior to the current report. The output data from that study will be used in this report since time limitation hinders an execution of a full spatial multi-criteria analysis. GIS will be used for the technical and economical evaluation of these predetermined sites.

Kandy performed a multi-criteria analysis in a GIS software. A multi-criteria analysis is an umbrella term for a collection of tools to be used for evaluation when several factors are important. The aim of such an analysis is to weight together the different factors to create the best compromise for the research question. Since spatial data is needed for this report a spatial MCA (SMCA), often also called GIS based MCA (GIS-MCA), is used. This way spatial data can be combined with the stakeholders' preferences to become valuable information for evaluation and decision-making.

Kandy collected data and clustered it into different boxes such as economic, technical, social, cultural and environmental. Stakeholders were then invited to provide their opinion on the importance of these factors. During the meeting, the participants was invited to rank the factors to gain insights into the importance, from the most to least important. The next step was to do pairwise comparisons of the factors starting from the bottom. In total 4 stakeholders participated in the ranking and rating of factors. The factors were standardised and then all factor layers were multiplied by the stakeholder weights. The factor maps were then linearly added.

When evaluating potential sites, a threshold value was considered. 0,75 was the suitability score cut off. The national wind strategy the allocation of desired wind power expansion in each county was used as a basis when creating the suitability polygons in GIS for each region.

Factors	**Description**
Wind speeds	Chosen hub height: 140 m < 3 m/s: 1% suitability 3-7 m/s: linear increasing suitability > 7 m/s: 100% suitability
Power grid	Regional grid with 40-150 kV Maximum distance: 3 km. Low suitability beyond 3 km.
Roads – state and municipal	≤ 250 m: 0% suitability > 250 m -3 km: highest suitability closest to 250 m and then linearly decreasing suitability > 3 km: 1% suitability
Roads - Private	25 m buffer around the roads on each side

	50% suitability

Table 5. Description of factors used in the MCA by Kandy.

In table 5 above some factors and their constraints or suitability are explained more thoroughly. Several more factors have been used to create both suitability maps and to gain the results which are the preferred sites. These factors are presented in appendix 10.1.

5.1.3 Input data for techno-economic assessment

The important input parameters for this study will be technical and economic factors known to affect performance and price of wind energy. The chosen factors are as described in table 6 below.

When discussing the source of the factors an aim has been to have as many Swedish sources as possible to align with official data currently offered of the region. In some instances, when Swedish sources have been proven difficult to attain, open-source alternatives have been used. Sources such as administrative borders, roads, transmission grid and wind speed model has been sourced from Swedish authorities. Lantmäteriet's site allows you to download important data regarding several areas of society, such as buildings, topography, technical infrastructure and data related to ecology. This site is used as a common site for several Swedish authorities such as the Swedish Transport Administration, Svenska kraftnät and the Swedish Maritime Administration. The data which could not be extracted from Swedish sources were regional power grids, substations and elevation. All sources for the different parameters have been accounted for in table 6 below.

Limitation/Evaluation	**Source**
Administrative borders	Lantmäteriet
K value/A value	Global Wind Atlas
National roads	Trafikverket – Nationell vägdatabas
Power grid	Lantmäteriet
Elevation	Lantmäteriet
Substations	Open street map
Wind speed	Energimyndigheten - MIUU

Table 6. Table of input data and their sources (Lantmäteriet, n.d.a.; Global Wind Atlas, n.d; Nationell vägdatabas, n.d.; Lantmäteriet, n.d.b.; Lantmäteriet, n.d.c.; Energimyndigheten, 2023).

5.1.3.1 National road infrastructure

When planning new wind power avoiding interference with current infrastructure is important. According to The Swedish Transport Administration (Trafikverket, 2025) the buffer zone between a public road and the wind turbine should be at least the total height of the wind turbine. They also request the smallest distance should always be 50 metres. These distances are estimated due to the risk of ice or hard snow thrown from the blades onto incoming traffic. Although, the accessibility of the wind power plant is also of significance since is affects the cost of the project and reduces the demand for new roads to be built (Mörtberg et al., 2023, p. 21). In Mörtberg et al. the maximum distance varied between 10-15 km (2023, p. 21).

5.1.3.2 National power grid and substations

For the electrical grid the requirements are a bit more complicated. If the total height of the wind turbine is less than 50 metres, the distance between the closest part of the power grid and the outermost part of the rotor diameter of the wind turbine should be 100 m (Svenska kraftnät, 2023). If the total height of the wind turbine is higher than 50 metres, the required distance increases to 200 m. The distance needs to be adjusted if the distance to the power grid would be less than the total hight of the wind turbine, with an added 10 m. This due to the requirement of at least 10 metres between the power grid and a collapsed wind turbine. Furthermore, the distance between the tower of the wind turbine and the power grid needs to be greater than 250 m of the diameter of the rotor is 100 m or more.

The distance to the grid is also an important economic parameter for a successful wind power project. According to IRENA (2012, p.19), the cost for grid connection for onshore wind power accounts for approximately 9-14% of the total cost, including cables, substations and buildings. Substations are a connection point in where the voltage is adjusted to fit the grid voltage. It is also of importance to have existing substations as a factor for this report. According to Mörtberg et al. (2023, p.21) the maximal distance from power grids used varied between 9-20 kilometres.

5.1.3.3 Elevation and slope

When searching literature for recommended gradients for slopes, the answers were mixed. Several reports used no more than 10° slope angle or a range between 10-20% (Siyal, S.H., 2019, p.18; Mentis, D. et al., 2016, p.82; Grassi, S. et al., 2012, p.76). Others have used 13,5° or 15° as slope limit while some use 30% or even range values of 10% to 45% for maximum slope, where intervals in the range is deemed high, medium or low suitability (Harrucksteiner, A. et al., 2023, p.5; Gass, V. et al., 2013, p.326; Zhou, Y., et al., 2011, p.420; Tegou, L-I. et al., 2010, p.2142; Jangid, J. et al., 2016, p.6-7).

Why steeper slopes are discarded is due to the increasing difficulties to construct and install the wind turbines in such locations. The accessibility may decrease for vehicles used during installation as well as needing more grading than a milder slope, or no slope at all (Jangid, J. et al., 2016, p.6-7; Grassi, S. et al, 2012, p.76). The cost of building wind farms at these sites also increase since transmission, transportation, accessibility and installation in general becomes more difficult. Another reason for setting a limit to the gradient of slopes is due to the change of wind speed and direction. Speed-up effect on the wind speed helps to a certain angle of the slope before the increased turbulence reduces wind quality, if the turbine is located on the top of a hilltop or ridge (Huang, C. et al., 2022). In the circumstances the wind turbine is placed in front of the slope, a steeper slope will increase the turbulence of wind due to hindering the advancement and thus reduce the power output of the turbine (Huang, C. et al., 2022).

For elevation, the most used limit was 2000 m and below (Siyal, S.H., 2019, p.18; Mentis, D. et al., 2016, p.82; Gass, V. et al., 2013, p.326). Everything above that limit was excluded. The most common reason for this was the lower air density as well as higher costs for transmission and transportation due to problems with ice (Gass, V. et al., 2013, p.326).

5.1.3.4 Wind speed

When planning for new wind power, the wind speed is a crucial aspect. The wind speed is an important factor for how much power the turbine can generate and is thus an integral factor for economic feasibility. The more electrical output from a site, the bigger financial gain could be obtained from selling the electricity generated or decreasing the need for purchased electricity. The Swedish Energy Agency has in the report *Riksintresse vindbruk 2013* used average yearly wind speed of 7,2 m/s for wind 100 m above ground. This value is used to distinguish locations with a national interest for wind power in Sweden.

The wind speed data used in this report is taken from the Swedish Energy Agency and is from the MIUU model. The model is based on both basic data for input as well as model calculations, where 192 different models of wind and temperature are combined (Energimyndigheten, 2023). The wind speed which is presented from the model is a yearly average value and the yearly climate is meant to be representative for a 30-year period.

5.1.4 Modelling in QGIS

The purpose of modelling in QGIS is to extract the data needed from the most suitable sites and use as input in Python for further analysing. When the data is downloaded from the sources it is inserted into QGIS and processed. This procedure could require clipping the data to reduce the amount of information processed, creating temporary layers or reprojecting the layers to assume the same coordinate system. If the layers do not have the same projection, it can be difficult to analyse the data, due to one layer might have longitude and latitude as distance unit while the other has metres. Since the data is in different format, for example vector and raster format, the process might be altered to achieve the same outcome.

Since the study area is several regions, some data may have been downloaded per region. In these instances, all layers containing data related to the same area, for example substations, have been merged into one. In other cases, such as for roads, the data could be downloaded to fit the study area on beforehand which simplifies the process. Mostly, the data was available for the entire area of Sweden, or even bigger zones, which requires some of the processing methods mentioned previously. Clipping of layers was used for data layers bigger than the regions. The data from Swedish sources, such as power grids, roads and wind speed model, was used as standard projection type for the rest of the layers. The chosen project coordinate reference system (CRS) is thus EPSG:3006 – SWEREF99 TM. The other layers from non-Swedish sources were in a different projection from the one used as standard in this project. It was important to change so the projections match since different projections may use different units of measurement and therefore making comparison impossible between the layers. These layers were reprojected into the EPSG:3006 – SWEREF99 TM. Slope was calculated from the elevation layer in the QGIS program processing toolbox.

When the processing of the layers was done, it was possible to extract essential data from the sites selected as most suitable. These sites are polygons in QGIS which makes it possible to use zonal statistics. What zonal statistics does is to extract data from the combination of the polygon layer and a raster layers, for example wind speeds, as input. This way extraction of data only inside the polygon zone is possible. The kind of data that could be extracted is for example the mean, maximum, minimum, standard deviation and variance values for the polygon zones. For this report the main value of importance was considered the mean. This zonal data was collected from the raster layers which is the wind speed, elevation, slope as well as k and a value for the Weibull probability function.

The use of zonal statistics was the result output from QGIS which was desired, and consequently the last procedure to be performed in the geospatial programme.

5.2 Technical analysis

For the technical analysis segment of the method, different parameters are to be calculated. This to get an idea of which location in the region which performs the best in technical terms.

5.2.1 Key performance indicators

5.2.1.1 Weibull probability function

The Weibull probability distribution function is a way to calculate the probability for each wind speed at a specific location. In this report, the Weibull function will be used to calculate wind speed frequency due to the prevalence in literature. The formula used in this report is:

$$f(v) = \frac{k}{a} \cdot (\frac{u}{a})^{k-1} \cdot exp^{(-(\frac{u}{a})^{k})}$$

$k = Shape\ parameter$
$a = Scale\ parameter$
$u = Wind\ speed$

The Weibull distribution has two parameters which it considers, as can be seen in the formula above, while the Rayleigh only has one parameter. For the latter function, the shape parameter is set to two and only has the scale parameter varying. The implication of this is reduced flexibility, since the accuracy is specific to when the shape parameter, k, is two.

The shape parameter, k, is the factor which affects the profile of the Weibull function curve, while the scale parameter fixes the location and the spread of the curve. A lower value of the shape parameter k indicates that the lower wind speeds are most probable, while a higher k value shows the highest probability lies around the mean value (Petrov, M., 2023). A higher k value relates to a tighter wind speed distribution, while a lower value shows a broader distribution. In this report the values for a and k is taken from the Global Wind Atlas (n.d.).

The Weibull function is in this report a stepwise function of 0.1 due to modelling preferences. In Python, when calculating the Weibull function, a wind speed range is necessary to be able to form the curve of the function. This wind speed range is created with 0.1 steps starting from 0 up to 25 m/s. This will also impact the Weibull function to have the same stepwise curve. The choice to iterate the function to 25 m/s is due to the turbine selection and the cut-off wind speed.

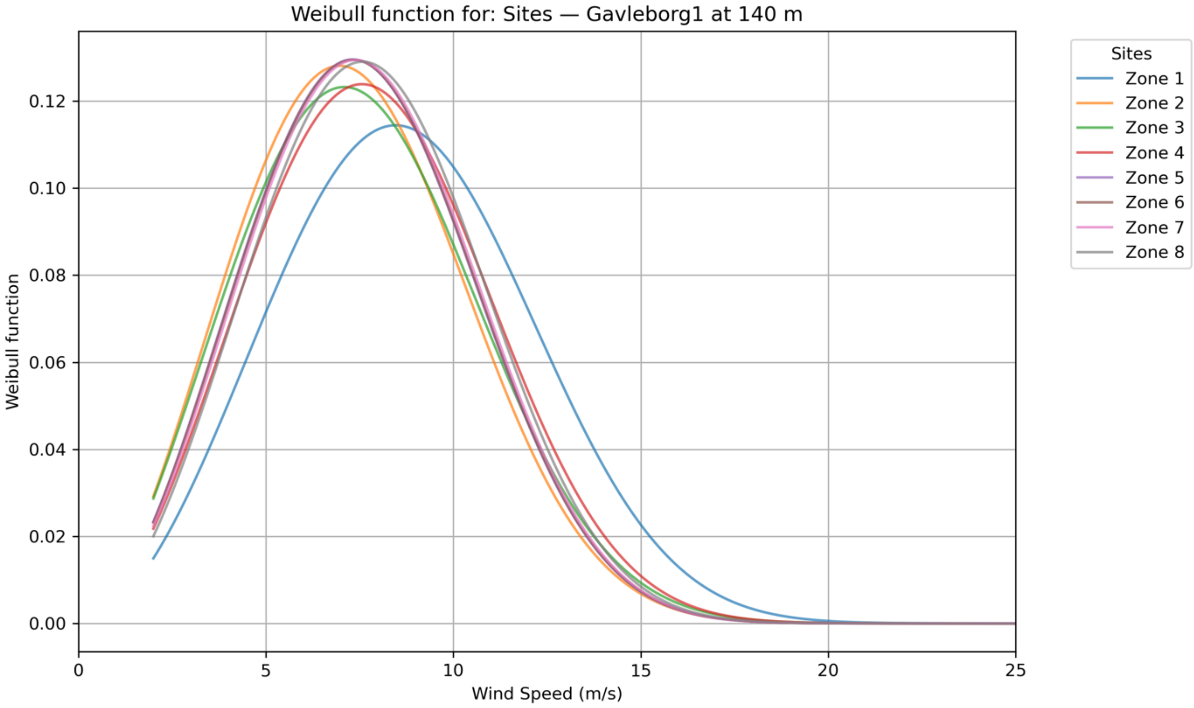


Figure 10. Weibull function for Gävleborg region at 140 m hub height.

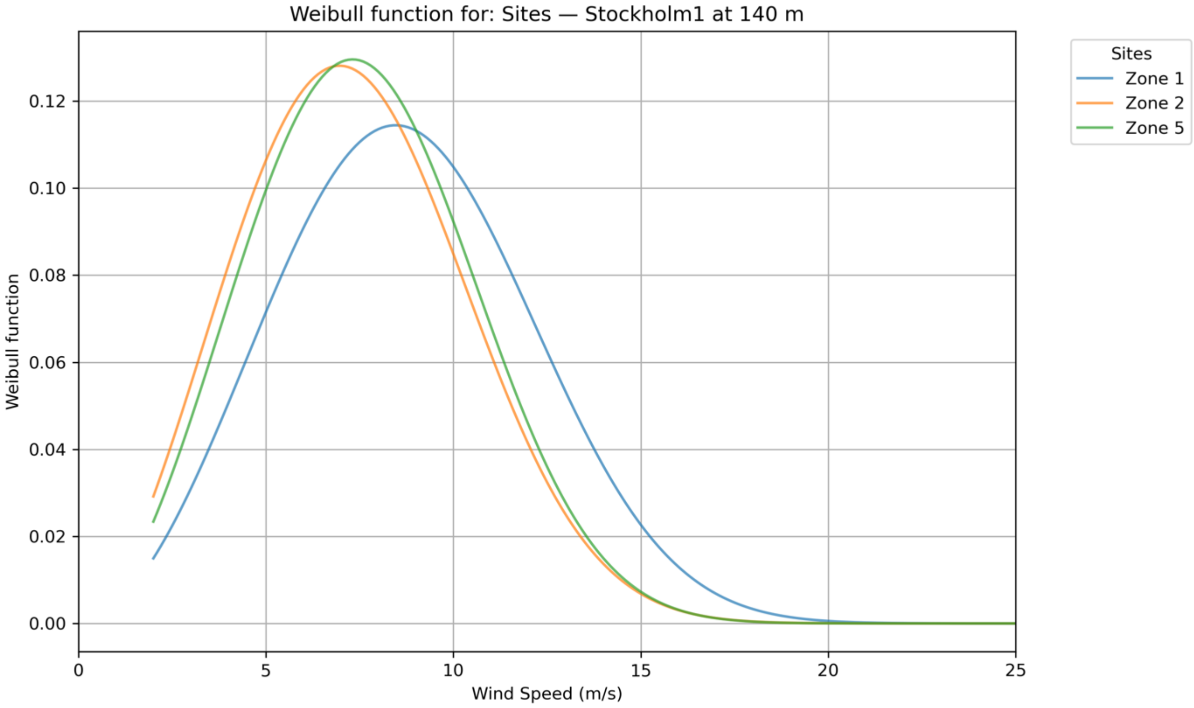


Figure 11. Weibull function for Stockholm region at 140 m height.

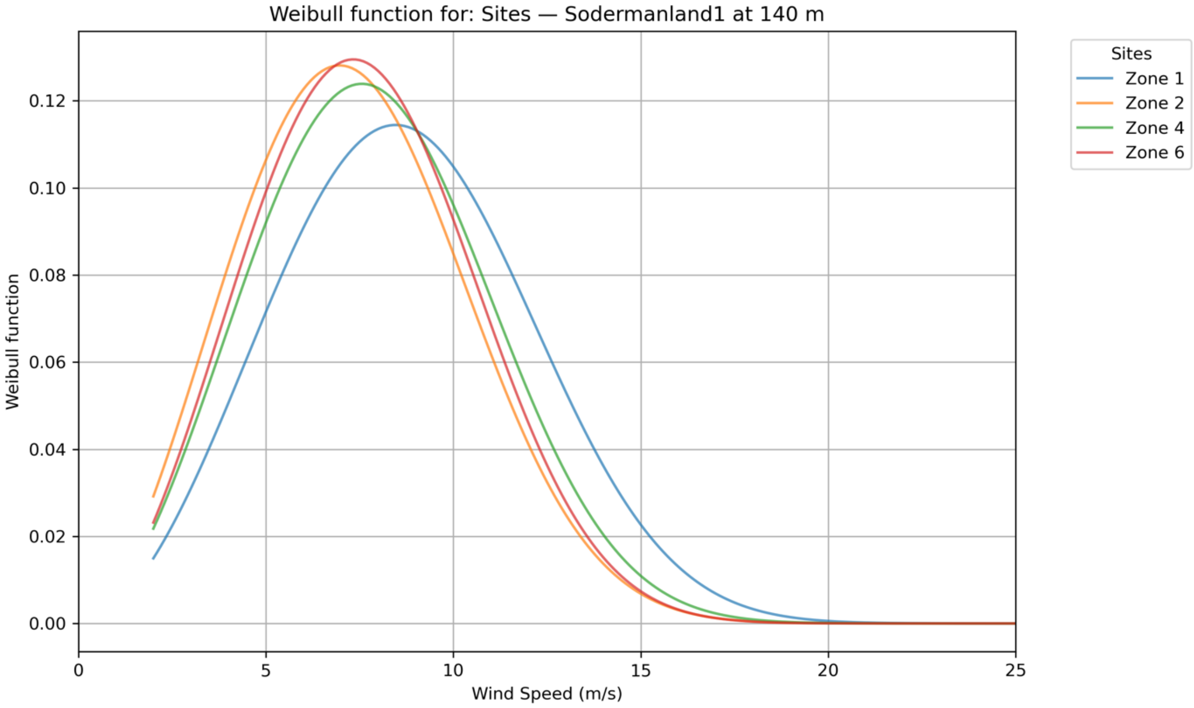


Figure 12. Weibull function for Södermanland region at 140 m hub height.

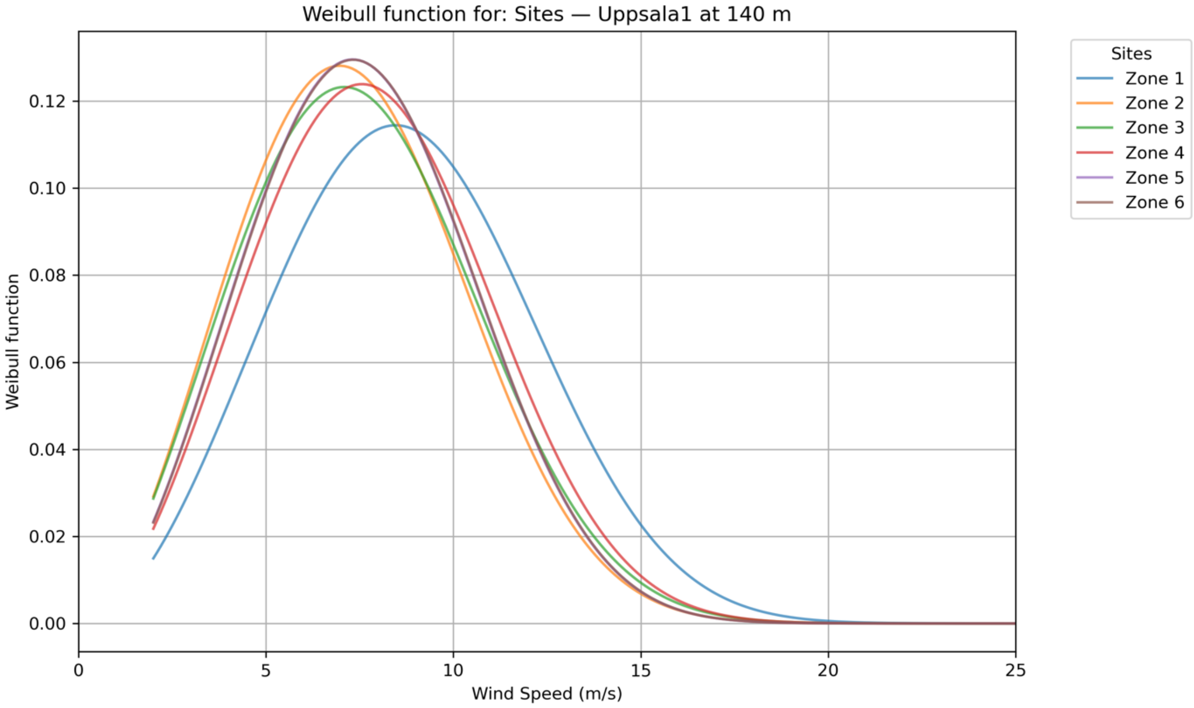


Figure 13. Weibull function for Uppsala region at 140 m hub height.

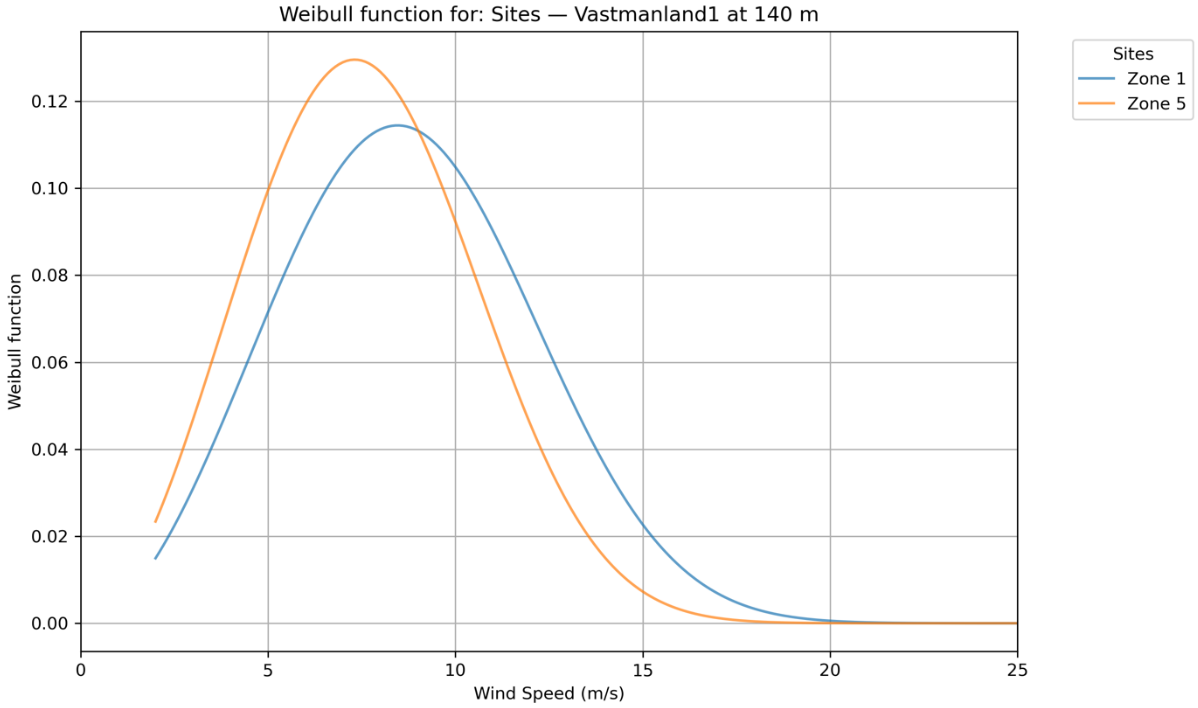


Figure 14. Weibull function for Västmanland region at 140 m hub height.

