Different Optimisation Perspectives in the Åland Energy Market due to the Increase of Renewable Energies

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Elektrische Energieversorgung unter Einsatz Erneuerbarer Energien

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Personal Declaration

I hereby affirm that I wrote the present thesis independently and did not use any external help and sources except for the ones marked and listed. This academic work has not been handed in to another examination board before and has not been published yet in the same or a similar form. The printed and the digital copies of this thesis are identical in content.

Darmstadt/Germany, 1. November 2016

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Place and date Julia Marie Leichthammer

List of Abbreviations

ABB	Asea Brown Boveri
AC	Alternating current
ACER	Agency for the Cooperation of Energy Regulators
ÅEA	Åland Elandelslag
ÅSUB	Ålands statistik- och utredningsbyrå, Statistics and Research Åland
ÅTEC	Åland Technology and Energy Centre
CACM	Capacity Allocation and Congestion Management
CEER	Council of European Energy Regulators
CET	Central European time
CHP	Combined heat power
DC	Direct current
DG	Distribution grid
DK	Denmark
DNV GL	Det Norske Veritas Germanischer Lloyd
DSO	Distribution system operator
DTU	Danmarks Tekniske Universitet
EE	Estonia
EEX	European Energy Exchange
ehpa	European Heat Pump Association
EMG	Electricity Market Group
ENTSO-E	European Network of Transmission System Operators for Electricity
EU	European Union
EWEA	European Wind Energy Association
FI	Finland
G	Giga, 10^9
GO	Guarantee of Origin
h	Hour
HVDC	High voltage direct current
KNÅ	Kraftnät Åland
LT	Lithuania
LV	Latvia

M	Mega, 10^6
M€	Million euros
m^3	cubic metres
min	Minute
NBS	Nordic balance settlement
NO	Norway
P2G	Power to gas
PV	Photovoltaics
R&D	Research and development
s	Second
SE	Sweden
SR	Settlement responsible
T	Terra, 10^{12}
t	tonne
TG	Transmission grid
TSO	Transmission system operator
UCD	University College Dublin
VAT	Value added tax
VPP	Virtual power plant
VTT	Valtion taloudellinen tutkimuskeskus, engl.: Institute for Technical Research Finland
W	Watt
Wh	Watt hour

1 Abstract

Today's energy markets undergo radical changes due to intentions to reduce CO_2-emissions. Analysing these changes requires a multi-level perspective. Ever since leading scientific experts from all over the globe have agreed upon the existence of the climate change, public awareness has risen and a willingness has developed to change people's attitude towards energy consumption and sustainability so that industries explore new business models as well as innovative products while politicians are forced to face new terrain and pave the way for future generations. The Åland community intends to develop an environmentally sustainable, self-sufficient smart grid increasing the renewable power installed up to 100% in order to strengthen the local energy industry, to benefit the local inhabitants and to participate in the global efforts to hinder the climate change.

This thesis offers different optimisation perspectives in the Åland energy market due to the increase of renewable energies regarding the aim to develop a local smart grid. The first optimisation perspective is the universal concern about global market changes being enforced by international laws, regulations and treaties regarding energy sufficiency and environmental sustainability in relation to climate change. The second perspective is the need to develop a clear understanding about the actual dimensions of the Åland network, about technical modernisation requirements to establish a smart grid as well as about market drivers that create new financing opportunities to realise a smart grid in Åland. The third perspective is the interest of all involved parties to minimise the costs of the transition towards a green smart grid.

Supported by the EU, there is a general trend to increase the use of renewable energies. Hence, centrally-located power supply systems are no longer reasonable since many small to medium sized renewable power plants decentralise generation gradually. So called prosumers, small energy consumers who produce their own electricity and even sell it, bring low voltage grids to their load limits so that grid operators need to enhance their grid to guarantee stable, reliable power supply. Furthermore, high infeed shares from renewable energies cause fluctuations which need to be balanced in order to keep voltage and frequency controlled, the system stable and, thus, the supply secure. Consequently, conventional power plants like diesel, coal or gas are used to cover temporary lacks of renewable electricity production and keep reserve power prepared without selling any electricity. It requires an immense amount of energy storage to develop a truly self-sufficient system with only renewable energy infeed. Storages, however, do not always work cost-efficiently enough in order that reasonable entrepreneurs would invest in such a system.

In a smaller grid like in Åland, where there is a comparatively low energy demand, smart solutions with 100% renewable infeed combined with several efficiency measures are technically possible as long as the necessary back-up power is provided internally and externally by the submarine cables connecting the island group to both Finland and Sweden. Since Åland demonstrates good qualifications to become a European smart grid flagship, the island group meets the challenge to become a green smart grid. Favourably, Åland enjoys extensive self-government while being part of the Finnish nation. Moreover, both the strategical position between two big electricity markets and the small size of the islands enable many opportunities for Åland to become a show case and remarkable trading platform.

This thesis will analyse the given situation in Åland identifying future chances and challenges in order to present perspectives how to optimise the local energy market.

In the second chapter the market environment will be analysed to enable an assessment of the Åland energy market. The term smart grid will be defined and the previous work of the Åland Smart Energy Platform will be presented. Also, all of the involved parties will be introduced.

In the third chapter an extensive technical analysis of the Åland energy market follows identifying the current situation