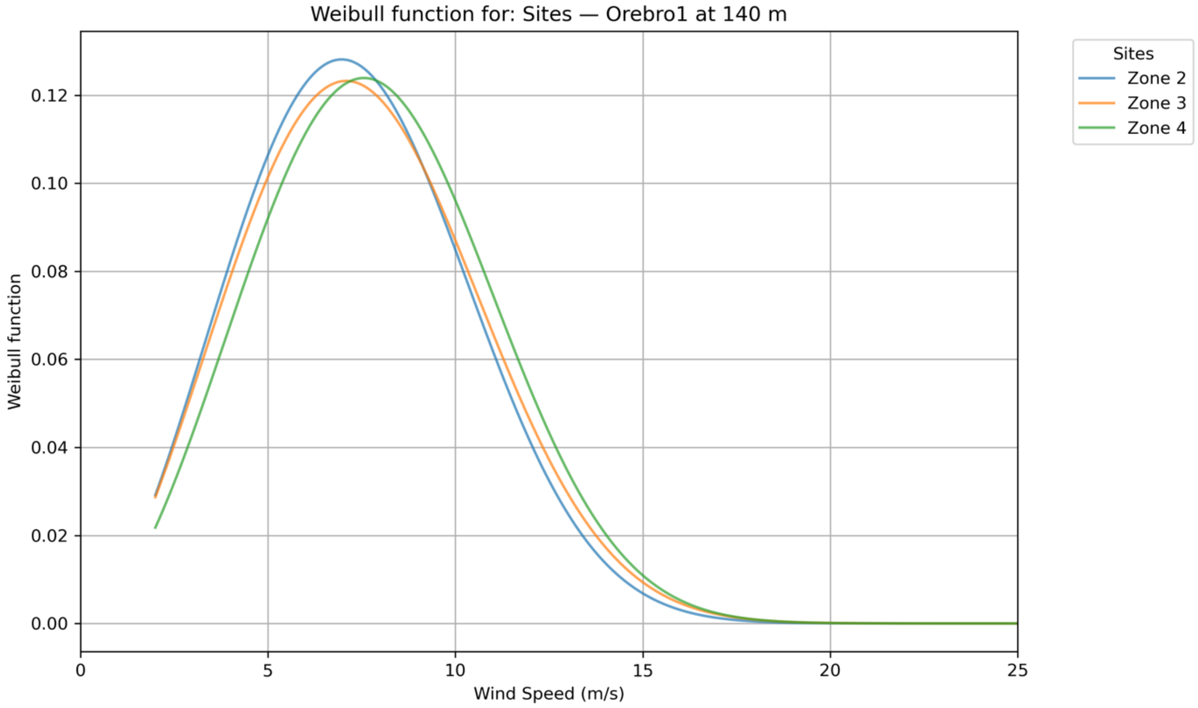


Figure 15. Weibull function for Örebro region at 140 m hub height.

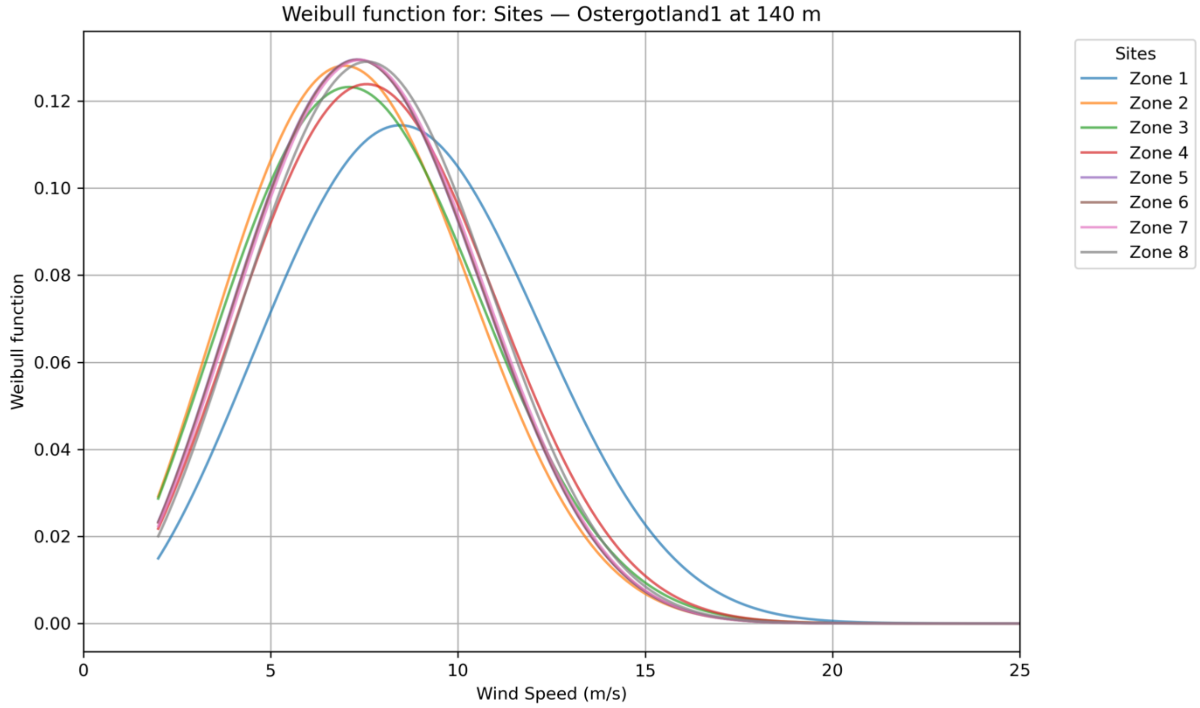


Figure 16. Weibull function for Östergötland region at 140 m hub height.

In figure 10-16 the Weibull function for the different sites in each county at 140 m hub height can be observed. All counties and sites have similar curves where the highest probability is centred around wind speeds between 6-8 m/s. In all counties but one, one site has a slightly different distribution. The site's wind speed frequency is more spread out and distributed at higher wind speeds, which could affect the energy output.

5.2.1.2 Power curve

The power curves of the turbines are important since they contain information from the manufacturers about the specific turbines output at the different wind speeds during ideal conditions. The power curve is thus provided by the manufacturer and is usually not available to find online for most turbines. The power curves found for the four chosen turbines in this report were all in the range of cut-in wind speed to the cut-off wind speed of the specific turbine, with an increment of 0.5 from the cut-in wind speed. The power curve is therefore interpolated, as the Weibull function, with wind speeds in steps of 0.1 for a tighter power curve. This will produce additional output values which in turn will give a more accurate AEY. The power curve is modelled up to each turbines cut-off wind speed which is 22,5 m/s for the Vestas V150, and 25 m/s for the other two. In figure 17, 18, and 19 are the power curves for the turbines plotted from the model. The curves are modelled from the technical specification sources sites in table 7.

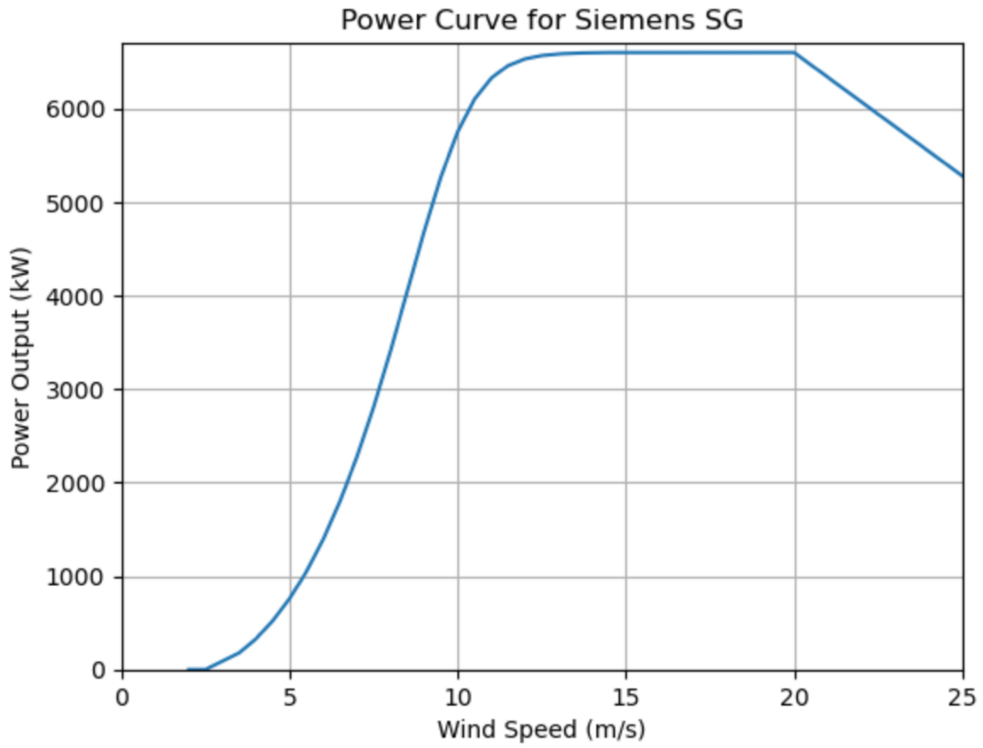


Figure 17. Power curve for Siemens SG 6.6-170 turbine.

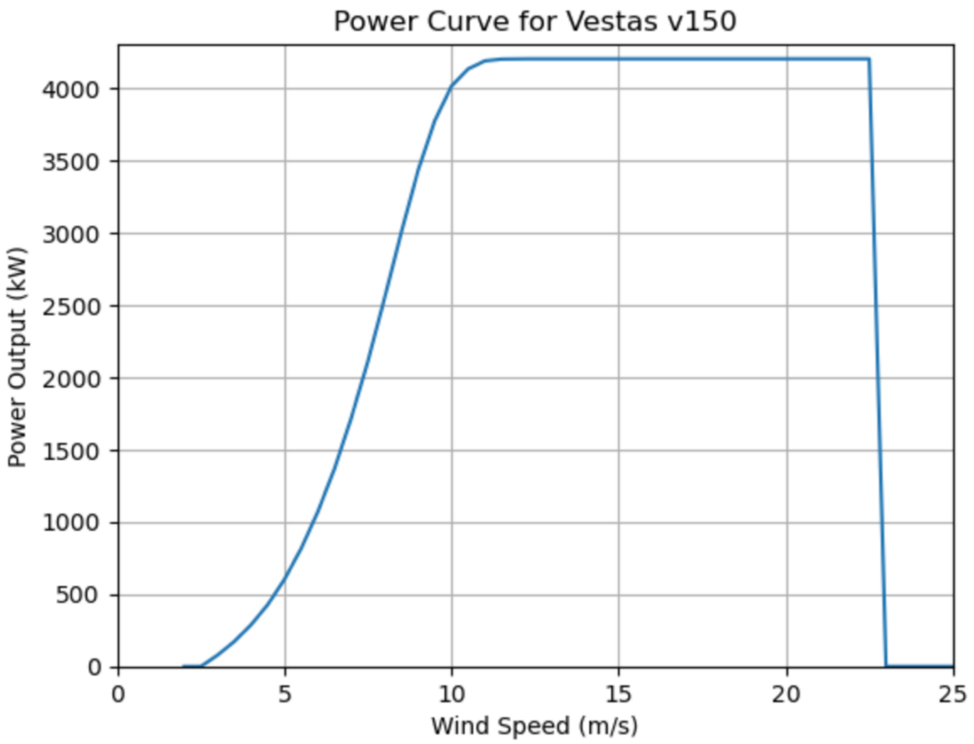


Figure 18. Power curve for Vestas V150 turbine.

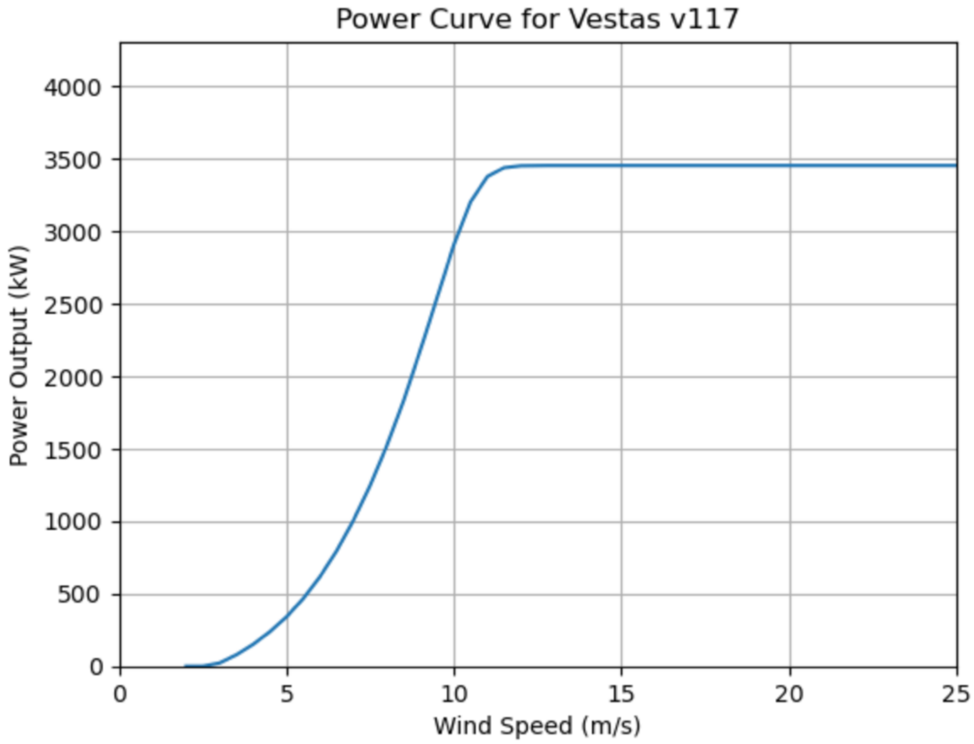


Figure 19. Power curve for Vestas V117 turbine.

5.2.1.3 Annual Energy Yield

The factors needed for calculating the annual energy yield (AEY) have now been determined, gathered, and calculated which makes for calculation of the annual yield left. The energy yield formula used for this will, for one turbine, be:

$$E(v) = \int_{Cut-in}^{Cut-out} h(v) \cdot P(v)dv \cdot 8760h$$

$h(v) = Wind\ frequency$
$P(v) = Power\ output/Power\ curve\ for\ the\ different\ wind\ speeds$

When correcting for losses, number of turbines, availability factor as well as array effect the formula is:

$$AEY = \int_{Cut-in}^{Cut-out} h(v) \cdot P(v)dv \cdot 8760h \cdot N \cdot \eta_{Array} \cdot \eta_{Availability} \cdot \eta_{Losses}$$

$N = Number\ of\ wind\ turbines$
$\eta_{Array} = Array\ efficiency$
$\eta_{Availability} = Availability\ factor$
$\eta_{Losses} = Technical\ losses$

The AEY is used as technical marker since it provides an estimation of the wind turbines power output over the year. This is an important indicator of performance from the wind energy farm which also impacts the systems' economical estimates as well as operational optimisation.

When tracking the AEY it gives an operational clue as to which system is not performing as expected. This makes for an opportunity to perform modifications to the system, where changes to maintenance and operational routines could be improved.

The more accurate the estimate of the AEY is, the better predictions of the systems' economic performance. This could be important for funding the project, but also for profitability analysis, since the energy output is an integral factor for economic feasibility. This information could also be of use when tracking and analysing energy prices and fluctuations on the market, to be able to improve future price prognosis.

5.2.1.4 Capacity factor

The capacity factor (CF) is the ratio between the actual energy output over the theoretical maximum output, during a specific period of time. In this report the specified time period is one year, but both shorter and longer time periods are applicable for this KPI. A longer time period would give a more generalised CF, while for example monthly assessments would give insights on fluctuations during the year.

$$Capacity\ factor = \frac{AEY}{Rated\ capacity \cdot 8760h}$$

The capacity factor is a parameter which can be assessed for any type of energy generating technology. The nature of this technical indicator also makes for comparisons between energy generating technologies, which could be of aid when planning for an energy project installation.

5.2.2 Choice of turbine

The choice of turbine can be difficult since the range and variety of the market is great, as well as it needs to be chosen based on the specific site's conditions, especially the wind speed frequency. For this report, three different turbines were used to compare the AEY and LCOE at each site. The technical specifications of these four turbines can be seen in the table 7 below.

Turbine model	**Min. hub height (m)**	**Max. hub height (m)**	**Rotor diameter (m)**	**Rated power (MW)**	**Cut-in wind speed (m/s)**	**Cut-off wind speed (m/s)**
Siemens SG 6.6-170	115	165	170	6,6	3,0	25,0
Vestas V150	105	166	150	4,0-4,2	3,0	22,5
Vestas V117	91,5	141.5	117	3,45	3,0	25,0

Table 7. Technical specifications of the three chosen turbines (Ministero dell'Ambiente e della Sicurezza energetica, n.d.; The Wind Power, 2025; wind-turbine-models; 2022).

As help choosing turbines the data from Vindbrukskollen was used, which is site with information about existing, awaiting and planned wind energy projects in Sweden. Initially, the most used turbines in the different regions as of latest date was planned to be used, but difficulty finding information regarding power curves and specifications for the turbines made that impossible. Therefore, the choice of turbines was a combination of the most installed in the different regions, the most current date installed, a difference in rated power as well as which power curves and specifications was freely available.

Three different turbines were chosen to be modelled to be able to compare which turbine is best suited to the specific location from an AEY and LCOE perspective. To model several different turbines could give a better perspective of which parameters affect the technical and economic output at that specific site.

5.2.3 Wind speed data at hub height

To calculate the Weibull probability function, shape parameter k and scale parameter a, is used. These parameters were extracted at a height of 150 m. Since the chosen turbines can be installed at different heights, three different heights have been chosen to evaluate the turbines at the sites. The heights are 115 m, 128 m, and 140 m.

To calculate the annual energy yield, the wind frequency will be multiplied with the power curve of the turbines as well as the hours of the year, for ideal energy output. The wind frequency will be calculated with the help of The Weibull probability function and when adjusting the hub height, the power law will be used for the a-value to make the corrections:

$$a_{adjusted} = a_{reference} \cdot \left(\frac{h_{hub}}{h_{reference}}\right)^{\alpha}$$

$a_{adjusted} = adjusted\ a\ value$
$a_{reference} = reference\ a\ value$
$h_{hub} = new\ hub\ height$
$h_{reference} = reference\ height\ of\ wind\ data, 150\ m$
$\alpha = wind\ shear\ value, terrain\ specific$

This will change the a-value through the different heights which in turn will change the Weibull probability function as well as the annual energy yield.

5.2.4 Losses

Actual wind energy installations experience losses through the entire system. These losses could be due to many reasons, for example mechanical or in relation to nature, as for icing. In this report 4 losses have been taken into consideration.

The first loss is the wake effect. Every wind energy project's largest affecting parameter is the wind. When the wind is reduced, so is the power output from the turbine. Behind every turbine, a reduction of wind speed is subjected to the wind due to its flow through the turbine's blades. A wake is created which will in turn affect whatever is behind the turbine. If another turbine is placed behind the first one, it will reduce the power output of the second turbine. To mitigate this wake effect, the wind farm layout is important. Usually, the wake effect can't be eliminated completely since the land reserved for wind energy is oftentimes limited. In this report a wake effect of 10% is used (Siyal, S.H: et al., 2015, p.452; Ossa, A. A., 2021, p.24; Lee, J.C.Y. & Fields, M.J., n.d., p.5).

The second loss accounted for in this report which affects the turbines output is the availability factor. This factor will account for all the time the turbine is available for power generation. There are times when a turbine can't generate electricity for example during planned maintenance or when there are too strong winds, when the turbine is designed to stop operation to prevent damage. An availability factor of 97% was used in the modelling (Siyal, S.H: et al., 2016, p.216; Elkadeem, M. R. et al., 2022, p.9).

The two remaining losses are mechanical and electrical losses which are estimated together as 10% in this report (Lee, J.C.Y. & Fields, M.J., n.d., p.5; Madariaga, A. et al., 2012, p.326). The mechanical losses could be losses in the gearbox, friction in rotating parts or blades and rotor losses. Inefficiencies of the generator, or losses in cables, inverters, converters and transformers could be examples of where electrical losses occur.

5.3 Economic analysis

5.3.1 Economic performance metrics

5.3.1.1 CAPEX

CAPEX is the capital a business or organisation spends to build, maintain or acquire a long-term asset. In this report a value of 1070 EUR/kW is used based on a long-term market analysis from Svenska kraftnät (SVK) (2025). This value is used to calculate CAPEX for all three turbines. The costs that go into CAPEX can vary depending in the project, but SVK has included four overall costs. The first include the physical facility and its equipment, which normally entails engineering, procurement and construction costs. The second set of costs are linked to infrastructure and connection costs. Also costs related to the development of the projects such as acquiring the land and permit processes. Lastly, interest costs reflecting the alternative cost of discontinued resources due to the project's construction.

5.3.1.2 OPEX

OPEX is the capital spent by a business or an organisation which is continuing due to the running of a product or system for example. A value of 30 EUR/kW have been modelled which comes from the SVK long-term market analysis (2025). The yearly costs they have accounted for are property taxes, insurances and network costs, labour costs, maintenance of the capital stock during the project, as well as planned and unplanned maintenance.

5.3.1.3 Levelised cost of electricity

As a primary economic evaluation parameter, the levelised cost of electricity (LCOE), is used. The formula for the LCOE can vary, in this report the following has been used:

$$LCOE = \frac{CAPEX + \sum_{t=1}^{N} \frac{OPEX}{(1+r)^t}}{\sum_{t=1}^{N} \frac{AEY}{(1+r)^t}}$$

$N = lifetime$
$r = WACC/discount\ rate$

LCOE is the net present cost average of generating electricity for a generator, or generators, over the expected lifetime and is a good way to make comparisons between energy generation methods. As can be seen by the formula, the parameter estimates the cost of generation of the electricity and not the price of electricity itself. Since the numerator is flexible as to the different post of cost, it is suitable for a variety of electricity generating techniques.

The LCOE can vary for the same energy technology in different areas due to the cost input variables. For example, the cost of turbine, building roads, substations or topology affecting construction can be factors affecting costs for the same energy technology. When uncertainty around input variables arise, caution needs to be applied to the LCOE output as well as any comparisons between LCOEs. The capacity to evaluate technologies or areas by LCOE is measured by the transparency of the input values.

From SVKs report *Long-term market analysis* (2025), the lifetime of 25 years has been used for the onshore wind energy, which will also be used in this report. The discount rate or WACC is set to 5% as in IRENAs *Renewable power generation costs in 2023* (2024, p.200).

5.4 Python

Python is one of the most popular programming languages to use today. Python is a programming language with a wide range, it can be used for data processing, programming games, machine learning and creating webpages for example. It is also possible to use Python as a calculator where you can code loops, write functions and plot graphs for a better visual experience.

In this report Python will mainly be used as a calculator for assessing technical and economic evaluation of the most suitable sites. The output from the zonal statistics in previous step, the modelling in QGIS, will be used to execute the calculations needed in this section of the assessment. To be able to extract the data prepared in QGIS into Python, GeoPandas is a suitable pathway. GeoPandas allows for geospatial data to be transferred into Python and perform operations to further process the data points. NumPy is also used during the modelling phase in Python since it is a scientific computing library which is essential for use in many instances.

5.4.1 Modelling in Python

The first step of modelling in Python is to make sure all required programs and libraries are installed for an efficient coding experience. In this report GeoPandas, NumPy, Pandas and Matplotlib has been used.

The next step is to ensure the data needed as input can be imported from external sources, in this case QGIS and Excel. GeoPandas is as mentioned previously preferred to read the file from QGIS, while Pandas is used to read the Excel file containing information about turbine power curves. The files used from QGIS contains data on wind speed, k value, a value, slope, grids, roads, substations and elevation, which are all the parameters mentioned in the QGIS section of the report.

A factor of assessment is the distance to the power grid, substations and roads. This was done through For-loops and iterating through each site's distance to every substation, grid or road. What is then returned through the loops are the infrastructures closest to each site which will indicate best way to access the proposed site. This means each site has a result of three different infrastructure parameters mapped to it, the closest road, grid and substation.

Further, the interpolation of power curves of the turbines is of importance. The data regarding power generation output found of the turbines is of discrete sort as mentioned above. To reduce the gaps in the data, interpolation is used. This creates a tighter power output which more resembles a curve. A For-loop is used here as well to iterate through all the different turbines to create a power curve matching to their specific output.

Additionally, sections adjusting the Weibull function to three different hub heights was coded. Also, the code was altered to calculate the number of turbines which could fit in one site based on the limitations around the area needed for each turbine to avoid collision and mitigate wake effect. These adjustments were made to accommodate more accurate values in regards of AEY and LCOE.

The next calculation is the Weibull probability distribution function and the AEY. Starting with the Weibull pdf to have a distribution curve of the probability of wind speeds at each specific site. The result of this operation is then incorporated into the calculation of the primary technical parameter, the AEY. For calculation of the AEY, both the Weibull pdf and the power curve is needed. This was also multiplied with the different losses accounted for, as well as the hours of the year.

The last step of the modelling in Python was the calculation of the LCOE. For-loops were used to calculate specific costs for CAPEX and OPEX for each site and turbine and then used to sum these values up over the lifetime of the project using a discount rate. The LCOE for each turbine at each site was the result of this operation.

6 Results & discussion

6.1 Number of turbines at each site

An important aspect of the AEY result is the number of turbines that could be fitted into the areas considered as the best suitable sites for each region. Gävleborgs region has 8 sites, Örebro has 3 sites, Östergötland has 8 sites, Södermanland has 4 sites, Stockholm has 3 sites, Uppsala has 6 sites and Västmanland has 2 sites. In total there are 34 sites across all regions. In the national wind energy expansion strategy (2021) by the Swedish Energy Agency and the Swedish Environmental Protection Agency it is mentioned that for each site and proposed allocation of wind turbines these is also a proposed claim of area as can be seen in table 4. To calculate the needed area for one turbine the required area in km^2 was divided by the number of estimated turbines for that region. This gave a value of approximately 0.94 km^2/turbine which was rounded up to 1 km^2/turbine. During a stakeholder consultation the number of turbines was also discussed, where an upper limit was proposed. This due to the increasing difficulty to get approval by the municipalities the higher the number of turbines in one project. A limit of 10-15 turbines was mentioned during the meeting where in this report the limit was set to 10 turbines per site. In table 8 below the number of turbines per site is presented for the sites which did not reach the maximum number of turbines. The sites not presented in the table has thus reached the maximum of 10 turbines.

Region	Site number	Number of turbines
Gävleborg	4	9
Östergötland	5	7
Östergötland	7	8
Östergötland	8	9
Södermanland	4	6

Table 8. Table of the sites in the study area not reaching the maximum of 10 turbines.

The AEY is dependent on the number of turbines, where the output will increase with a higher number of turbines installed. From the table, Östergötland has the most locations which could not accommodate the maximum number of turbines. Östergötland could have a larger area with higher conflict score in QGIS, which makes the sites suitable for wind energy smaller in size. This can explain the reduced number of sites reaching the upper limit of turbines. In total, these five sites represent 14,7% of the total locations where the maximum number of turbines cannot be installed.

All sites reaching 10 turbines could have more installed. The lowest number of extra turbines that could be installed ranges from one, in site 2 in Östergötland and site 2 in Södermanland, to 92 extra turbines in site 1 in Gävleborg. There was also a lower limit of two turbines put into place to avoid the possibility of just installing one turbine.

This turbine limit would mean at several locations, there is more energy to be extracted. 20 out of 34 sites could at least double the number of installed turbines, if just the area was a limiting factor. To the municipalities on the other hand, land use is a complex matter where estimations for several years ahead must be evaluated. Wind energy projects are expected to last at least 25 years which means the land is mainly used for that purpose. Depending on where the wind turbines are located, there are possibilities for different land use options to co-exist, as for example agriculture and wind turbines, which could be an attractive alternative for the municipalities.

Technological advancements mean the turbines installed today are higher, and with a larger rotor diameter than historically, which also means fewer turbines is needed for installation to reach same output.

Also, the national strategy contains an estimation of the number of turbines needed for installation to reach the goal for wind energy expansion. In this report, a percentage of the cover of the estimated can be found in table 9.

Region	**Total number of installed turbines**	**Percentage of the national strategy**
Gävleborg	79	22,1%
Stockholm	30	31,6%
Södermanland	36	37,9%
Uppsala	60	50,4%
Västmanland	20	21,1%
Örebro	30	25,2%
Östergötland	74	62,2%

Table 9. Percentage of the installed turbines in the study sites needed of the total in the national strategy.

From table 9 above, it is observed the highest fulfilment of the national strategy is observed in Uppsala and Östergötland, while the lowest installation realisation is observed in Gävleborg, Västmanland and Örebro.

6.2 Aggregated AEY per county and turbine

The aggregated AEY results for all sites in each region are shown in figures 20-26 below.

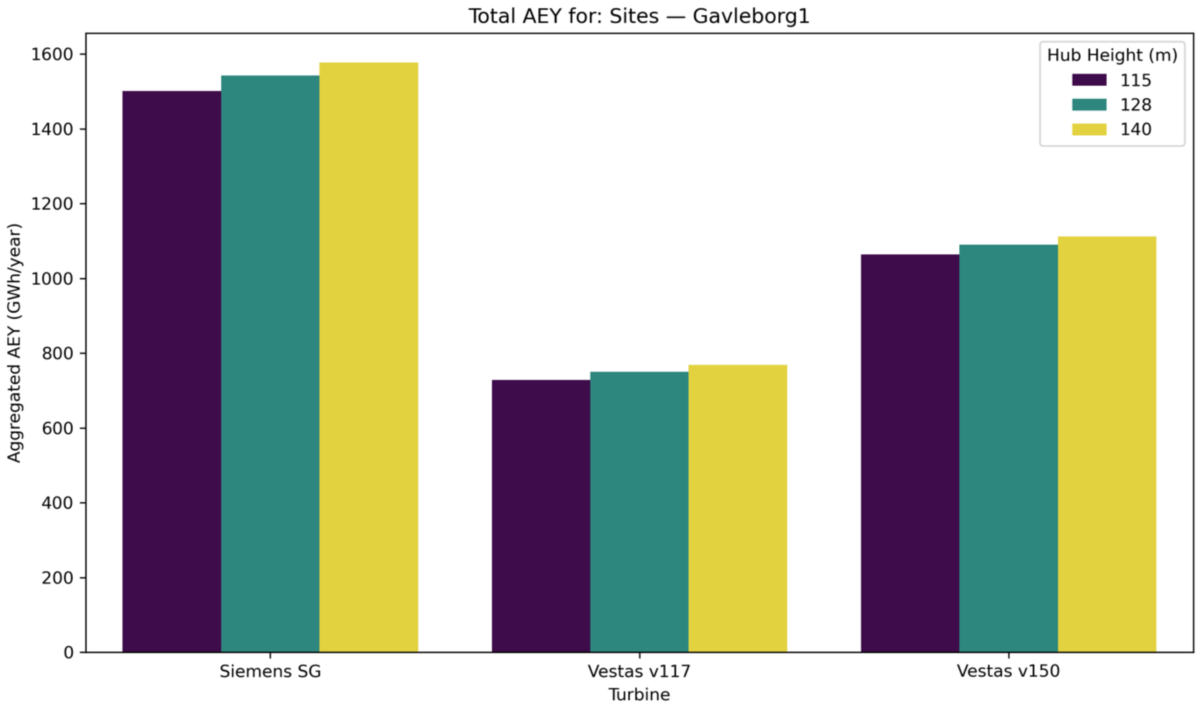


Figure 20. Aggregated AEY for Gävleborg region.

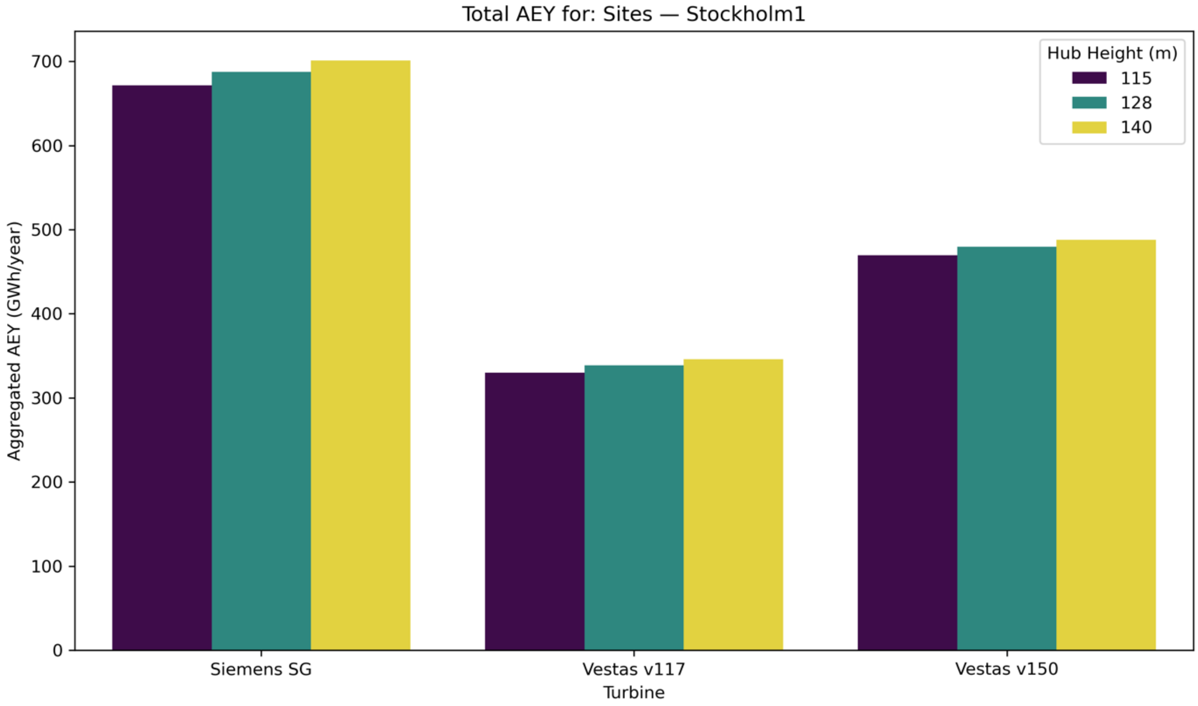


Figure 21. Aggregated AEY for Stockholm region.

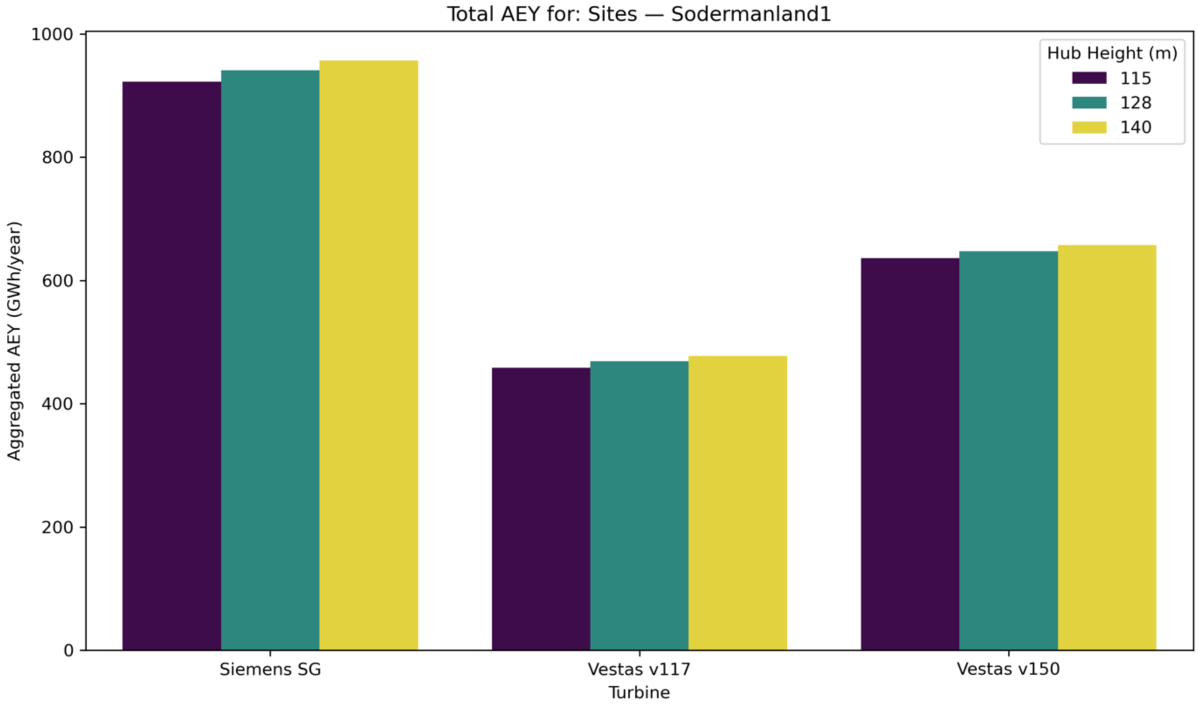


Figure 22. Aggregated AEY for Södermanland region.

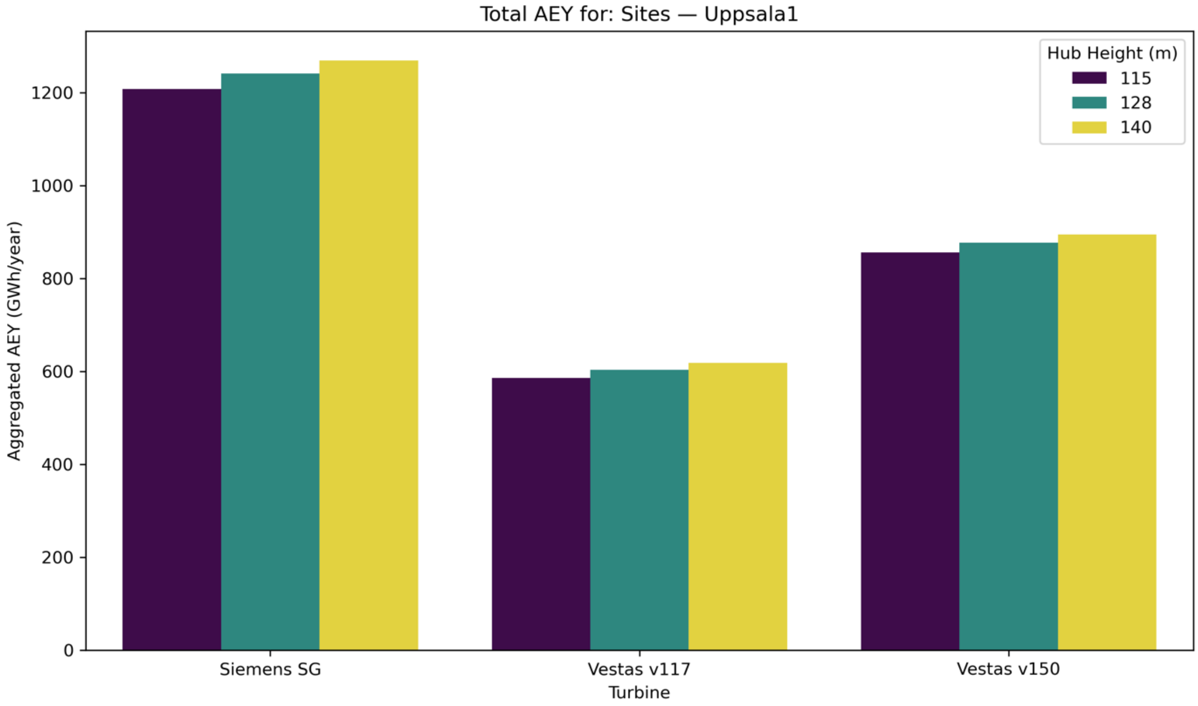


Figure 23. Aggregated AEY for Uppsala region.

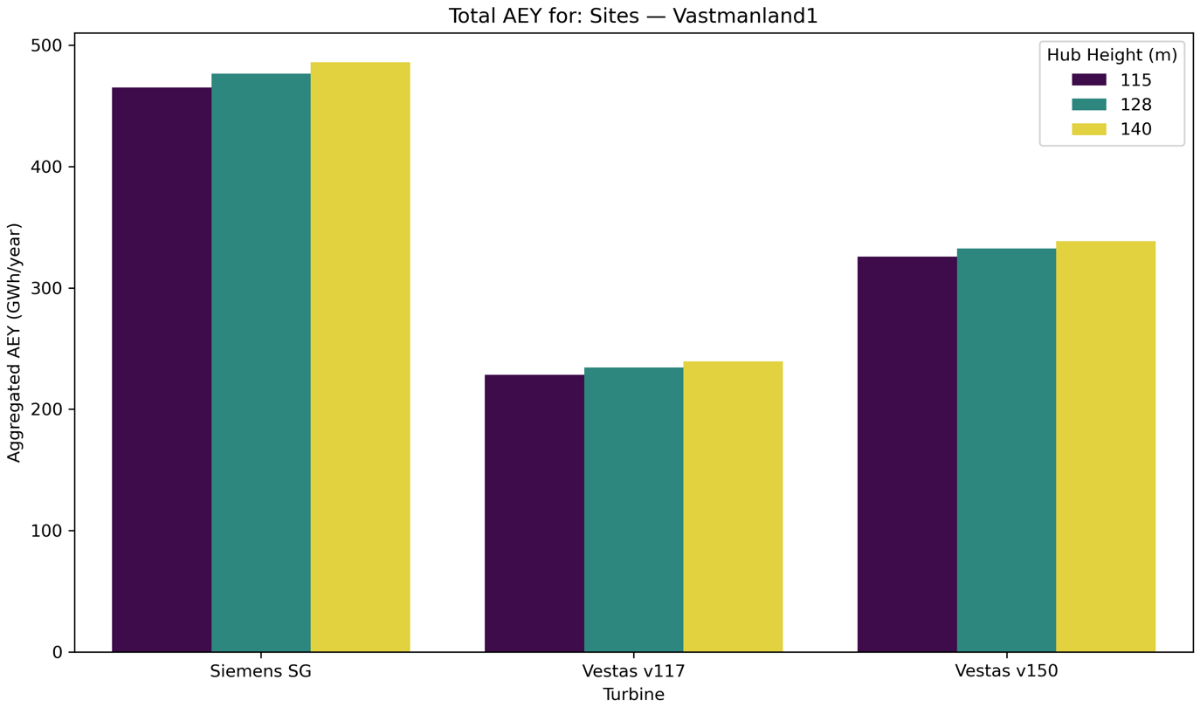


Figure 24. Aggregated AEY for Västmanland region.

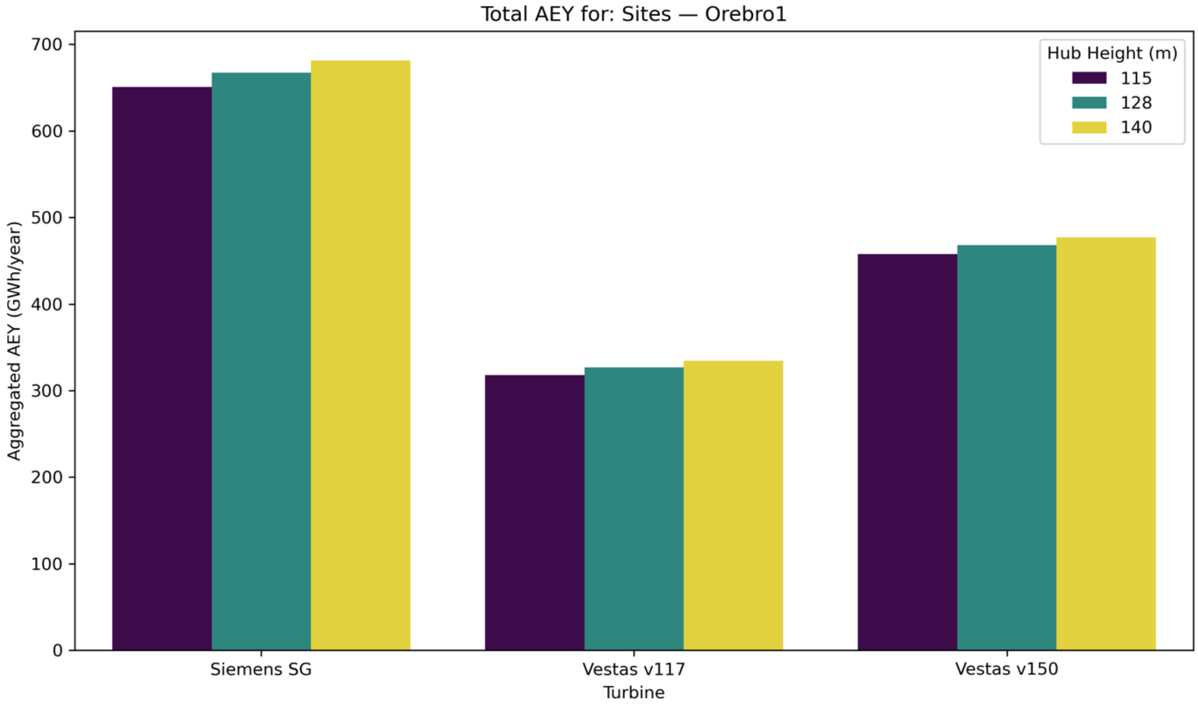


Figure 25. Aggregated AEY for Örebro region.

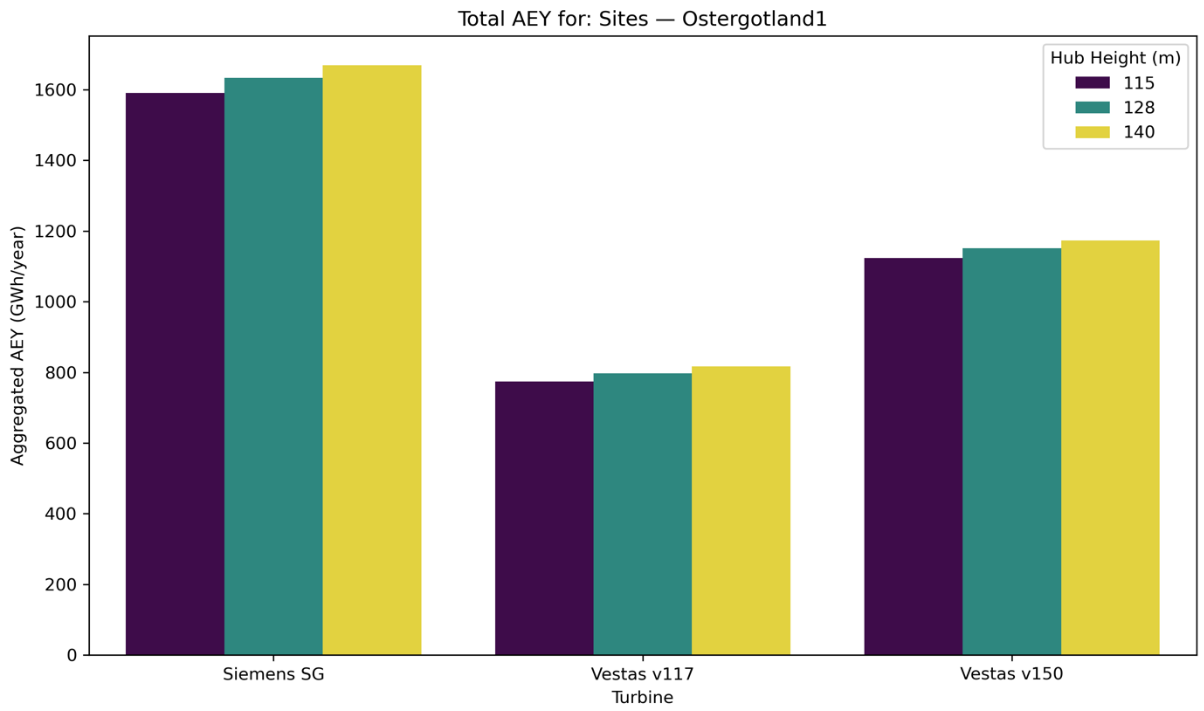


Figure 26. Aggregated AEY for Östergötland region.

Regarding the hub height, the same patterns can be seen through all regions; the best performing hub height is 140 m, second best is 128 m, and the least good results are observed at 115 m hub height. An expected result, since the wind speeds normally gets higher and undisturbed with increased hub height. Since coding loops through the same heights for all turbines, the chosen range stays within minimum hub height for the largest turbine, and the maximum hub height for the smallest turbine. As the two largest turbines has a maximum hub height of 165 m and 166 m, there is most likely more output available for these turbines not modelled nor shown in this result section.

Consistently, throughout all sites, the turbine performing the best is the Siemens SG 6.6-170. It is the largest turbine with 6,6 MW rated power, reaching the rated power at 15,5 m/s until 20 m/s. The cut-in wind speed is at 3,0 m/s with a power output at 89 kW, which is the highest output at that wind speed, and already at 13 m/s the turbine reaches an output of 6585 kW. This steep incline in generated power from 3-15,5 m/s could be a reason for the turbines' top performance for the AEY. This turbine reaches best aggregated performance in Östergötland with 1668,8 GWh/year at 140 m hub height, and least good, aggregated result in Västmanland with 465,1 GWh/year at 115 m hub height.

The second-best performing turbine is the Vestas V150 and is also the second largest rated turbine of the three at 4,2 MW. This turbine has a cut-in wind speed at 3 m/s with a power output at 78 kW and reaches rated power at 12 m/s with 4200 kW generation. Nominal generation is kept until cut-off wind speed at 22,5 m/s. Although the turbine does not have as high-power output as the Siemens SG 6.6-170, it is a good performing turbine which reaches the rated power output already at 12 m/s which could be a reason behind its second-best performance. Here, best aggregated performance is in Östergötland at 140 m hub height with 1173,2 GWh/year, and the least good, aggregated result is shown in Västmanland with 325,6 GWh/year at 115 m hub height.

The smallest rated turbine, Vestas V117 at 3,45 MW is also the turbine with the least output. Similarly having its cut-in wind speed at 3 m/s, but with 22 kW output it differs from the other two turbines. Rated power is reached at 12,5 m/s and is kept until the cut-off wind speed at 25 m/s. The nominal power for this turbine is almost half of the Siemens SG 6.6-170, which shows in the results. It shows the best aggregated result in Östergötland with 816,4 GWh/year at 140 m hub height and the least good, aggregated results in Västmanland with 228,4 GWh/year at 115 m hub height.

The aggregated results show the regions can be roughly categorised in three different groups: The two regions performing the best at around 1600 GWh/year, Östergötland and Gävleborg, the middle group generating around 1000-1200 GWh/year which is Uppsala and Södermanland, and the third group generating around 500-700GWh/year which is the three regions Örebro, Stockholm and Västmanland.

The reasons behind the results could be manyfold. Firstly, a major factor to affect the AEY is the quality of the wind. The wind frequency is, as previously mentioned, assessed by the Weibull function. The scale parameter a is related to the average wind speed, and the shape parameter k, which determines the curve of the distribution. Since they change depending on site, they could be a source of explanation to the aggregated results from the above plots. The aggregated k values range between 2,47-2,83, while the adjusted a values range between 8,01-9,93 m/s. When analysing the aggregated values for the k values and adjusted a values, no relation between a higher energy output and a higher a or k values could be seen. Overall, a high scale parameter can be seen in the aggregated results which suggests more frequent and stringer winds. This will impact the energy output for all regions but is no strong reason of influence for the current results.

Also wake effect and other losses could be affecting the AEY output, but since all sites have been modelled with the same values for this, it is unlikely this would be a causing factor. In reality, technical, mechanical and electrical losses, wake effect, downtime and other such factors affect the AEY, but for simplicity are these changes not modelled.

The number of installed turbines in a region could also be an answer to the results, but since all sites with fewer turbines are part of the best or middle performing group, no greater impact can be seen. It is more likely the number of sites in each region could be a major contributing factor. The two regions which are best performing, Gävleborg and Östergötland, are also the ones with the most locations, namely 8. Uppsala and Södermanland, which are in the middle performing group, have 6 and 4 locations respectively, while the least good performing regions according to the aggregated results are Örebro, Stockholm and Västmanland with 3, 3 and 2 sites respectively. Despite Östergötland having 3 out of 8 locations with a lower number of turbines installed, it is still the best performing when looking at the entire county. The number of sites in each county depends on factors such as area of the county, land use previously discussed under section 2, military interests and the developing plan of the county. The underlying decisions made with affecting factors have great impact on the outcome of the wind energy generation.

County	**Aggregated AEY (TWh)**	**Percentage of the national strategy**
Gävleborg	1,577	20,8%
Stockholm	0,700	35%
Södermanland	0,956	47,8%
Uppsala	1,268	50,7%
Västmanland	0,485	24,3%
Örebro	0,681	27,2%
Östergötland	1,668	83,4%

Table 10. Percentage of the power generated in the study sites needed of the total in the national strategy.

Observable in table 10 is the aggregated generated energy in each county and how big share it relates to in the national strategy. The county which can fulfil most of the needed energy allocation is Östergötland which covers over 80% if wind energy is to be realised at the study areas. Other counties which have a high percentage is Uppsala and Södermanland. The county which reaches the lowest percentage is Gävleborg. It is also the only county of all 7 which has an allocation of 7,5 TWh.

6.3 Aggregated LCOE per county and turbine

Figures 27-33 show the average LCOE per region and turbine type.

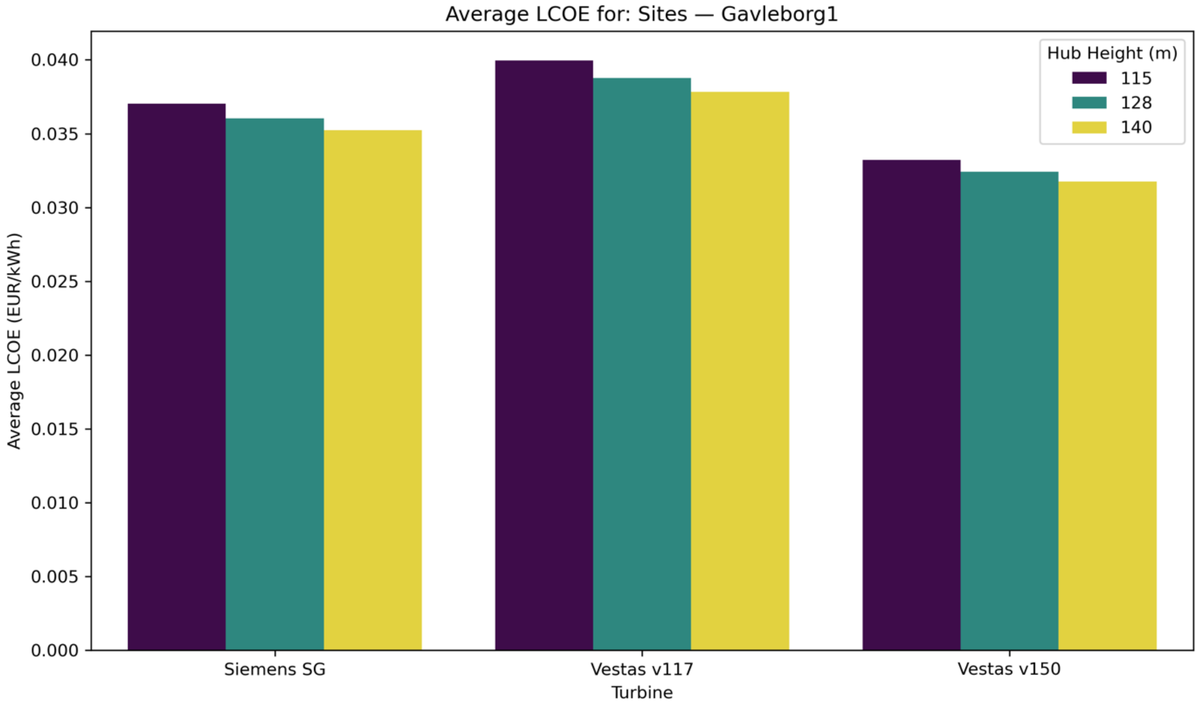


Figure 27. Average LCOE for Gävleborg region.

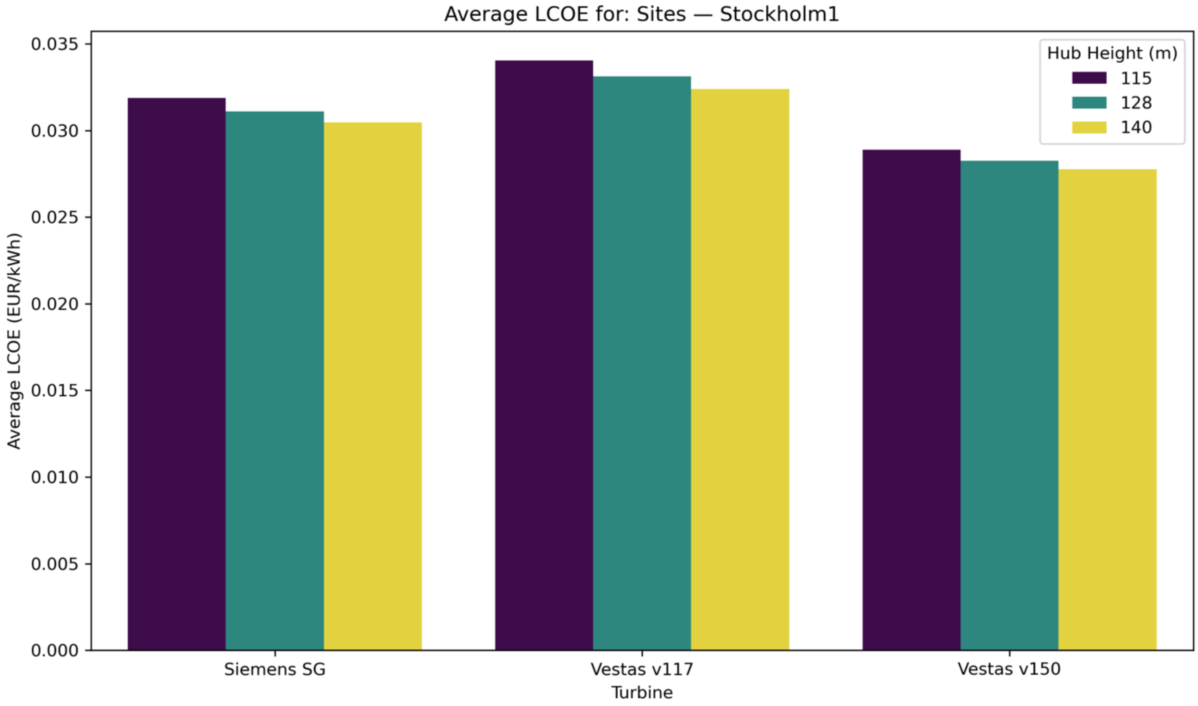


Figure 28. Average LCOE for Stockholm region.

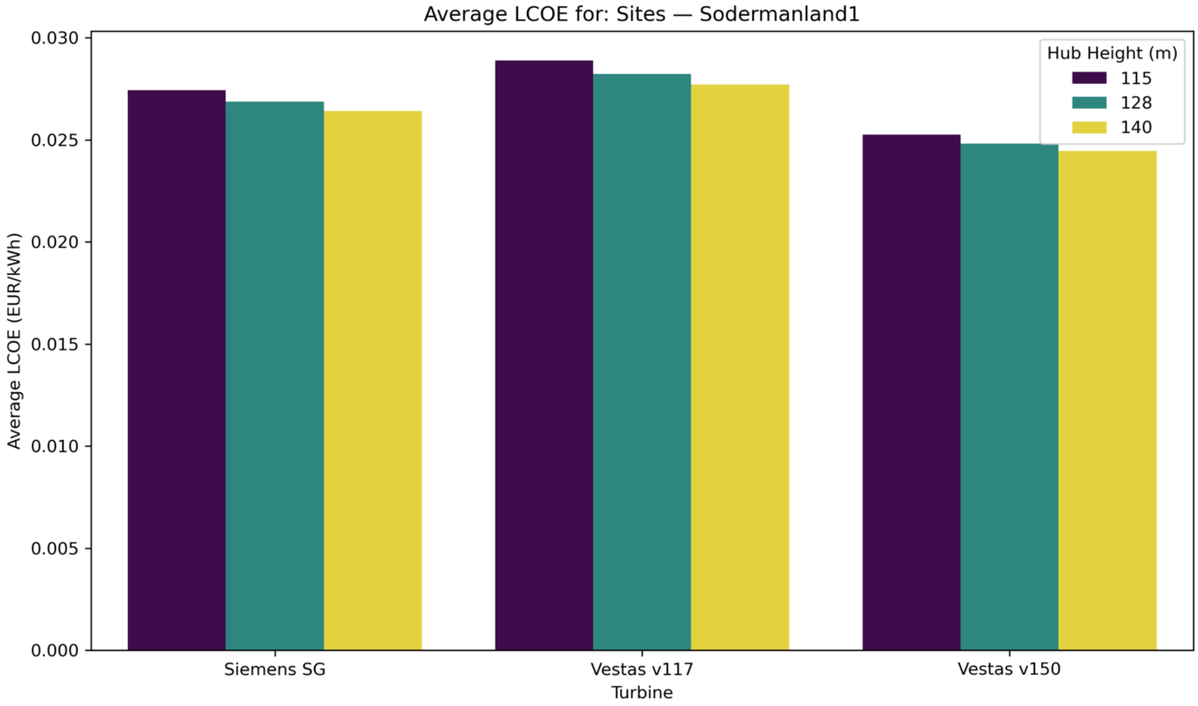


Figure 29. Average LCOE for Södermanland region.

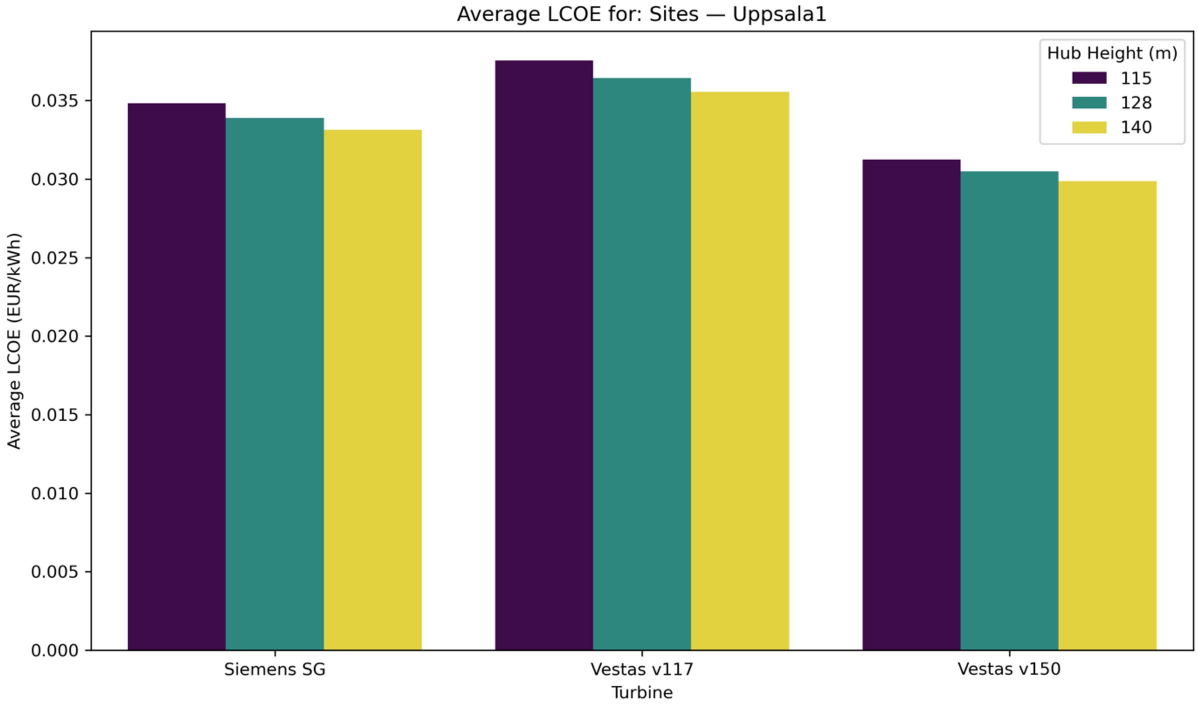


Figure 30. Average LCOE for Uppsala region.

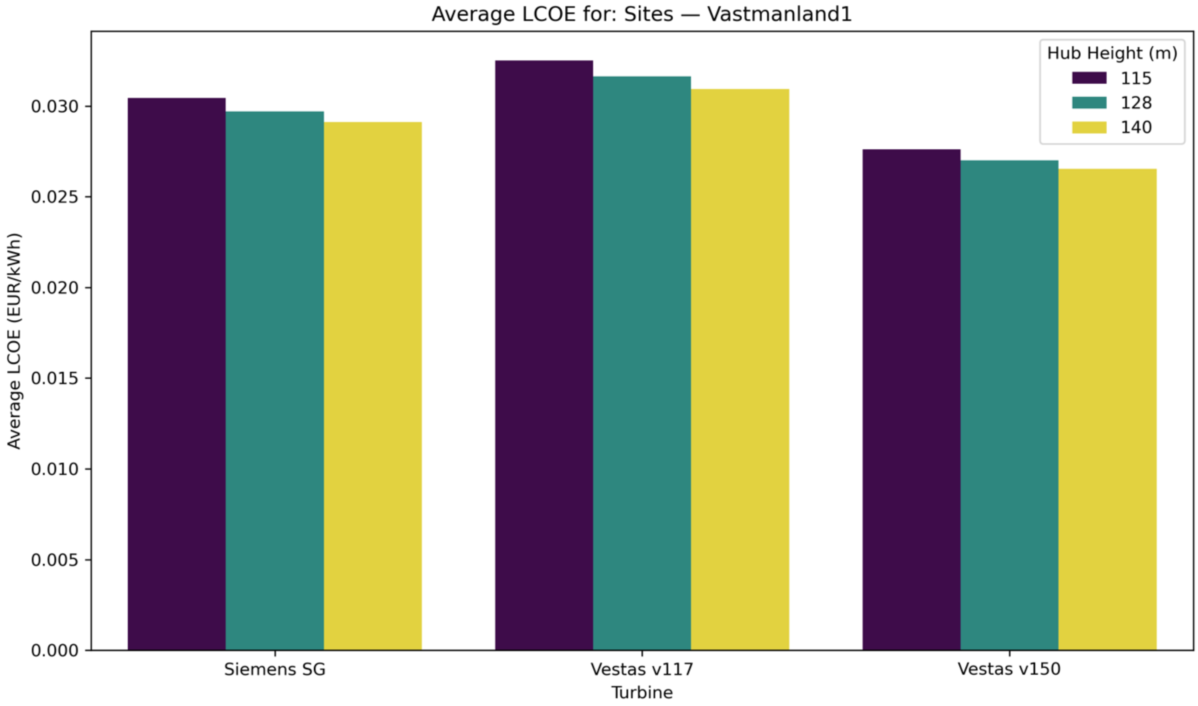


Figure 31. Average LCOE for Västmanland region.

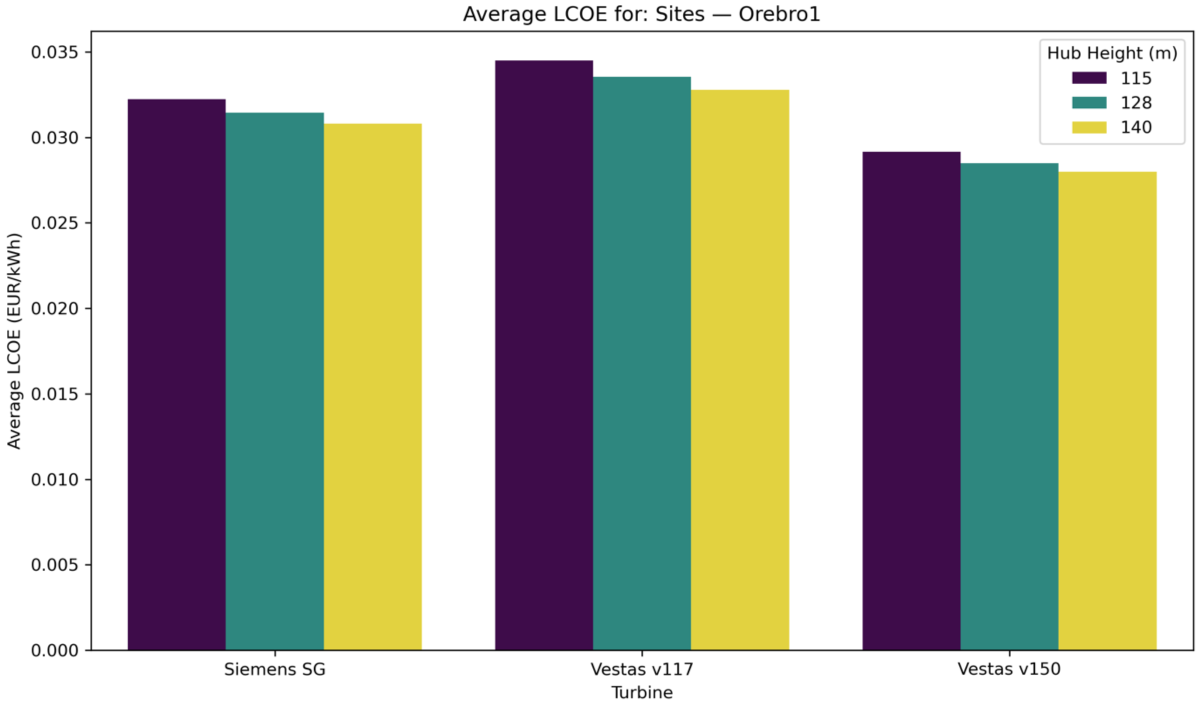


Figure 32. Average LCOE for Örebro region.

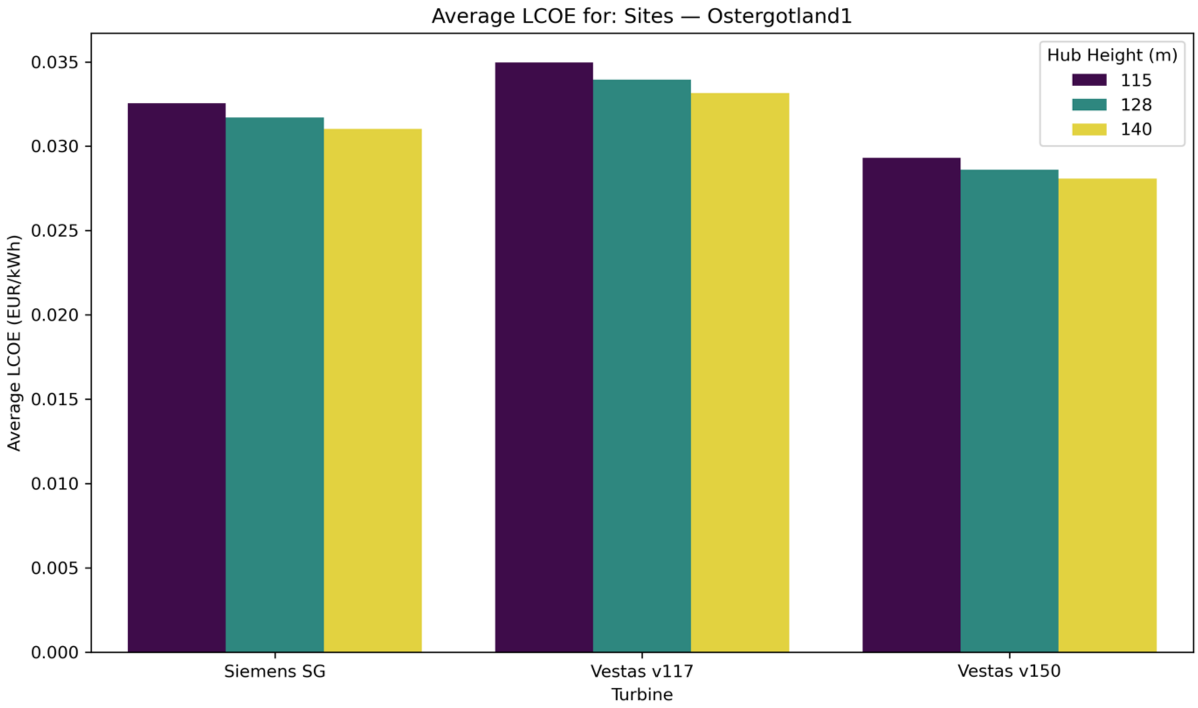


Figure 33. Average LCOE for Östergötland region.

Firstly, what is observed is that throughout all regions, the lowest LCOE is found with the highest hub height. As mentioned previously, the wind speed is higher with increased altitude since the friction from for example trees and buildings is reduced. This matches the aggregated AEY results where the highest output could be found at 140 m hub height. Since the formula for LCOE divides different cost inputs of the technology over the AEY, a higher energy output would generate a lower LCOE.

Secondly, the best performing turbine for all regions when analysing the economic parameter is the Vestas V150. When analysing the technical parameter AEY, the best performing turbines was the Siemens SG 6.6-170. The Siemens has the largest nominal output at 6600 kW, while the Vestas V150 is the second largest rated at 4200 kW. This indicates the costs for the best performing turbine technically are too high to achieve best performance economically. The capex cost for a single Siemens SG 6.6-170 turbine is 7 062 000 EUR while a single Vestas V150 turbine is 4 494 000 EUR according to the values from SVK mentioned previously. This was calculated using the capes cost of 1070 EUR/kW multiplied by the rated kW of the turbines. Possibly, the hub height needs to be higher for the largest rated turbine to reach the highest rated output at higher wind speeds. Increased hourly output at nominal rating, would increase the AEY further and thus lower the LCOE, given the cost stay the same. This could be a solution to making the Siemens SG 6.6-170 economically feasible for the ÖMS region.

Furthermore, the Vestas V150 could also be installed at a higher elevation according to the technical specifications. This could add to the AEY which would again lower the LCOE if costs remained stagnant. At which height, if at all, the Siemens SG 6.6-170 could overtake the Vestas V150 is an optimising problem not further elaborated in this report.

The least good performing turbine for all regions is the Vestas V117. When comparing the economical parameter for this turbine to the previous technical parameter, the results follow a logic. The Vestas V117 was the least good performing turbine also for the AEY which indicates the LCOE would possibly not be the best value of all three turbines. This turbine has the lowest range of hub heights possible for installation which indicates the Vestas V117 is not the preferred turbine for any of the ÖMS regions.

For the Vestas V150 the best performance is observed in Södermanland, 140 m hub height, at 0,0244 EUR/kWh and the least good performance is in Gävleborg, 115 m hub height, at 0,0332 EUR/kWh. The best performing Siemens SG 6.6-170 turbine can be observed in Södermanland, 140 m hub height, at an LCOE of 0,0264 EUR/kWh, while the least good output is in Gävleborg, 115 m hub height, at 0,0370 EUR/kWh. When analysing the Vestas V117 the best performance is in Södermanland, 140 m hub height, at 0,0277 EUR/kWh and the least good output is in Gävleborg, at 115 m hub height, with 0,0399 EUR/kWh.

Also, when analysing the mean values of the LCOE in the different regions the situation is not the same as for the AEY output. The top 10 sites with the lowest LCOE are observed in Södermanland and Västmanland region. The lowest LCOE can be seen in Södermanland by the Vestas V150, 140 m hub height, at 0,0244 EUR/kWh, while the highest LCOE value is spotted in Gävleborg by the Vestas V117, 115 m hub height, 0,0399 EUR/kWh.

Overall, the regions with the highest LCOE across all turbines are Gävleborg, Uppsala and Östergötland, while the lowest LCOE is observed in Södermanland and Västmanland. Stockholm and Örebro land in the middle. The values for the LCOE are in a narrower range and does not vary as much between regions as for the AEY. The results from the regions are compatible to those of IRENA (2024) for 2023 where the weighted average LCOE for Europe 0.046 USD/kW. According to Holmberg, P. and Tangerås, T.P. (2023) the onshore wind energy in Sweden had the lowest LCOE with 30-35 Swedish öre/kWh, approximately 0.028-0.032 EUR/kWh, which would also match the results from this report.

6.4 AEY and capacity factor per site

When analysing the AEY and CF per site, the hub height of 140 m will be the focus. This due to the historically increasing hub heights installed for wind energy projects globally, which would make lower hub heights outdated faster. The plots for AEY for 115 m and 128 m hub heights for each region and site is available in appendix 10.2.

6.4.1 AEY per site

Figures 34-40 show the AEY per turbine, per site for all regions and turbines.

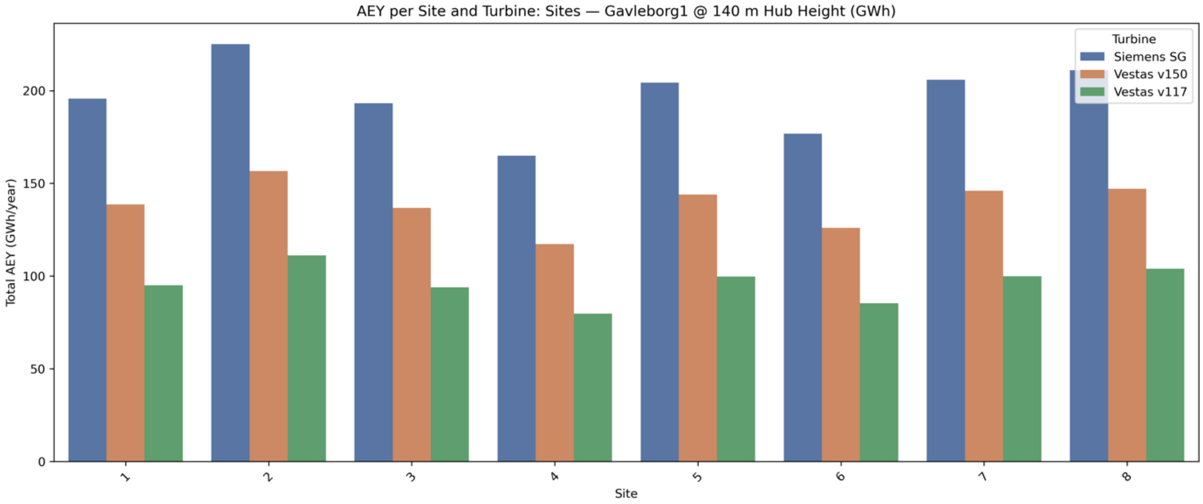


Figure 34. AEY of each site in Gävleborg region.

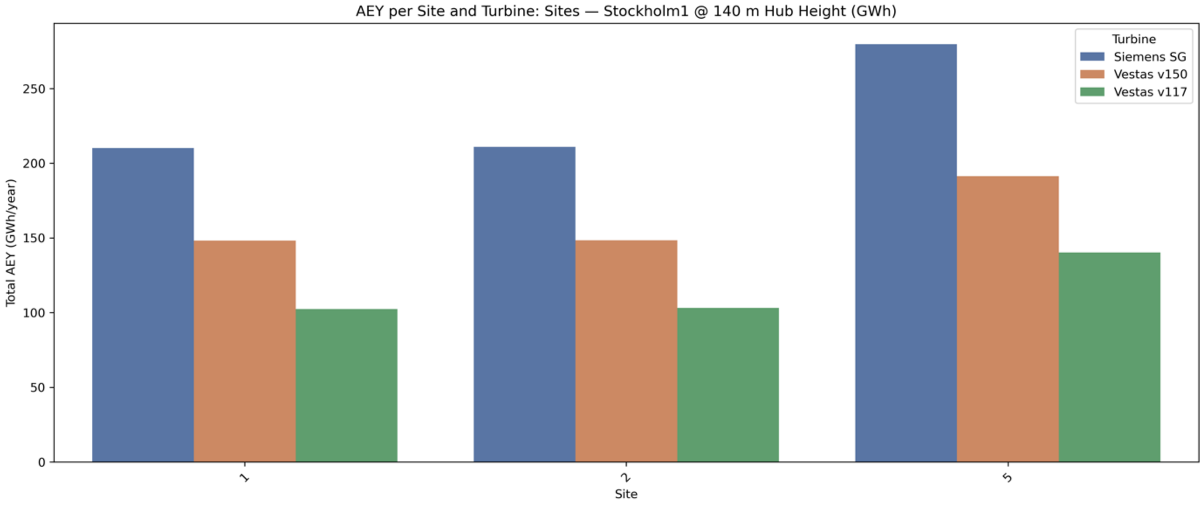


Figure 35. AEY of each site in Stockholm region.

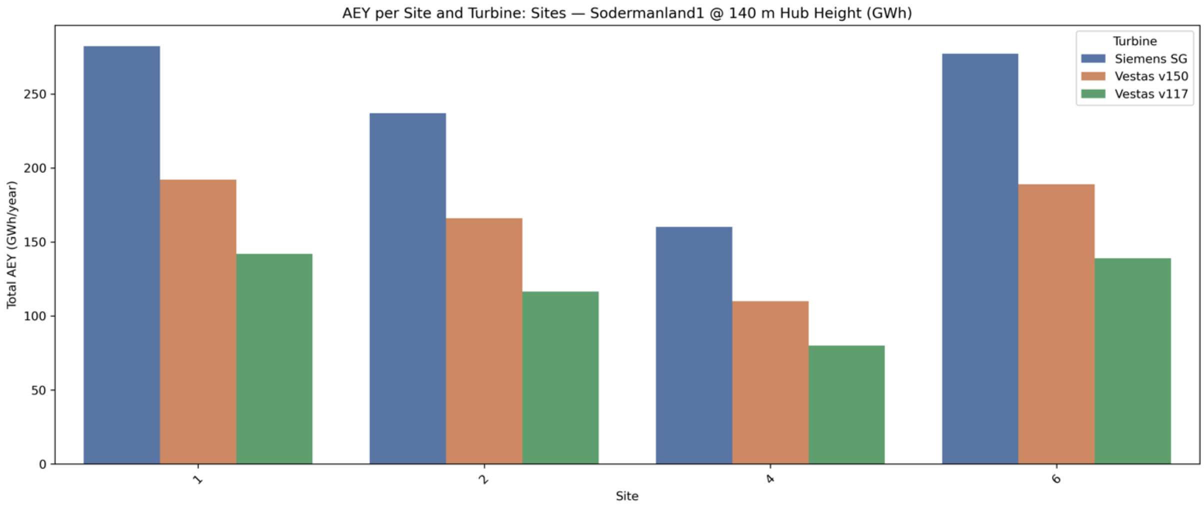


Figure 36. AEY of each site in Södermanland region.

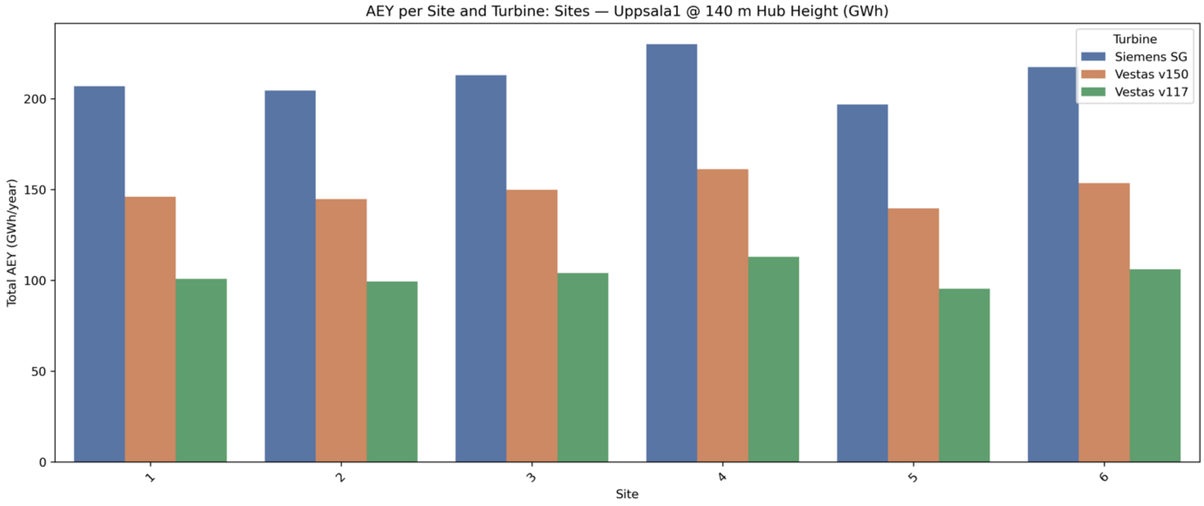


Figure 37. AEY of each site in Uppsala region.

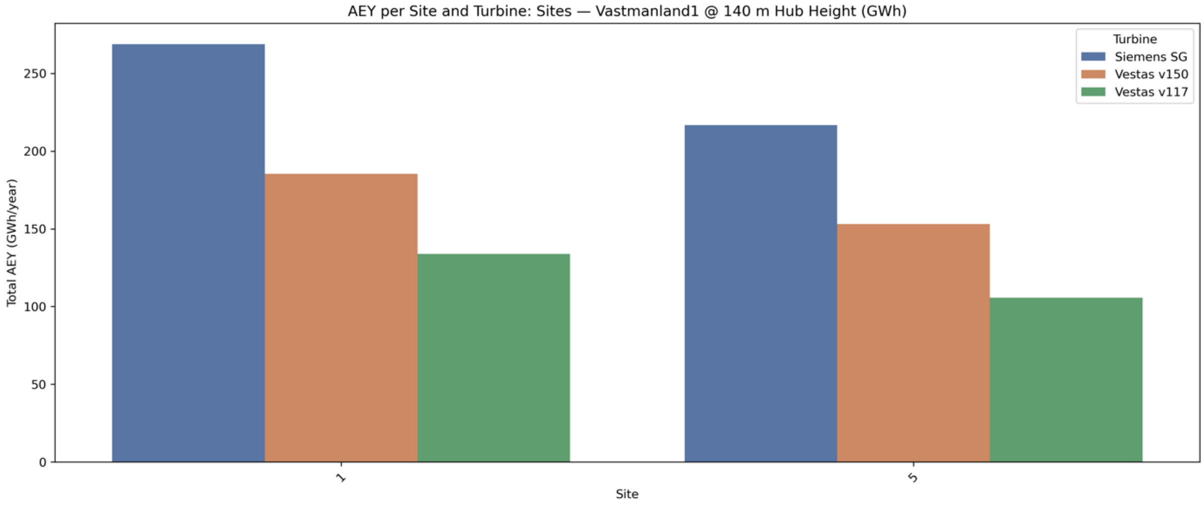


Figure 38. AEY of each site in Västmanland region.

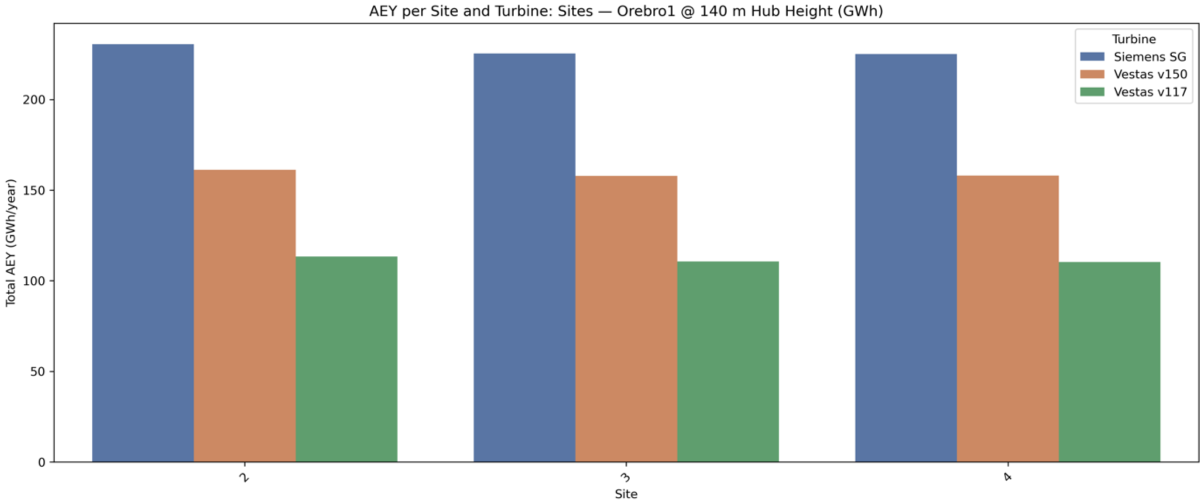


Figure 39. AEY of each site in Örebro region.

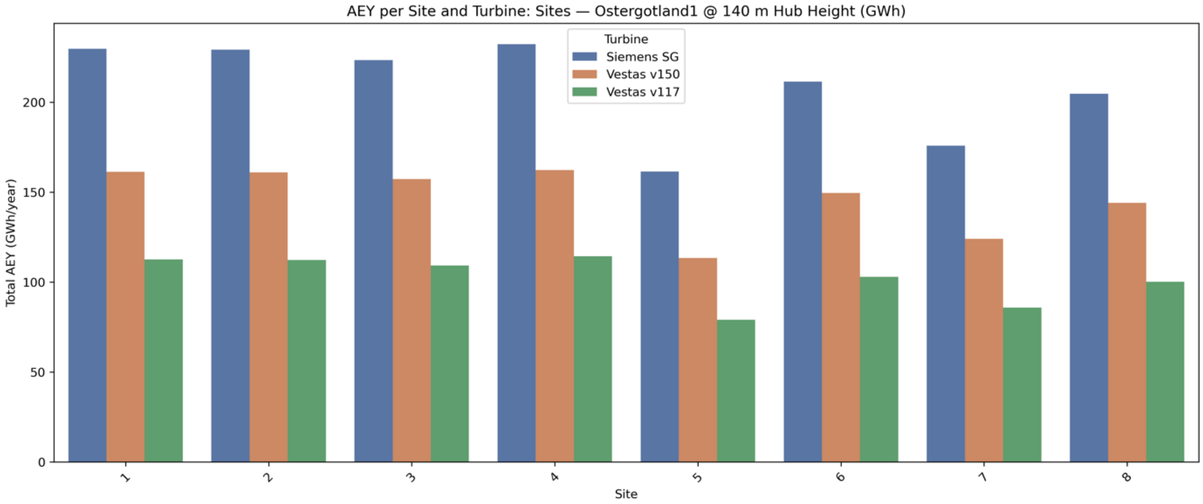


Figure 40. AEY of each site in Östergötland region.

When evaluating the previous figures, similar results regarding the turbines can be seen when analysing individual sites as with aggregated AEY for each region. The best performing turbine is the largest rated one, Siemens SG 6.6-170, second best performing is the Vestas V150, and the least good performing turbines is Vestas V117. When looking at the power curve of the Siemens turbine, the curve starts at a higher output, with a higher nominal output, which gives the curve a steeper incline and a larger overall output of electricity than the other two turbines. This is of importance since the Weibull probability function shows wind speeds between 5-10 m/s are the most probable for all sites. The turbine with the highest output in the lower wind speed region will be the best performing for the studied locations. Also, as mentioned previously, the 140 m turbine height has a general higher wind speed due to less obstacles and friction from surrounding objects which aids AEY output.

When comparing site results to the aggregated result above, it is observed Gävleborg is not necessarily the best performing site wise. 3 of 4 sites in Södermanland is the top regarding performance where, if only looking at the Siemens SG, site 1 is best performing of all sites with 282,3 GWh, site 6 is third with 277,2 GWh and site 2 is fifth with 236 GWh. Site 4 is the least good performing of all sites with 160 GWh. This result indicates the sites in Södermanland region are in the most suitable range of all locations. The best site in Gävleborg is site 2 and can be seen in twelfth place with 225,2 GWh, while the least good performing location is site 4 in 32nd place with 164,9 GWh.

When analysing the AEY of Vestas V150, the same ranking is true for Södermanland region, but with a lower AEY output, but the best site in Gävleborg drops in ranking. Site 2 is in 14th place, while site 4 is still in 32nd place.

An important comparison between the Siemens SG and Vestas V150 is no site has an output above 200 GWh when analysing the AEY of Vestas V150. The highest output is site 1 in Södermanland with 192,2 GWh, and the lowest output is site 4 in the same region with 109,9 GWh. When analysing the Siemens SG AEY, only 8 out of 34 sites have an output below 200 GWh. The least good performing sites are site 5 in Uppsala at 27th place, site 1,3, 4 and 6 in Gävleborg, site 5 and 7 in Östergötland and site 4 in Södermanland. The AEY for these locations ranges from 196,9 GWh for site 5 in Uppsala to 160,1 GWh for site 4 in Södermanland. The same 8 locations which performs the least good with Siemens SG, are also the ones performing the least good with Vestas V150 and having the same ranking.

Furthermore, 4 out of 8 of the least good performing sites are sites with a lower number of installed turbines than 10. The four last sites in the ranking are those with fewer turbines installed, and from highest ranking site to lowest, the sites have 8, 9, 7, and 6 turbines installed respectively. This ranking is true for both the Siemens SG and Vestas V150 turbine.

The Vestas V117 shows the least output of all three turbines. No site reaches above 150 GWh output: the best site is location 1 in Södermanland with 141,9 GWh and the least output is from site 5 in Östergötland with 79,1 GWh.

The 10 sites adjusted for the best performing turbine presented in table 11 below.

Site number	**Region**	**Turbine**	**Number of turbines**	**AEY (GWh)**
1	Södermanland	Siemens SG	10	282,4
5	Stockholm	Siemens SG	10	279,8

6	Södermanland	Siemens SG	10	277,2
1	Västmanland	Siemens SG	10	268,9
2	Södermanland	Siemens SG	10	237
4	Östergötland	Siemens SG	10	232,4
2	Örebro	Siemens SG	10	230,6
4	Uppsala	Siemens SG	10	230,2
1	Östergötland	Siemens SG	10	229,8
2	Östergötland	Siemens SG	10	229,2

Table 11. Top 10 sites with highest AEY, adjusted for Siemens SG 6.6-170.

Analysing above table shows one other region repeatedly occurring in the top: Östergötland. 3 out of 8 sites are in the top ten, and 4 out of 8 is in top 14 sites. Stockholm, which has 3 locations, has one in a top placement and the other two locations both generating around 210 GWh per year. Östergötland is the region which performs well for both aggregated values as well as site wise.

When analysing the results they show differences which could not be seen in the aggregated results. The number of sites in a region affecting the aggregated AEY most was proposed as a reason for the results, which site wise results also indicate. When studying the sites individually, different patterns show up compared to the aggregated results, which give insights to the locations with the best conditions for wind power.

6.4.2 Capacity factor per site

Figure 41-47 shows the capacity factors per site and turbine.

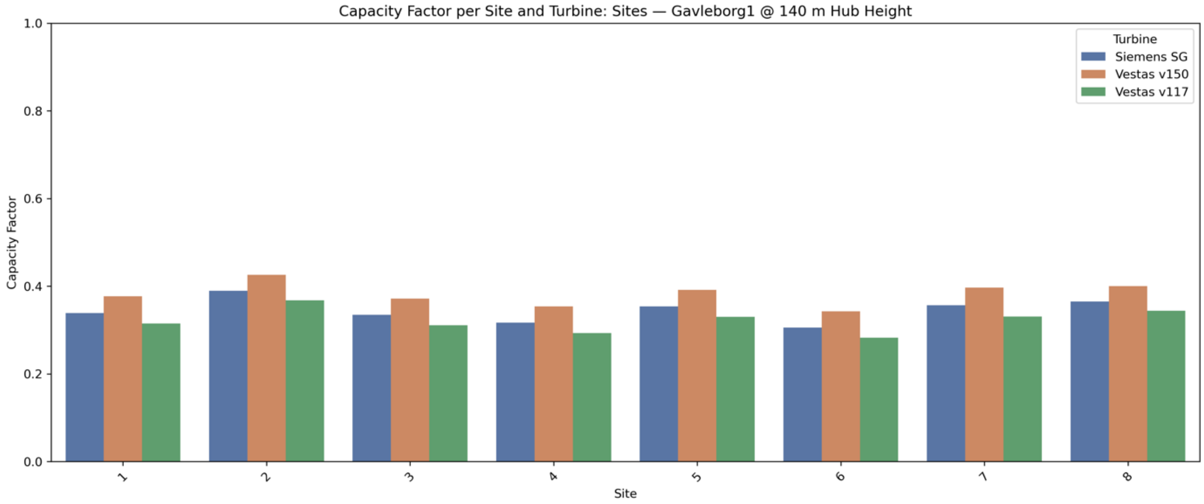


Figure 41. CF for each site in Gävleborg region.

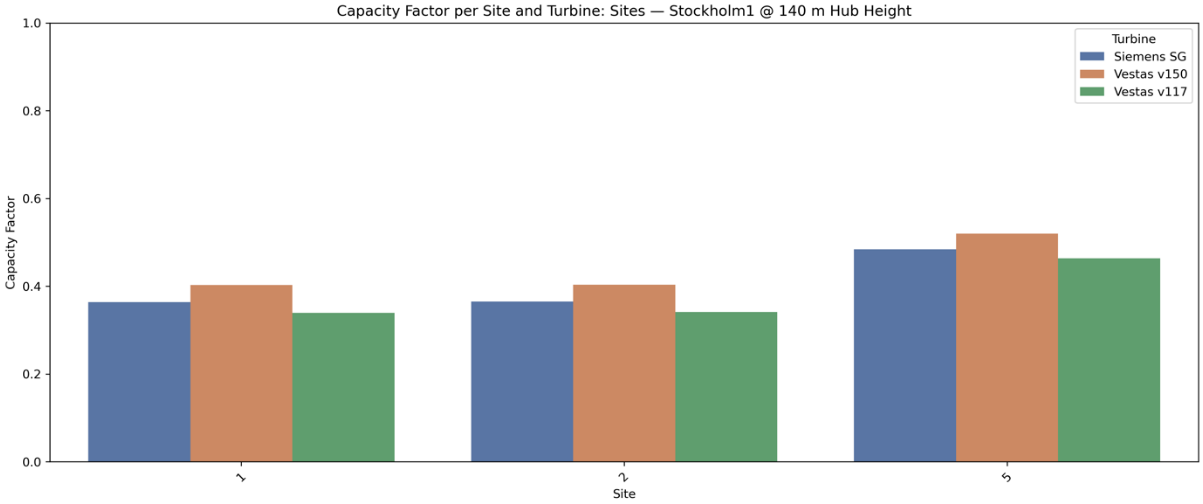


Figure 42. CF for each site in Stockholm region.

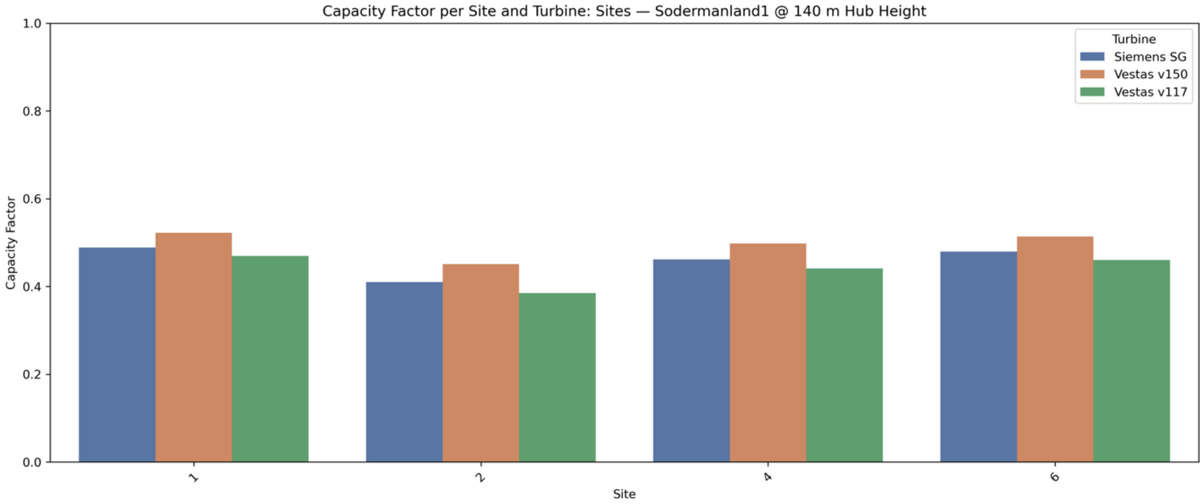


Figure 43. CF for each site in Södermanland region.

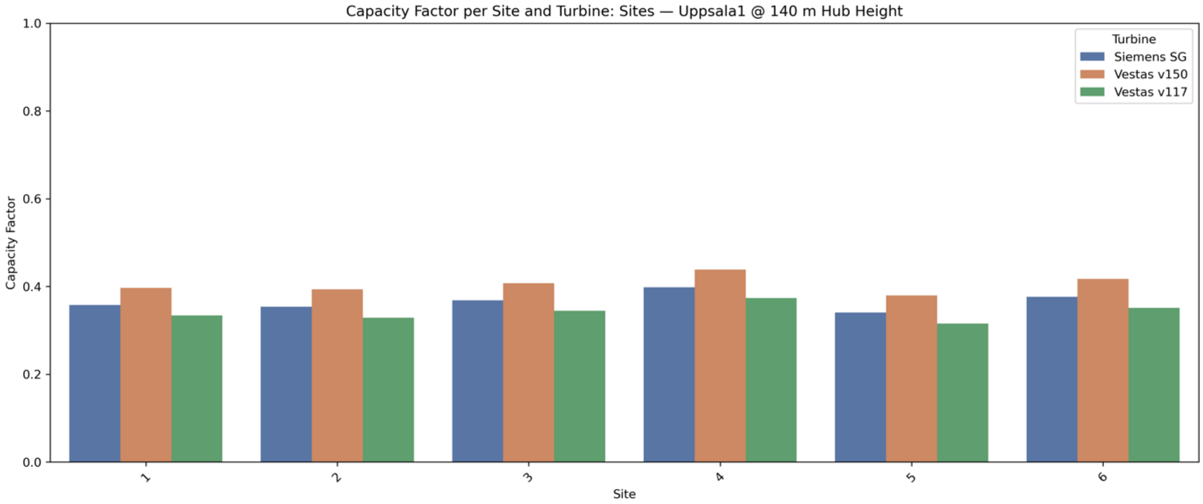


Figure 44. CF for each site in Uppsala region.

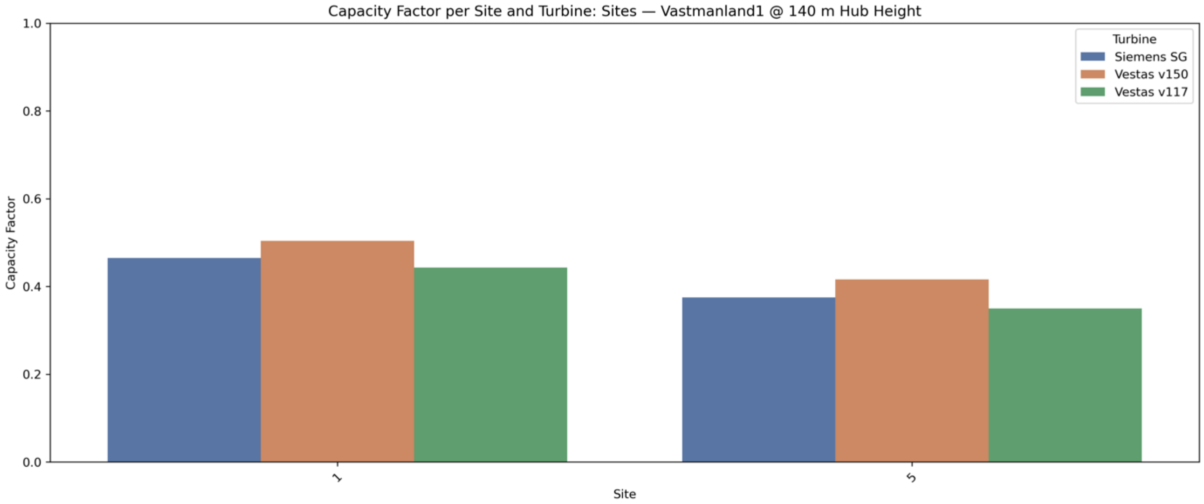


Figure 45. CF for each site in Västmanland region.

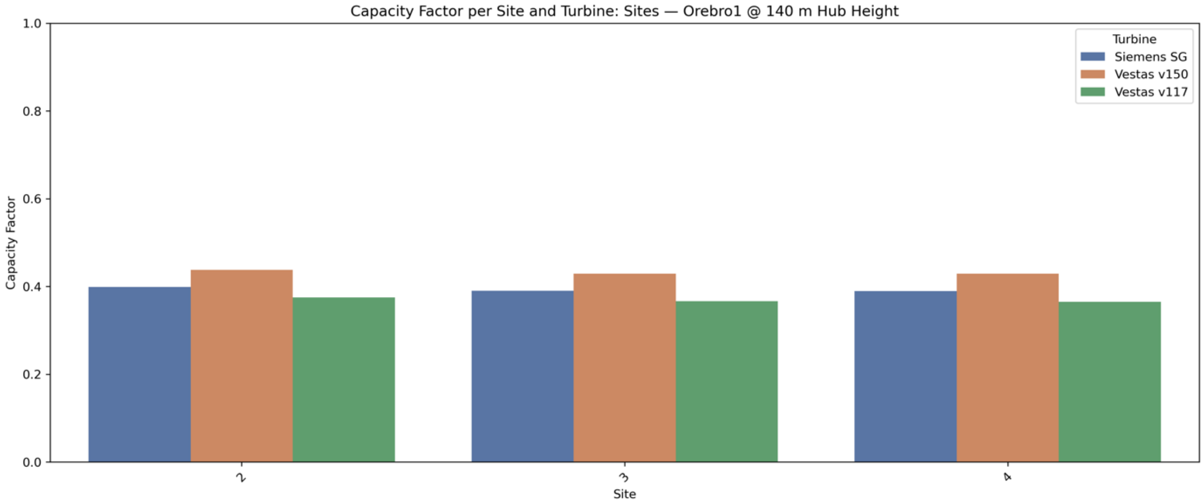


Figure 46. CF for each site in Örebro region.

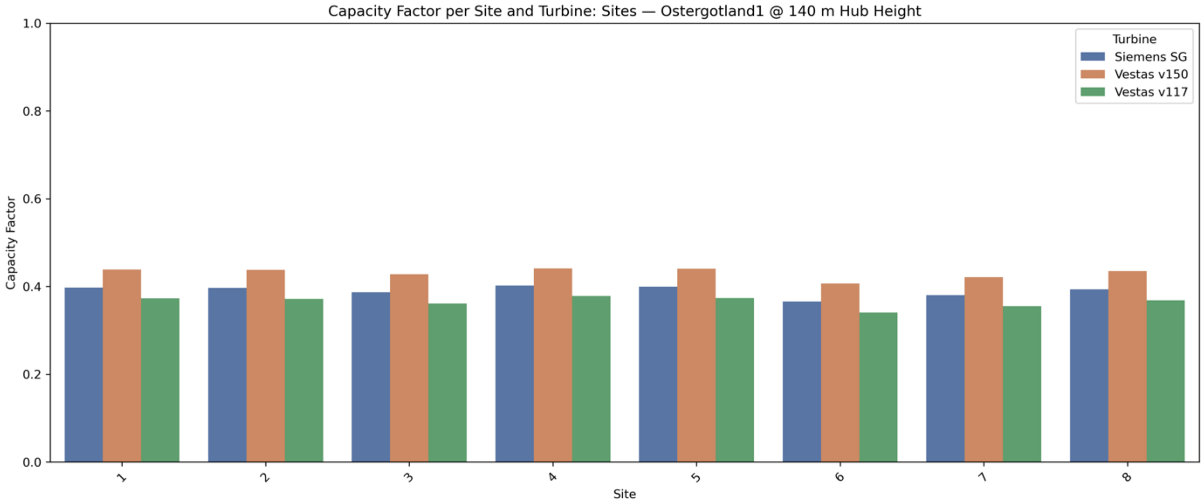


Figure 47. CF for each site in Östergötland region.

The plots show the capacity factors follow a different pattern than the AEY. Firstly, the Vestas V150 is the turbine with the highest capacity factor, secondly Siemens SG, and lastly the Vestas V117. This is a pattern seen through all sites in all regions.

Focusing on the Vestas V150, what can be observed is the highest capacity factors can generally be found in Södermanland and Östergötland, while the lowest are spotted in Uppsala and Gävleborg. This is a slight shift from the AEY results.

Generally, the CF follows the AEY output for Vestas V150, but with some exceptions. The higher the AEY, the higher capacity factor. This is true for all instances but for the sites with a smaller number of turbines installed. They generally show a high CF, but a lower AEY than the sites placed above or below. For example, ranking in fifth place is site 4 in Södermanland with 6 turbines installed, with a CF of 49,8% and an AEY of 109,9 GWh/year. In sixth place, site 2 in Södermanland with 10 turbines installed and a CF of 45,1% has an AEY of 166 GWh/year.

Again, focusing on Vestas V150, the highest CF is observed in site 1 in Södermanland with 52,2%, while site 6 in Gävleborg has the lowest CF with 34,2%. The bottom 10 in the CF ranking show 7 out of 8 sites in Gävleborg. Also 3 out of 6 sites in Uppsala are in the lowest ranking CF, site 1, 2, and 5. The CF for the lowest 10 sites ranges from 40% to 34,2%. Only site 2 in Gävleborg is in the middle of the ranking.

6.5 LCOE per site

Figures 48-54 show the LCOE for each site per turbine type.

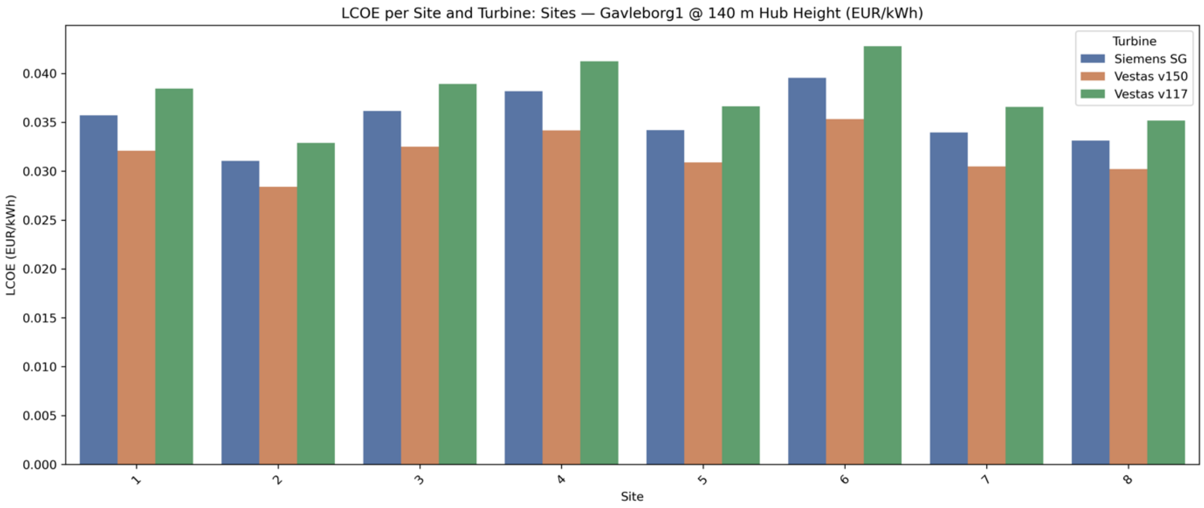


Figure 48. LCOE for each site in Gävleborg region.

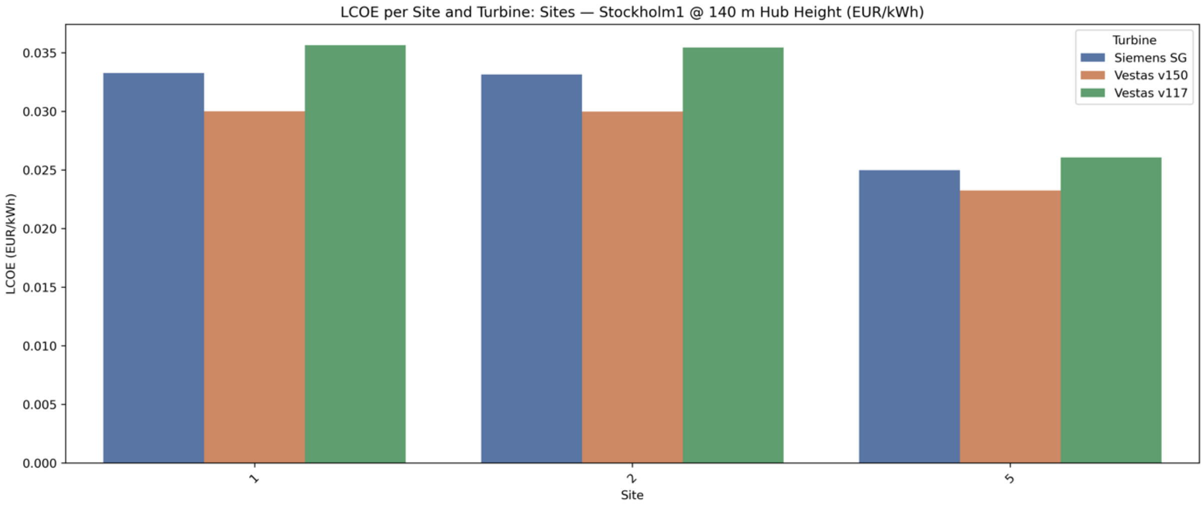


Figure 49. LCOE for each site in Stockholm region.

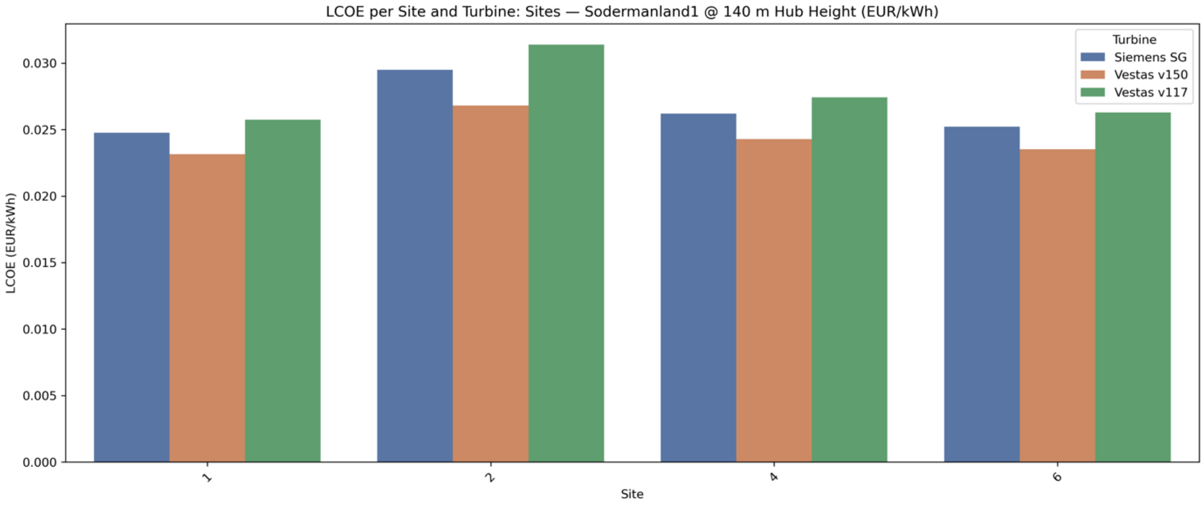


Figure 50. LCOE for each site in Södermanland region.

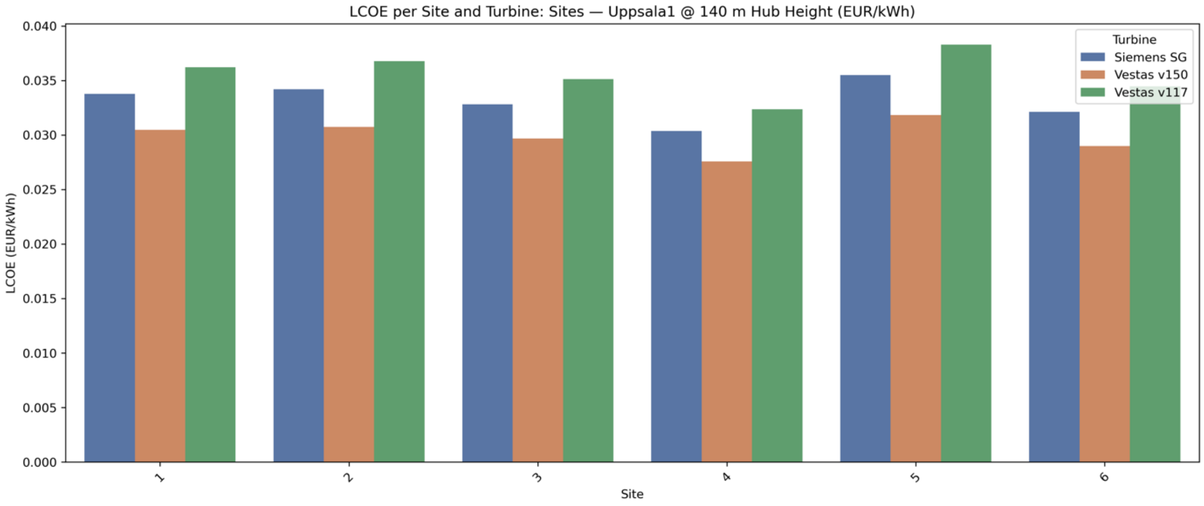


Figure 51. LCOE for each site in Uppsala region.

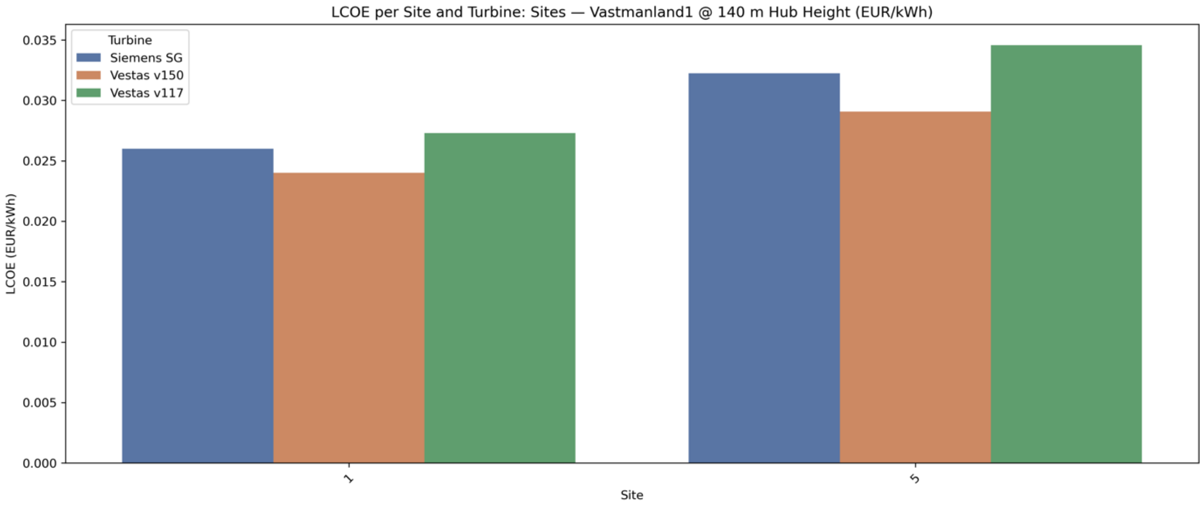


Figure 52. LCOE for each site in Västmanland region.

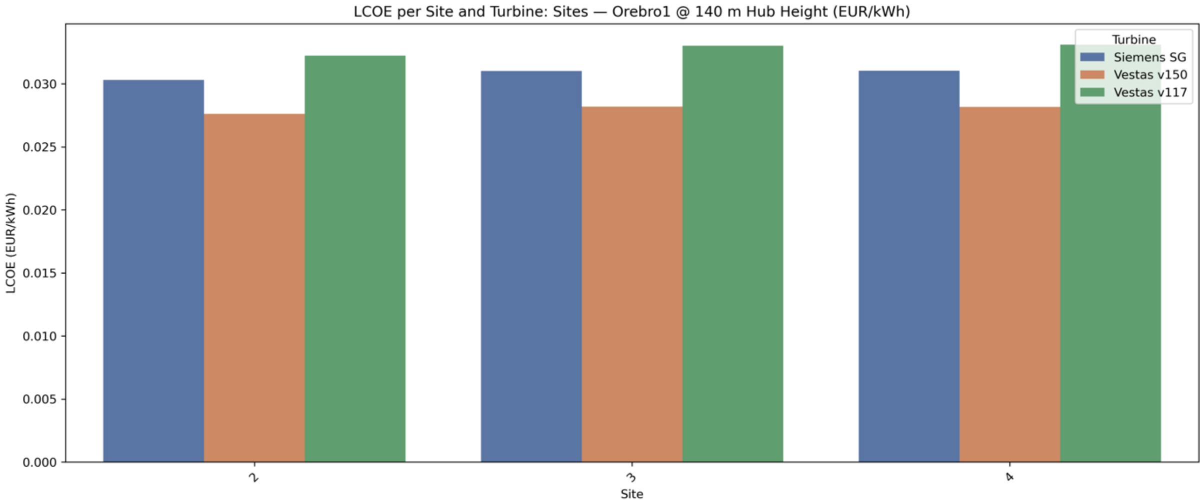


Figure 53. LCOE for each site in Örebro region.

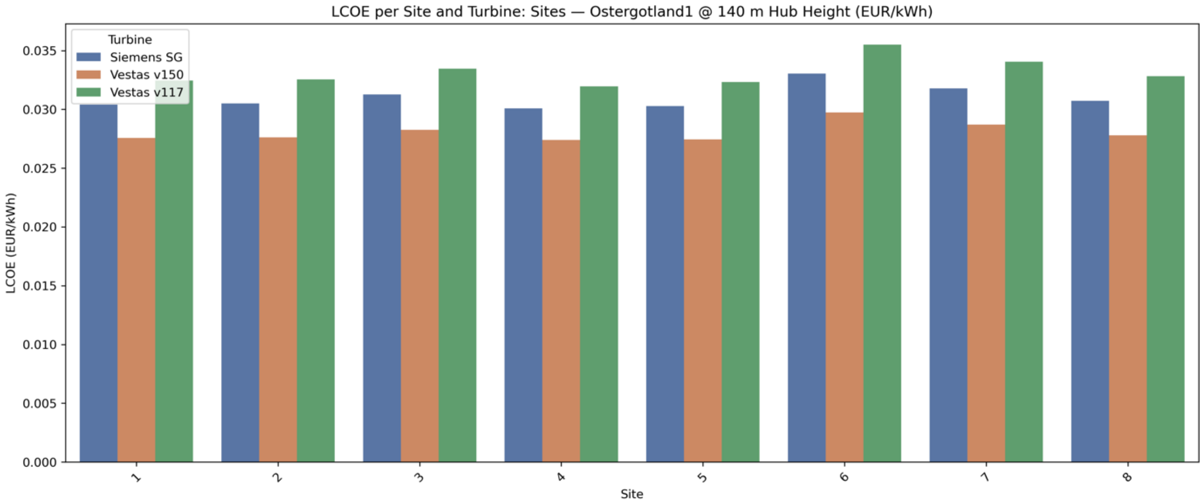


Figure 54. LCOE for each site in Östergötland region.

Firstly, the site results show a resemblance to the aggregated results for the LCOE. This meaning the lowest LCOE can be found with the Vestas V150 for each site. The second lowest LCOE is by the Siemens SG, while the highest LCOE is found with the Vestas V117. The smallest turbine Vestas V117 performing the least good was expected since the AEY was the lowest through all regions, sites and hub heights. The largest turbine, the Siemens SG, having the highest output but not the lowest LCOE is an indication the costs are too high for the turbine. It clearly performs best for AEY but is, for the tested sites and hub heights, not best performing for LCOE. As discussed previously, this result could possibly be changed if Siemens SG and Vestas V150 had an increase in hub height, since their elevation could be raised to 165 and 166 respectively.

The top 10 lowest LCOE can be found in table 12 below.

Site number	**Region**	**Turbine**	**LCOE (EUR/kWh)**
1	Södermanland	Vestas V150	0,0232
5	Stockholm	Vestas V150	0,0233
6	Södermanland	Vestas V150	0,0235
1	Västmanland	Vestas V150	0,0240
4	Södermanland	Vestas V150	0,0243
1	Södermanland	Siemens SG	0,0248
5	Stockholm	Siemens SG	0,0250
6	Södermanland	Siemens SG	0,0252
1	Södermanland	Vestas V117	0,0258
1	Västmanland	Siemens SG	0,0260

Table 12. Top 10 lowest LCOE.

Analysing the above table gives the insight that the lowest LCOE through all turbines can be found in Södermanland at site 1, since it occurs in the list three times. Just outside the list, at eleventh place, is the Stockholm region, site 5 by Vestas V117. This makes site 5 in Stockholm also one of the best for the overall LCOE through all turbines. If regarding top 15 also site 1 in Västmanland and site 6 in Södermanland has all three turbines with the lowest LCOE on the list.

When adjusting for the Vestas V150, to see only different sites, table 13 shows site specific LCOE.

Site number	**Region**	**Turbine**	**LCOE (EUR/kWh)**
1	Södermanland	Vestas V150	0,0232
5	Stockholm	Vestas V150	0,0233
6	Södermanland	Vestas V150	0,0235
1	Västmanland	Vestas V150	0,0240
4	Södermanland	Vestas V150	0,0243
2	Södermanland	Vestas V150	0,0268

4	Östergötland	Vestas V150	0,0274
5	Östergötland	Vestas V150	0,0274
1	Östergötland	Vestas V150	0,0276
4	Uppsala	Vestas V150	0,0276

Table 13. Top 10 sites with lowest LCOE, adjusted for the Vestas V150 turbine.

In the adjusted list it can be observed Södermanland has all 4 locations in top 10. This indicates this region is well suited for wind energy. Also 3 out of 8 locations in Östergötland appears on the list. Östergötland similarly showed good results for AEY, and when combined is an indicator this region has good conditions for wind energy generation.

The region with the overall highest LCOE when adjusted for only the Vestas V150 is Gävleborg. 4 out of 8 sites has the highest LCOE of all sites, ranking at the bottom of the list, and if extending the list of highest LCOE to bottom 10 sites, Gävleborg has 7 out of 8 sites on the list. For the bottom 10 the LCOE ranges from 0,0302 EUR/kWh at site 8 in Gävleborg, to 0,0353 EUR/kWh at site 6 in Gävleborg. It is only site 2 that ranks in the middle of the LCOE list.

The differences in LCOE between the Vestas V150 and the Siemens SG are small. As previously mentioned, the lowest LCOE for the vesta V150 is 0,0232 EUR/kWh, while for the Siemens SG, the lowest LCOE is 0,0248 EUR/kWh. Both values are from site 1 in Södermanland. In second place is site 5 in Stockholm where Vestas V150 reached an LCOE of 0,0233 EUR/kWh and the Siemens SG 0,025 EUR/kWh. In the other end, the highest LCOE is found in site 6 in Gävleborg. Here the Vestas V150 has an LCOE of 0,0353 EUR/kWh and the Siemens SG 0,0395 EUR/kWh.

Reiterating to table 2, which shows land use in the different regions, some explanations could be found to the uneven number of allocated sites in each region. Firstly, Gävleborg and Östergötland are by far the biggest regions with areas almost 2 or 3 times the other regions. Reasonably, the more space available for wind energy installation, the more sites available. Secondly, the more conflict of interest between different stakeholders and uses of land, the more difficult it is to find suitable sites within the threshold of 0,75 which Kandy used. Regions with high percentage of for example residential areas, transport infrastructure, agriculture or areas valuable to the military could impact the possible locations for wind energy installations negatively. The Stockholm region and Gävleborg region are each other's opposites when observing table 2. Gävleborg is almost 3 times bigger than Stockholm and has the largest forest area while Stockholm has the smallest. Stockholm has a bigger residential, as well as agriculture, area than Gävleborg, and has the largest area for "other" purposes of all regions while Gävleborg has the smallest. These differences are likely a reason of conflict of interest which makes for impact when assigning sites to the regions.

As seen, when analysing the aggregated values in comparison to the site wise results, they differ. Regions with high aggregated energy output might not perform as good on a site level. This could be due to regions with many high conflict areas, but with good conditions for wind energy generation, has a lower number of sites possible which makes the aggregated values lower. The site wise AEY gives an insight into the conditions for wind energy at specific locations which does not always match the region wise result.

Comparing the CF to the LCOE for the Vestas V150, it shows they follow each other. The site with the lowest LCOE has the highest CF, while the opposite also is true, the site with the highest LCOE has the lowest CF.

6.6 Distances to roads, the power grid and substations

In literature, it is often the distance to the power grid which is of interest when calculating the cost impact of infrastructural factors. In the stakeholder consultation mentioned previously, it was indicated connection to substations were more commonly used in practice. Both have been considered in this report.

The furthest distance to a substation was found at site 4 in Gävleborg. The distance to nearest substation is 83,9 km, while the distance to the nearest grid 1,5 km. The shortest distance to a substation was found in site 1 in Västmanland where the distance was 1,5 km, while for the grid is was 0,4 km.

Moreover, the shortest grid distance is found in 4 sites, where the grid goes through the site, creating a distance of 0 km. These sites are site 3 in Örebro, site 2 and 6 in Östergötland, and site 5 in Uppsala. When comparing the distance to the substations from these sites it is 28,9 km, 24,7 km, 30,6 km, and 2,5 km respectively. The furthest distance from the grid is observed at site 6 in Södermanland with a distance of 7,3 km. The distance to the nearest substation is even further away at 26,2 km.

What is observed when analysing the results of the distance to the grid and substations, is that the distance to the grid is shorter for all sites, than for the substations. The average distance to a substation is 23,2 km while for the power grid it is 1,9 km.

When analysing the distance to roads, the average is 1,1 km to the nearest. The shortest distance is 0,5 km to site 3 in Östergötland, while the furthest away is to site 1 in Södermanland with 2 km to nearest road.

When attending the stakeholder consultation, the distance to grid and substations were discussed. In literature, usually it is the distance to the grid which is of greatest importance as cost factor parameter. However, a participant in the meeting, working with wind energy, mentioned substations were usually the parameter of greater importance to the company. Moreover, letting the cable from the wind farm to the substation run where the grid runs, is a common practice to facilitate the wind project.

These distance aspects are an important cost factor for the wind energy projects. Initially, the intent was to calculate these cost indicators specifically to see how they affected the LCOE, but due to difficulties in finding sources with information regarding these specific costs, it could not be executed.

6.7 Sources of error

There are several possible sources of error in this report. One source of error difficult to assess in the management of the data input regarding the sites. For example, depending on the weighting of factors and constraints, the threshold for the conflict score or data management, the results of where the best sites are located can be changed. Since the results of another report was used as input into this report, there is difficulty knowing exactly how data was handled and processed, as well as all decisions made.

Another origin of inaccuracy can be found in the processing of data for the current report. There can be issues with missing values unbeknownst to the author, or errors in handling the data in QGIS. The re-projection and clipping of data could be instances where inaccuracies could appear and then be propagated through the results. Also, the data used as input into QGIS could be faulty or outdated, which would cause the errors to propagate as well.

Coding the techno-economic evaluation in Python can be a root of error since mistakes are easily made when there are many lines of code. Regardless of Python's error prompts, mistakes can appear in the code which would impact both the results and plots of the report. Additionally, errors could occur in Python if the data, accessed from outside of Python, is not correctly read into the different functions and loops of the code.

Furthermore, the inaccuracies in the technical specifications of the turbines or the input costs for the LCOE can be sources of error for the results. If, for example, the technical specifications show wrong numbers for the power curve, it has implications for both AEY and LCOE in the report.

Lastly, an issue with the location of the sites was observed in 2 counties. Site 5 in Stockholm County and sites 1, 4, and 6 in Södermanland County was found in a body of water. This was due to an error in the modelling section of the MCA prior to this report and was an issue regarding lacking constraints for bodies of water. Unfortunately, because of time restriction, these sites could not be exchanged.

One way to reduce errors is to verify or check the results. This can be done through for example comparison of results with an existing wind energy installation in a site near or similar to those locations studied in the report. This has unfortunately not been done in this report due to difficulties finding accessible data from existing wind energy projects and time limitations.

7 Conclusions

In this report, a techno-economic evaluation of 34 different sites in 7 regions have been performed. QGIS was used for the processing and preparation of the data to access vital information in the sites specifically. Python was then used for the techno-economic assessment and plotting of the results.

The average distance to the grid is shorter than to the substations, 1,9 km and 23,2 km respectively. It is indicated that literature assesses the distance to the grid more often than to substations, while in practice the distance to substations is more commonly used. The average distance to a road is 1,1 km.

The best performance of the turbines occurs at 140 m hub height. The higher the output, the lower the LCOE given all else constant. Both Vestas V150 and Siemens SG 6.6-170 could be installed at a higher hub height which made the Vestas V117 the limiting turbine out of the three. Installing at higher hub height could mean increased energy output.

Both the aggregated and site wise results show the vestas V117 is not the preferred turbine for current locations. The turbine has the lowest AEY and highest LCOE, which is true for all three hub heights. This makes for a recommendation not to aim for this turbine primarily when considering wind energy installations at the study sites.

The best performing turbine for the technical parameter AEY was the Siemens SG 6.6-170. This turbine had the largest nominal rating and the highest output for the lower wind speeds which were commonly occurring at the sites observed through the Weibull function. The Siemens SG was performing the best both for the aggregated results and the site specific.

However, the best performing turbine when assessing the economic parameter LCOE was the Vestas V150. Both aggregated and site-specific results show this turbine had the lowest LCOE for all regions and sites when compared to the other turbines. When comparing the LCOE for Vestas V150 and Siemens SG the difference is small. At the site with the lowest LCOE, 1 in Södermanland the Vestas V150 had 0,0232 EUR/kWh, while for the Siemens SG, the lowest LCOE was 0,0248 EUR/kWh. Depending on the application of the output of the wind energy installation, the choice between having the lowest LCOE or generating the largest AEY is on the planners of the municipalities and regions. Generally, due to the small difference in LCOE between Vestas V150 and Siemens SG, but the larger difference in AEY, the preferred turbine would be the Siemens SG. If keeping the national wind energy expansion strategy in mind, the Siemens SG would fulfil the requirements of that strategy to a greater extent.

The best regions for wind energy projects regarding AEY depends on the perspective. The aggregated results for the current sites show the two regions with best aggregated results are Gävleborg and Östergötland. This partly due to the many sites in those regions compared to some of the other regions. The site specific AEY show Södermanland and Östergötland have several sites each in the top 10.

The region with the lowest aggregated LCOE was observed to be Södermanland and Västmanland, while the highest LCOE was in Gävleborg, Uppsala and Östergötland. Best site specific LCOE was generally observed in Södermanland and Östergötland, and the least good in Gävleborg.

The sites with the highest capacity factors also had the highest AEY, except for the occasions when the sites had a smaller number of turbines installed. The opposite was true for the LCOE. The lower the LCOE, the higher the capacity factor.

8 Future work

As future work there are several ways to build on the results from this report whilst elevating them. The three turbines were chosen to evaluate which nominal rating was best suited for the sites. They had different ranges of hub height which resulted in the optimisation of hub height through the different sites to being insufficient. This due to the optimisation range being too narrow for the two highest rated turbines. The tested hub heights in the report were at 115 m, 128 m and 140 m, while two turbines could go up to 165 m and 166 m. While this report shows the lowest rated turbine, the Vestas V117, is not the best choice, it can be changed for another turbine in future work, to better match the height of the other turbines so the hub height optimisation could provide other results.

Another factor for optimisation is the rotor diameter. Changing the rotor diameter could be a parameter to change if the hub height is static. Altering the rotor diameter to a larger size could increase the AEY due to the swept area of the rotor enlarges. Optimising for both hub height and rotor diameter would be an interesting aspect for future work.

Additionally, one feature disregarded in this report, which could be of importance is the adjustment for air density when modelling. Also using a different wind shear value would be interesting to compare results to.

Furthermore, if specific cost factors regarding substations, connection to the grid and road infrastructures could be found it would elevate the results of this report and would also be an interesting aspect to compare the results to.

9 Reference list

Abdelhady, S., Borello, D., & Shaban, A. (2017). Assessment of levelized cost of electricity of offshore wind energy in Egypt. *Wind Engineering*, *41*(3), p. 160–173. https://www.jstor.org/stable/90010044. (Accessed 250304).

Ali, S., & Jang, C.-M. (2019). Selection of Best-Suited Wind Turbines for New Wind Farm Sites Using Techno-Economic and GIS Analysis in South Korea. *Energies*, 12(16), 3140. https://doi.org/10.3390/en12163140. (Accessed 250228).

Andersson, M. (2021). *Spatial modelling of sustainable wind power development*. Master thesis, Uppsala university. https://www.diva-portal.org/smash/get/diva2:1631135/FULLTEXT01.pdf. (Accessed 250304).

Elkadeem, M. R., Younes, A., Mazzeo, D., Jurasz, J., Campana, P. E., Sharshir, S. W., Alaam, M. A. (2022). Geospatial-assisted multi-criterion analysis of solar and wind power geographical-technical-economic potential assessment. *Applied Energy*. Volume 322, 2022, 119532. https://doi.org/10.1016/j.apenergy.2022.119532. (Accessed 250228).

Energiforsk. (2021). *El från nya anläggningar*. Rapport 2021:714. https://energiforsk.se/media/30970/el-fra-n-nya-anla-ggningar-energiforskrapport-2021-714.pdf. (Accessed 250501).

Energimyndigheten. (2013). *Riksintresse vindbruk 2013*. Energimyndigheten. https://www.energimyndigheten.se/49f8d6/globalassets/fornybart/riksintressen/riksintresse-vindbruk-2013_beskrivning.pdf. (Accessed 250401).

Energimyndigheten, Naturvårdsverket. (2021). *Nationell strategi för en hållbar vindkraftsutbyggnad*. Energimyndigheten. https://energimyndigheten.a-w2m.se/System/TemplateView.aspx?p=Arkitektkopia&id=1a323958b619442089211a507ff4ee48&q=Nationell%20strategi&lstqty=1. (Accessed 250404).

Energimyndigheten. (2023). *Vindkartering – MIUU*. Energimyndigheten. https://www.energimyndigheten.se/energisystem-och-analys/elproduktion/vindkraft/kunskap-och-data/nationell-vindkartering/#:~:text=Vindkarteringen%20MIUU%20%C3%A4r%20en%20kartl%C3%A4ggning,underlag%20f%C3%B6r%20lokalisering%20av%20vindkraft. (Accessed 250304).

Energimyndigheten. (2025a). *Vindkraftsstatistik*. Choose: Tabeller, 3. Antal verk, installerad effect och vindkraftsproduktion per län, 2003-. https://www.energimyndigheten.se/statistik/officiell-energistatistik/tillforsel-och-anvandning/vindkraftsstatistik/. (Accessed 250428).

Energimyndigheten. (2025b). *Produktion och utbyggnad*. https://www.energimyndigheten.se/energisystem-och-analys/elproduktion/vindkraft/produktion-och-utbyggnad/#:~:text=Vindkraft%20%C3%A4r%20en%20betydande%20del,kr%C3%A4vs%20f%C3%B6r%20elektrifieringen%20av%20samh%C3%A4llet. (Accessed 250530).

European Commission. (2025). *Clean Industrial Deal - A plan for EU competitiveness and decarbonisation*. European Commission. https://commission.europa.eu/topics/eu-competitiveness/clean-industrial-deal_en. (Accessed 250305).

Gass, V., Schmidt, J., Strauss, F., Schmid, E. (2013). Assessing the economic wind power potential in Austria. *Energy Policy*, Volume 53, Pages 323-330. https://doi.org/10.1016/j.enpol.2012.10.079. (Accessed 250413).

Global Wind Atlas. (No date). *GIS files & API access*. https://globalwindatlas.info/en/download/gis-files. (Accessed 250414).

Grassi, S., Chokani, N., Abhari, R.S. (2012). Large scale technical and economical assessment of wind energy potential with a GIS tool: Case study Iowa. *Energy Policy*, Volume 45, Pages 73-85. https://doi.org/10.1016/j.enpol.2012.01.061. (Accessed 240413).

Harrucksteiner, A., Thakur, J., Franke, K., Sensfuß, F. (2023). A geospatial assessment of the techno-economic wind and solar potential of Mongolia. *Sustainable Energy Technologies and Assessments*, Volume 55, 102889. https://doi.org/10.1016/j.seta.2022.102889. (Accessed 250413).

Holmberg, P. and Tangerås, T.P. (2023). The Swedish electricity market – today and in the future. *Sveriges Riksbank Economic review 2023 no. 1*. https://www.riksbank.se/globalassets/media/rapporter/pov/artiklar/engelska/2023/230512/2023_1-the-swedish-electricity-market--today-and-in-the-future.pdf. (Accessed 250524).

Huang, C., Yan, J., Zhang, D., Zhong, Y. (2022). Analysis of the effect of slope on the power characteristics of wind turbines in hillside terrain. *Energy Reports*, Volume 8, Supplement 12, Pages 352-361. https://doi.org/10.1016/j.egyr.2022.10.074. (Accessed 250413).

IEA. (No date). *Sweden*. https://www.iea.org/countries/sweden/energy-mix. (Accessed 250219).

IRENA. (2012). *Renewable Energy Cost Analysis: Wind Power*. International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-WIND_POWER.pdf. (Accessed 240404).

IRENA. (2024). *Renewable power generation costs in 2023*. International Renewable Energy Agency. Abu Dhabi. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2024/Sep/IRENA_Renewable_power_generation_costs_in_2023.pdf. (Accessed 250428).

Jangid, J., Bera, A.K., Joseph, M., Singh, V., Singh, T.P., Pradhan, B.K., Das, S. (2016). Potential zones identification for harvesting wind energy resources in desert region of India – A multi criteria evaluation approach using remote sensing and GIS. *Renewable and Sustainable Energy Reviews*, Volume 65, Pages 1-10. https://doi.org/10.1016/j.rser.2016.06.078. (Accessed 250502).

Johnsson, F., Henrysson, J., Westander, H. (2022). *Studie av förutsättningar och hinder för vindkraftsutbyggnad*. Mistra Electrification. https://research.chalmers.se/publication/534519/file/534519_Fulltext.pdf. (Accessed 250428).

Kandy, D. M. (2018). *Spatial planning for wind energy development using GIS - A study of Västernorrland County*. Master thesis, The Royal Institute of Technology. https://www.diva-portal.org/smash/get/diva2:1271251/FULLTEXT01.pdf. (Accessed 250304).

Kandy, D.M., Mörtberg, U., Wretling, V., Kuhlefelt, A., Byström, G., Polatidis, H., Barney, A., Balfors, B. (2024). Spatial multicriteria framework for sustainable wind-farm planning – Accounting for conflicts. *Renewable and Sustainable Energy Reviews*, Volume 189, Part A, 113856. https://doi.org/10.1016/j.rser.2023.113856. (Accessed 250325).

Lee, J.C.Y. & Fields, M.J. (No date). *An Overview of Wind Energy Production Prediction Bias, Losses, and Uncertainties*. National Wind Technology Center. https://wes.copernicus.org/preprints/wes-2020-85/wes-2020-85-manuscript-version4.pdf. (Accessed 250418).

Madariaga, A., Martínez de Ilarduya, C. J., Ceballos, S., Martínez de Alegría, I., Martín, J.L. (2012). *Electrical losses in multi-MW wind energy conversion systems. International Conference on Renewable Energies and Power Quality (ICREPQ'12)*. Santiago de Compostela, Spain, 28th to 30th March. https://www.icrepq.com/icrepq'12/305-madariaga.pdf. (Accessed 250515).

Marcianò, P. (2017). Localising suitable areas for wind power development in Kiruna Municipality. A spatial multi-criteria decision analysis. Master thesis, Umeå university. https://www.diva-portal.org/smash/get/diva2:1109432/FULLTEXT01.pdf. (Accessed 250414).

Mentis, D., Siyal, S. H., Korkovelos, A., Howells, M. (2016). A geospatial assessment of the techno-economic wind power potential in India using geographical restrictions. *Renewable Energy*. Volume 97: P. 77-88. https://doi.org/10.1016/j.renene.2016.05.057. (Accessed 250301).

Ministero dell'Ambiente e della Sicurezza energetica. (No date). *Developer Package SG 6.6-170*. A003a-D2830475_016_SGRE_ON_SG_6_6-170.pdf. (Accessed 250414).

Mörtberg, U., Kandy, D. M., Wretling, V., Kuhlefelt, A., Balfors, B. (2023). *Regionalt planeringsstöd för vindkraft*. Naturvårdsverket. https://www.naturvardsverket.se/4acd1e/globalassets/media/publikationer-pdf/7000/978-91-620-7095-3.pdf. (Accessed 250328).

Nationell vägdatabas. (No date). *Hämta vägdata*. https://www.nvdb.se/sv. (Accessed 250414).

Naturvårdsverket. (No date). *Frågor och svar om vindkraft*. https://www.naturvardsverket.se/amnesomraden/vindkraft/fragor-och-svar-om-vindkraft/. (Accessed 250414).

Negash, T., Möllerström, E., Ottermo, F., Zeraebruk, K. (2021). Technical Feasibility of Large-scale Wind Energy Production in Eritrea. In: ZEMCH 2021 International Conference Proceedings: ZEMCH 2021. Dubai, UAE, 26-28 October 2021, p. 613-624. https://hh.diva-portal.org/smash/get/diva2:1626387/FULLTEXT01.pdf. (Accessed 250304).

Lantmäteriet. (No date, a). *Administrativ indelning Nedladdning, Inspire*. https://www.lantmateriet.se/sv/geodata/vara-produkter/produktlista/administrativ-indelning-nedladdning-inspire/. (Accessed 250414).

Lantmäteriet. (No date, b). *US.TransmissionsnätFörEl*. https://www.geodata.se/geodataportalen/srv/swe/catalog.search#/search?resultType=swe-details&_schema=iso19139*&type=dataset%20or%20series&from=1&to=20&fast=index&_content_type=json&sortBy=relevance&topicCat=utilitiesCommunication. (Accessed 250414).

Lantmäteriet. (No date, c). *Markhöjdmodell Nedladdning, grid 50+*. https://www.geodata.se/geodataportalen/srv/swe/catalog.search#/search?resultType=swe-details&_schema=iso19139*&type=dataset%20or%20series&from=1&to=20&fast=index&_content_type=json&sortBy=relevance&topicCat=elevation. (Accessed 250414).

Ossa, A. A. (2021). *Evaluating the onshore wind power potential of Gotland using the new European wind atlas*. Master thesis, Uppsala university. https://www.diva-portal.org/smash/get/diva2:1645885/FULLTEXT01.pdf. (Accessed 250304).

SCB. (2022). *Markanvändningen i Sverige 2020*. https://www.scb.se/hitta-statistik/statistik-efter-amne/boende-bebyggelse-och-mark/markanvandning/markanvandningen-i-sverige/pong/tabell-och-diagram/markanvandningen-i-sverige/. (Accessed 250428).

SCB. (2025). *Befolkningstäthet i Sverige*. https://www.scb.se/hitta-statistik/sverige-i-siffror/manniskorna-i-sverige/befolkningstathet-i-sverige/. (Accessed 250428).

Siyal, S.H., Mörtberg, U., Mentis, D., Welsch, M., Babelon, I., Howells, M. (2015). Wind energy assessment considering geographic and environmental restrictions in Sweden: A GIS-based approach. *Energy*, Volume 83, p. 447–461. https://www.sciencedirect.com/science/article/pii/S0360544215001991. (Accessed 250314).

Siyal, S.H., Mentis, D., Howells, M. (2016). Mapping key economic indicators of onshore wind energy in Sweden by using a geospatial methodology. *Energy Conversion and Management*, Volume 128, P 211-226. https://doi.org/10.1016/j.enconman.2016.09.055. (Accessed 250314).

Siyal, S.H. (2019). *Techno-economic assessment of wind energy for renewable hydrogen production in Sweden*. Doctoral thesis, The Royal Institute of Technology. https://www.diva-portal.org/smash/get/diva2:1296393/FULLTEXT01.pdf. (Accessed 250228).

Svenska kraftnät. (2023). *När vindkraft planeras*. https://www.svk.se/utveckling-av-kraftsystemet/samhallsplanering/nar-vindkraft-planeras/#:~:text=N%C3%A4r%20totalh%C3%B6jden%20A%2DA%20%C3%A4r%20l%C3%A4gre,och%20l%C3%A4gga%20till%20200%20meter. (Accessed 250403).

Svenska kraftnät. (2025). *Långsiktig marknadsanalys - Scenarier för kraftsystemets utveckling fram till 2050*. https://www.svk.se/siteassets/om-oss/rapporter/2024/lma_2024.pdf#page36. (Accessed 250509).

Swedish Climate Policy Council. (2024). *2024 Report of the Swedish Climate Policy Council*. Swedish Climate Policy Council. https://www.klimatpolitiskaradet.se/wp-content/uploads/2024/06/reportoftheswedishclimatepolicycouncil2024.pdf. (Accessed 250305).

Tegou, L-I., Polatidis, H., Haralambopoulos, D.A. (2010). Environmental management framework for wind farm siting: Methodology and case study. *Journal of Environmental Management*, Volume 91, Issue 11, Pages 2134–2147. https://doi.org/10.1016/j.jenvman.2010.05.010. (Accessed 250415).

The Wind Power. (2025). *Vestas V150/4000–4200*. https://www.thewindpower.net/turbine_en_1490_vestas_v150-4000-4200.php. (Accessed 250414).

Tillväxt- och regionplaneförvaltningen. (2019). *Kraftförsörjning inom östra Mellansverige*. https://www.regiongavleborg.se/globalassets/regional-utveckling/rapporter-och-publikationer/samhallsplanering-och-infrastruktur---fillistning/oms---kraftforsorjning-inom-ostra-mellansverige---rapport.pdf. (Accessed 250422).

Trafikverket. (2025). *Master, torn och vindkraftverk*. https://bransch.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/samhallsplanering/Sakerhet-och-konflikter/Master-och-vindkraftverk/#:~:text=Avst%C3%A5ndet%20mellan%20sp%C3%A5rmitt%20och%20ett,packad%20sn%C3%B6%20slungas%20fr%C3%A5n%20rotorbladen. (Accessed 250403).

Vattenfall. (No date). *Hur fungerar tillståndsprocessen för en vindkraftspark på land?*. https://group.vattenfall.com/se/var-verksamhet/vindprojekt/faq-vindkraft/hur-fungerar-tillstandsprocessen-for-en-vindkraftpark-pa-land. (Accessed 250306).

VGR, RISE. (2024). *Kärnkraft kunskapsunderlag – Teknik och förutsättningar för livstidsförlängning och nybyggnation*. Västra Götalandsregionen. https://mellanarkiv-offentlig.vgregion.se/alfresco/s/archive/stream/public/v1/source/available/sofia/rs7897-268913469-822/native/K%C3%A4rnkraft%20kunskapsunderlag.pdf. (Accessed 250306).

Wind-turbine-models. (2022). *Vestas V117-3.45*. https://en.wind-turbine-models.com/turbines/1248-vestas-v117-3.45. (Accessed 250414).

Zhou, Y., Wu, W.X., Liu, G.X. (2011). Assessment of Onshore Wind Energy Resource and Wind-Generated Electricity Potential in Jiangsu, China. *Energy Procedia*, Volume 5, Pages 418–422. https://doi.org/10.1016/j.egypro.2011.03.072. (Accessed 250413).

9.1 Oral sources

Petrov, M. (2023). Wind Energy Analysis – Turbine rotor performance, wind resource estimation and annual energy yield. Lecture at KTH university on 26 September 2023.

10 Appendix

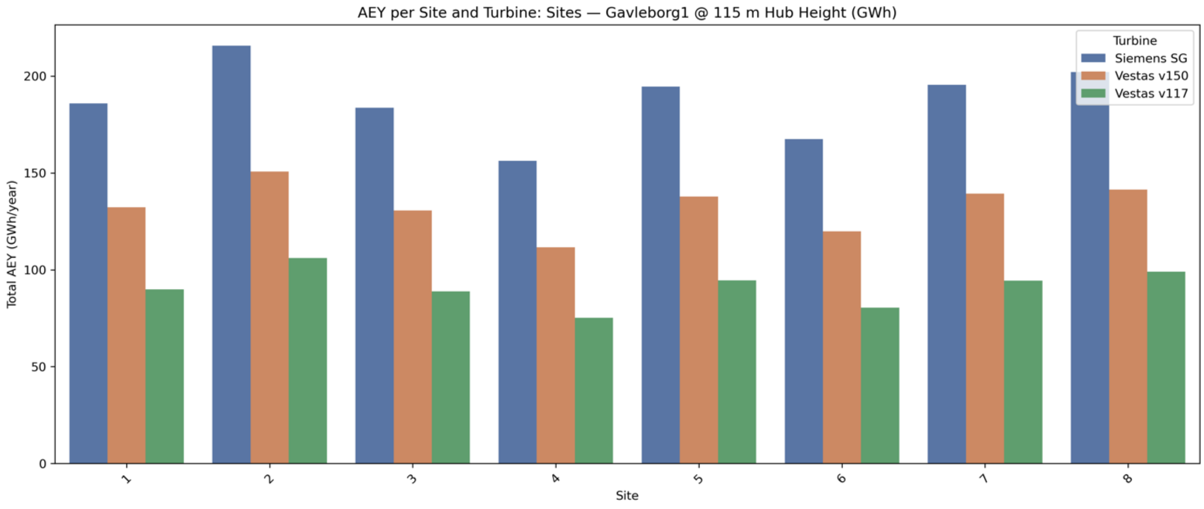
10.1 Kandy: Factors for input into GIS

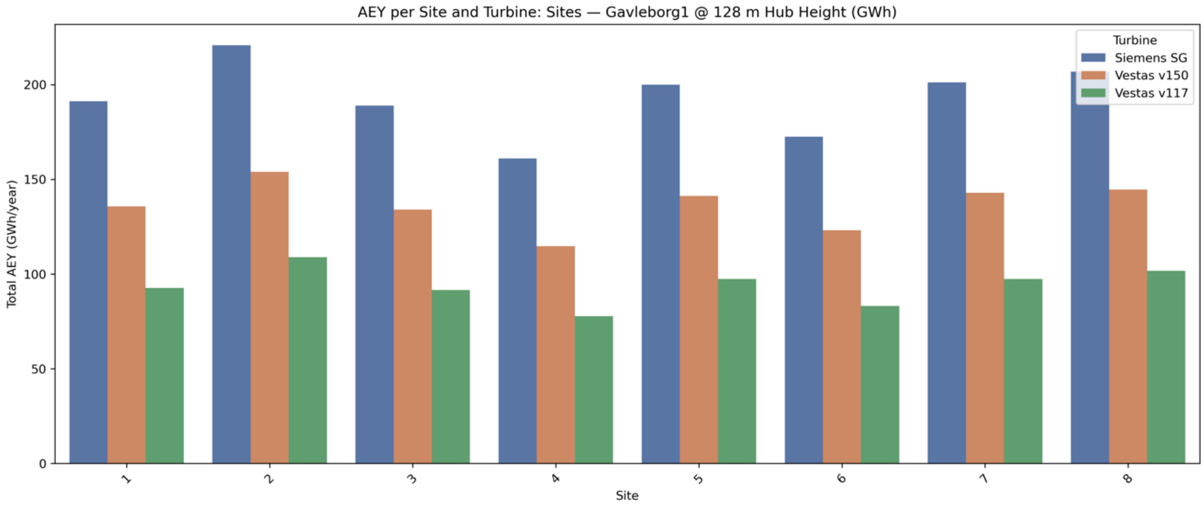
Övriga faktorer och deras behandling

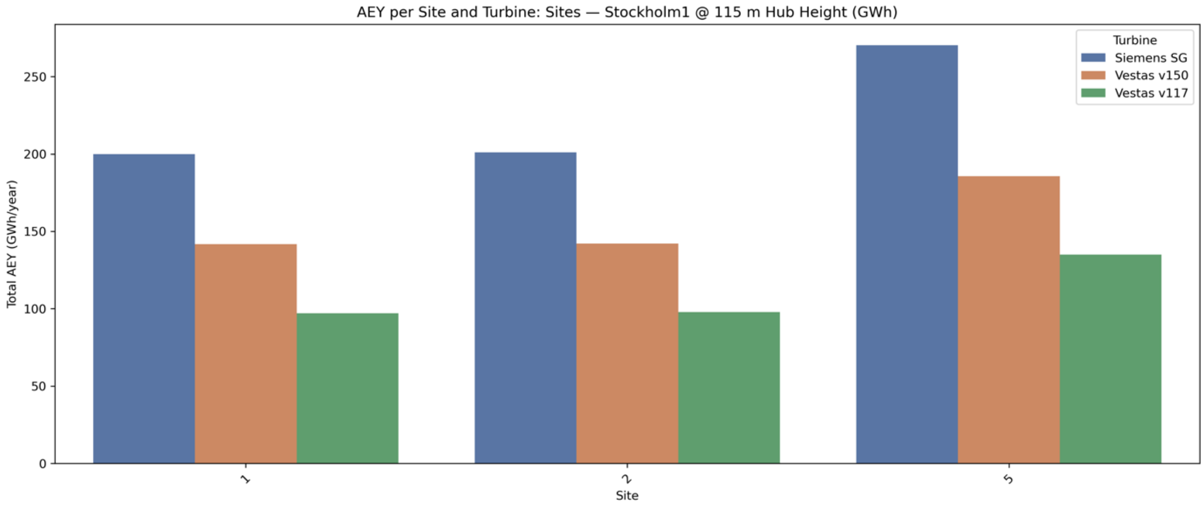
Sociala värden	Behandling av data	Kommentar
Boendemiljö: bostäder, samhällsfunktion: brandstation, kommunhus, skola, sjukhus, kriminalvårdanstalt	Inom 800 m = 0, därefter linjär ökning till 1 vid 1200 m och längre avstånd	
Friluftsliv		
Friluftsliv: Camping, golfbana, kolonilott	Mellan 0-500 meter: Linjärt ökande lämplighet Därefter 100 % lämplighet	
Friluftsliv: Vandringsled/Cykelväg Pilgrimsleder	Inom 50 m från led: 1% lämplighet Mellan 50-500m: Linjärt ökande lämplighet Därefter 100% lämplighet	
Friluftsliv: Riksintresse friluftsliv och Riksintresse rörligt friluftsliv	Inom området 1% lämplighet Utanför området: 100% lämplighet	
Riksintresse obruten kust	Inom området 0 % lämplighet Utanför området: 100% lämplighet	
Kulturmiljö		
Kulturmiljö: Kulturreservat och Världsarv	Inom området 0 % lämplighet Utanför området: 100% lämplighet	
Kulturmiljö: Riksintresse kulturmiljövård	Inom området 1% lämplighet Utanför området: 100% lämplighet	
Kulturmiljö: Fornlämningar	Inom 50 meter buffer: 50 % lämplighet Utanför buffer: 100 % lämplighet	
Kulturmiljö: Landskapsbildskydd	Inom området 0 % lämplighet Utanför området: 100% lämplighet	
Naturvärden		
Skogliga naturvärden		
Skogliga naturvärden: Nyckelbiotoper storskogsbruk, Nyckelbiotoper Skogsstyrelsen, Naturvärden,	Innanför området: 1 % lämplighet • Utanför området: 100 % lämplighet	

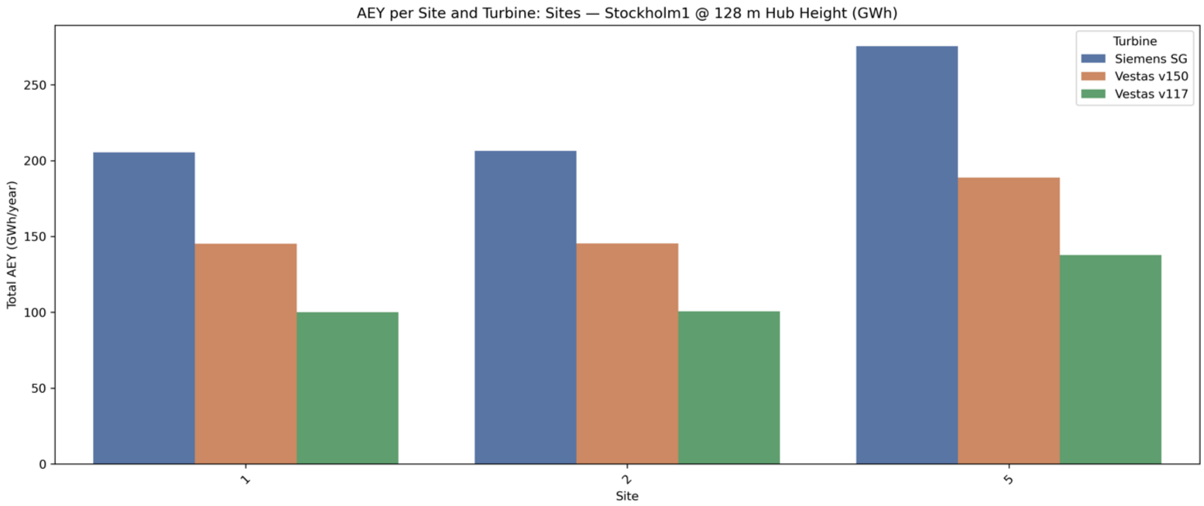
Skogliga naturvärden: Naturvårdsavtal, Biotopskyddsområden	• Innanför området: 0 % lämplighet • Utanför området: 100 % lämplighet	
Våtmarker		
Våtmarker: Ramsarområden, Våtmarksinventeringen – höga naturvärden	• Inom området: 0 % lämplighet • Utanför området: 100 % lämplighet	
Våtmarker: Återvatningsyta, Sumpskogar, Myrskyddplan	Inom området: 1 % lämplighet • Utanför området: 100 % lämplighet	
Övrig naturvård		
Övrig naturvård: Djur och växtskyddsområde, Natura 2000, fågeldirektivet, Natura 2000 art- och habitatdirektivet, Nationalpark, Naturreservat, Naturvårdsområde, Naturminne, Naturvårdsavtal	Inom området: 0 % lämplighet • Utanför området: 100 % lämplighet	
Övrig naturvård: strandskydd och utökat strandskydd		Data var inte tillgängligt vid kontakt för någon månad sedan
Övrig naturvård: Riksintresse naturvård	Inom området: 1 % lämplighet • Utanför området: 100 % lämplighet	
Övrig naturvård: Livsmiljöer grön infrastruktur (främst naturgräsmarker)	• Inom området: 1 % lämplighet • Utanför området: 100 % lämplighet	
Övriga anläggningar och anspråk		
Försvaret: MSA-områden (minimum safety altitude), Område med särskilt behov av hinderfrihet, Påverkansområde för buller eller annan risk, Påverkansområde väderradar, Påverkansområde övrigt	Inom området: 50 % lämplighet • Utanför området: 100 % lämplighet	
Försvaret: Stoppområde för vindkraft, Område av betydelse på land, Riksintresse i havet, Riksintresse på land, Stoppområde för höga objekt	• Inom området: 0 % lämplighet • Utanför området: 100 % lämplighet	
Infrastruktur: Byggnader som inte är bostäder, Riksintresse befintlig hamn, Riksintresse för flygplats	0 % inom området och 100 % lämplighet utanför objekt.	
Infrastrktur: Järnvägsnätet, Riksintresse järnväg	Inom 250 meters avstånd 0 % lämplighet.	
Övriga anläggningar: permanent jordbruksmark	• Inom området: 0 % lämplighet • Utanför området: 100 % lämplighet	Enligt Jordbruksverket så är åkermarksgraderingen från 1972 ej lämlig som underlag

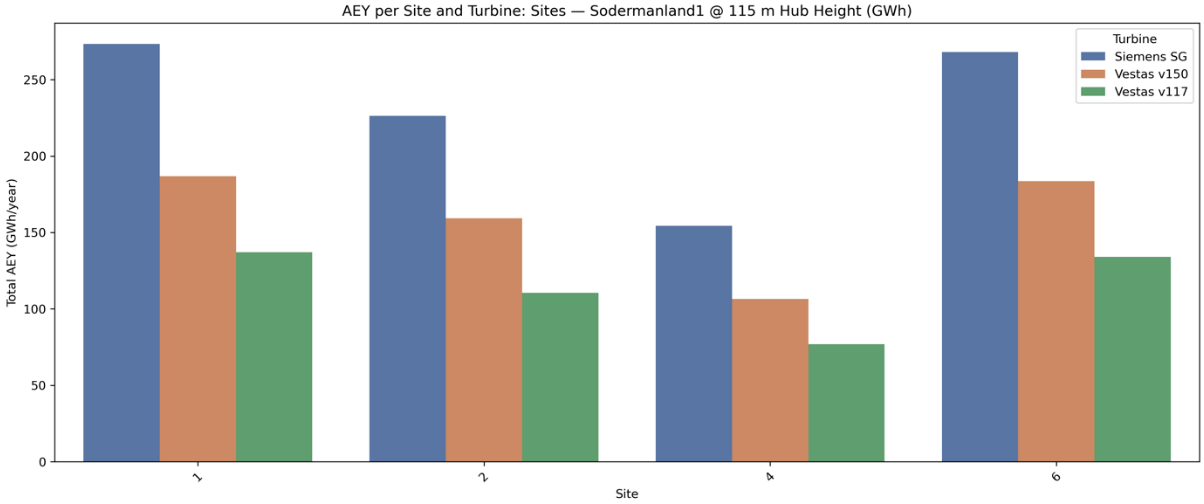
10.2 Plots AEY hub height 115 m and 128 m

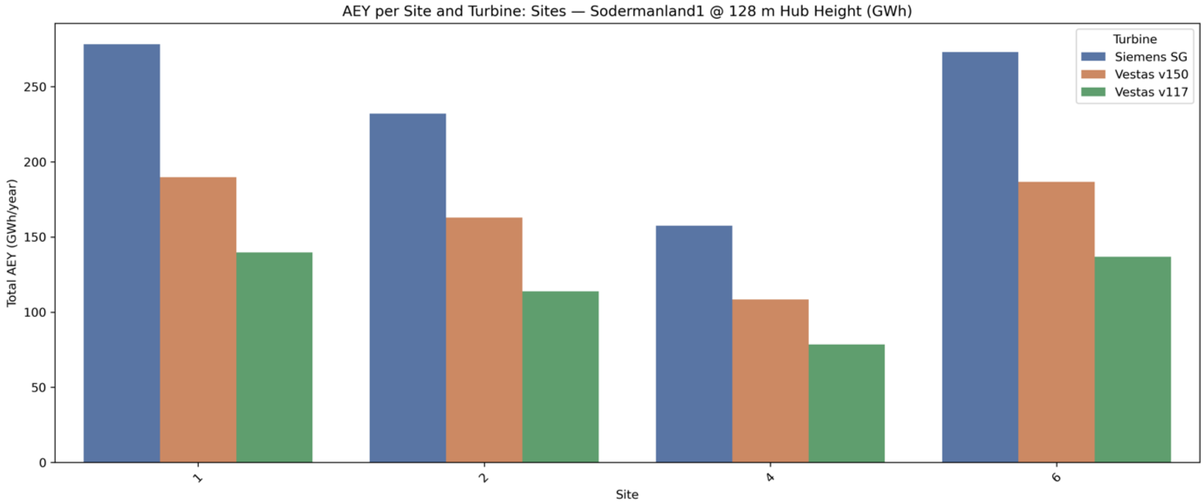







AEY per Site and Turbine: Sites — Stockholm1 @ 128 m Hub Height (GWh)
Total AEY (GWh/year)
0
50
100
150
200
250
Site
1
2
5
Turbine
Siemens SG
Vestas v150
Vestas v117


AEY per Site and Turbine: Sites — Sodermanland1 @ 115 m Hub Height (GWh)
Total AEY (GWh/year)
0
50
100
150
200
250
Site
1
2
4
6
Turbine
Siemens SG
Vestas v150
Vestas v117


AEY per Site and Turbine: Sites — Sodermanland1 @ 128 m Hub Height (GWh)
Total AEY (GWh/year)
0
50
100
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Site
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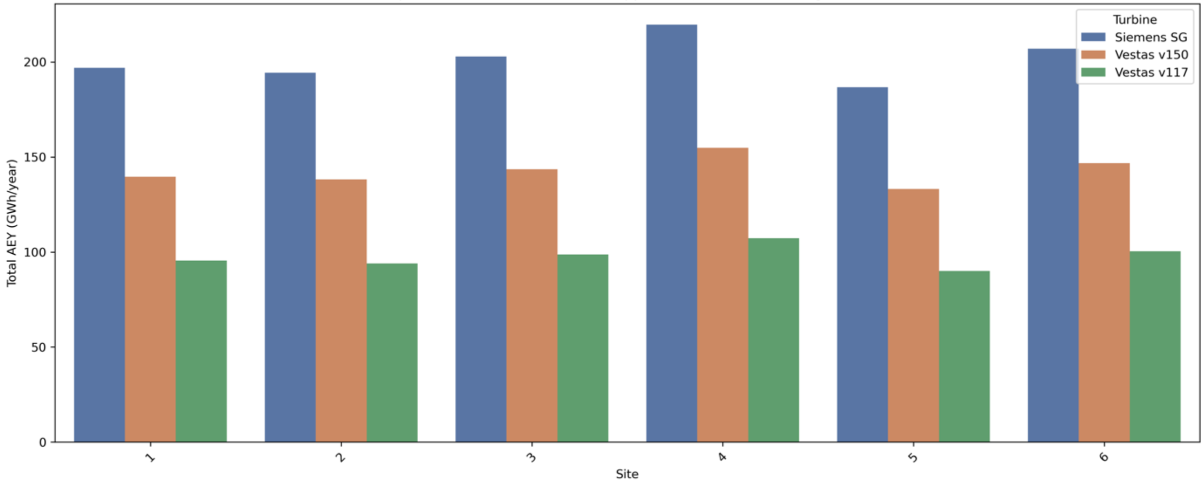
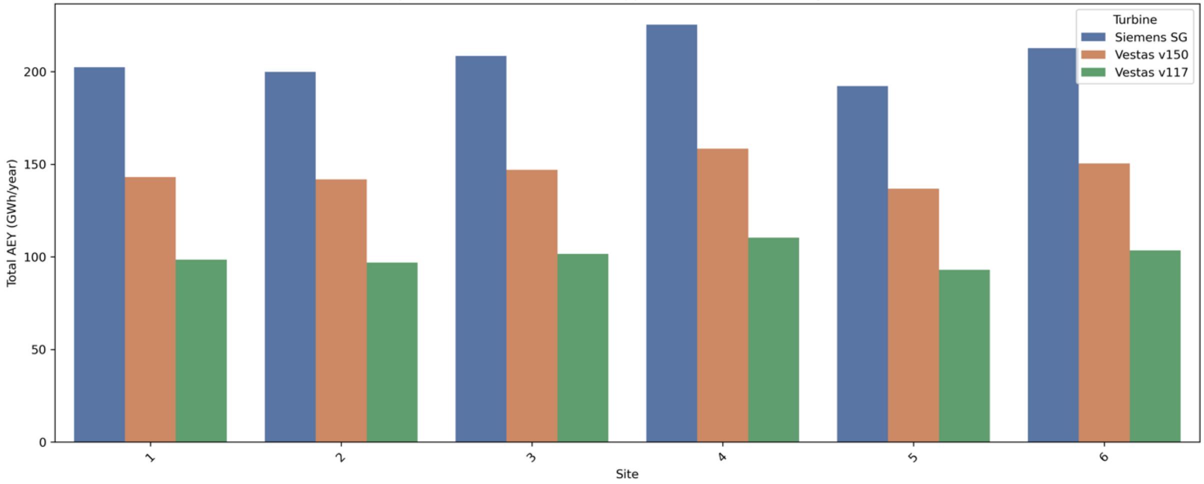
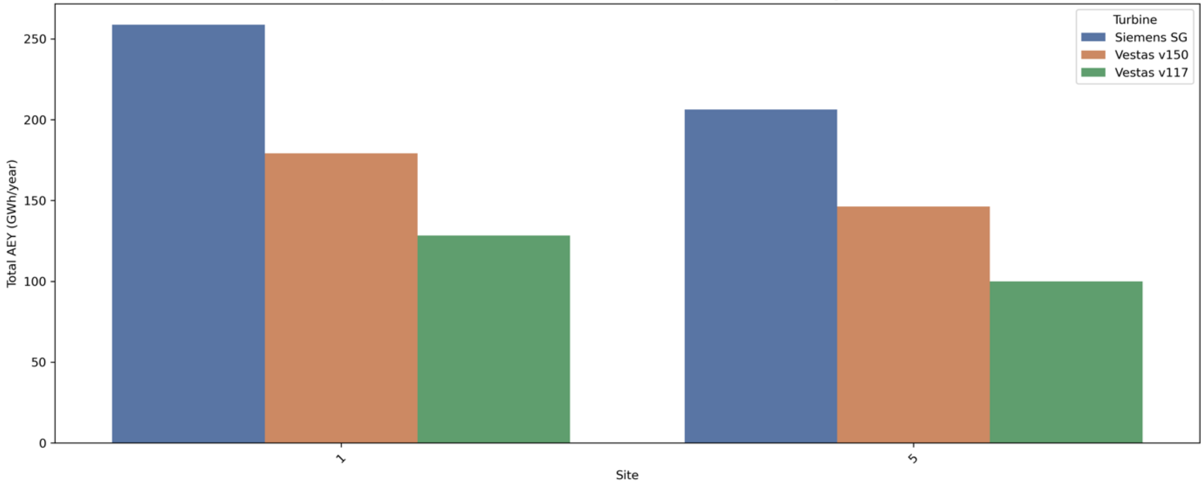
6
Turbine
Siemens SG
Vestas v150
Vestas v117



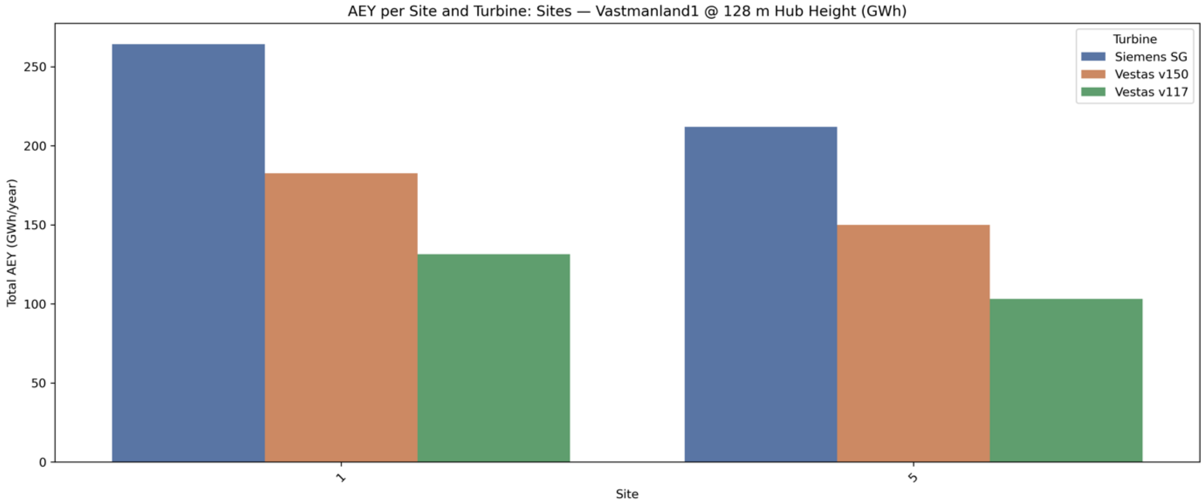
AEY per Site and Turbine: Sites — Uppsala1 @ 115 m Hub Height (GWh)

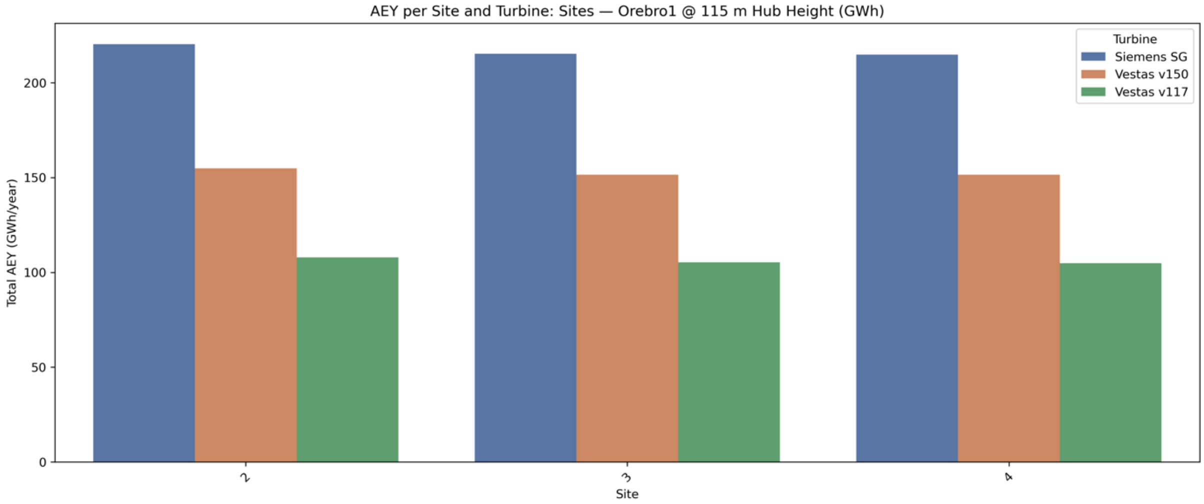


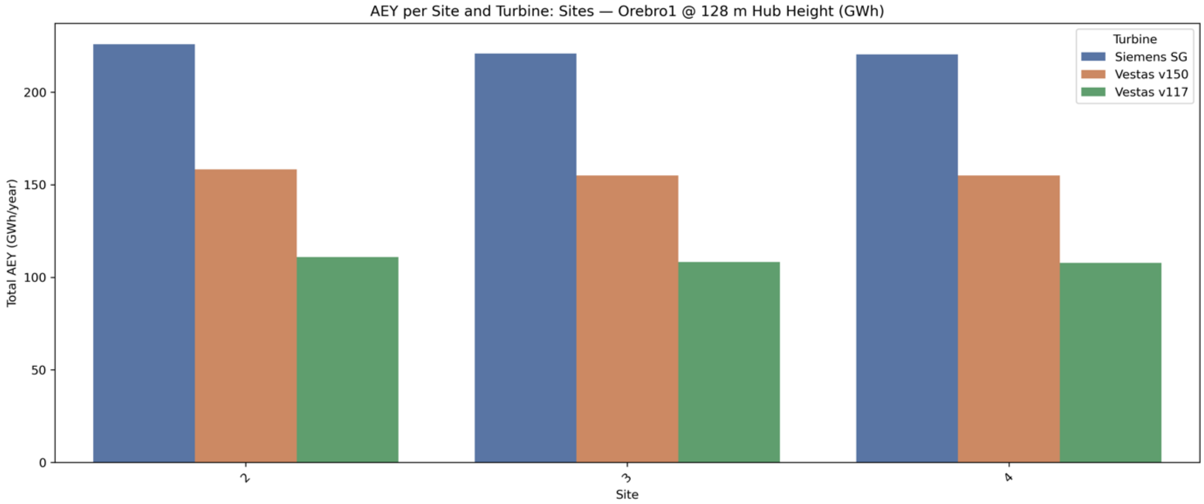
AEY per Site and Turbine: Sites — Uppsala1 @ 128 m Hub Height (GWh)

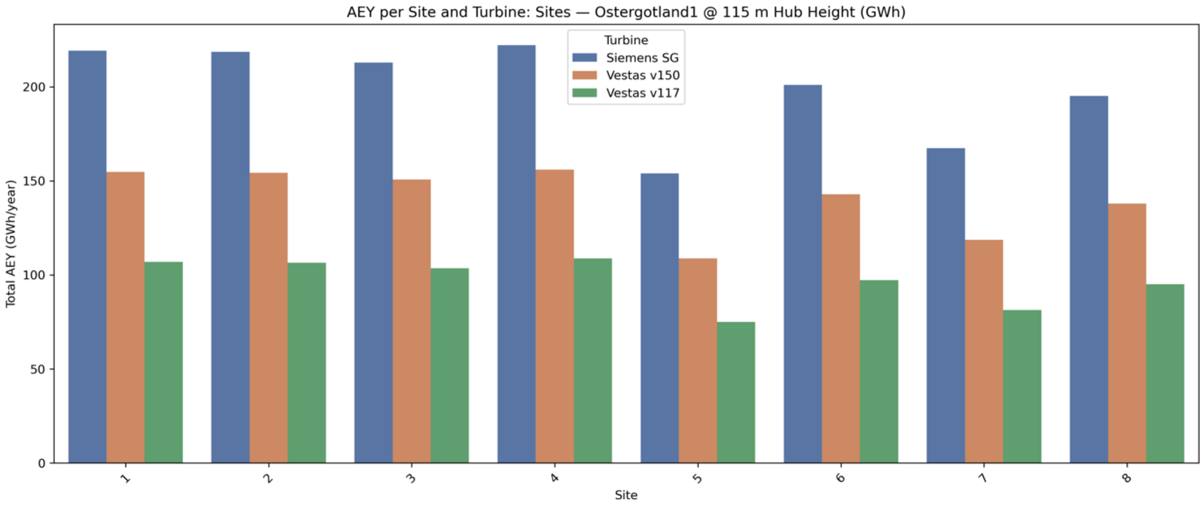


AEY per Site and Turbine: Sites — Vastmanland1 @ 115 m Hub Height (GWh)


AEY per Site and Turbine: Sites — Vastmanland1 @ 128 m Hub Height (GWh)


AEY per Site and Turbine: Sites — Orebro1 @ 115 m Hub Height (GWh)


AEY per Site and Turbine: Sites — Orebro1 @ 128 m Hub Height (GWh)


AEY per Site and Turbine: Sites — Ostergotland1 @ 115 m Hub Height (GWh)
Turbine
Siemens SG
Vestas v150
Vestas v117
Total AEY (GWh/year)
0
50
100
150
200
1
2
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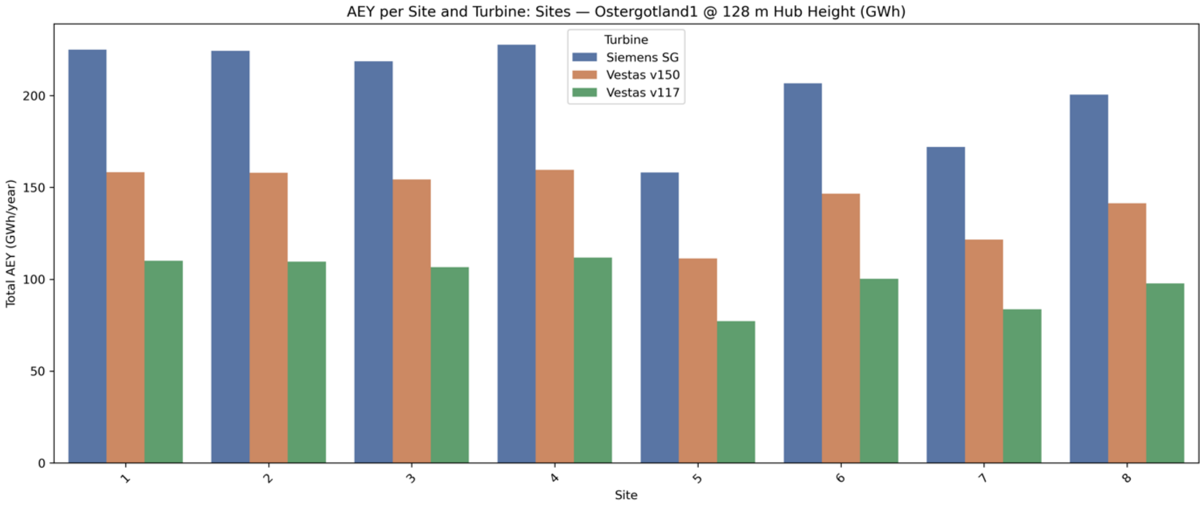
Site


AEY per Site and Turbine: Sites — Ostergotland1 @ 128 m Hub Height (GWh)
Turbine
Siemens SG
Vestas v150
Vestas v117
Total AEY (GWh/year)
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Site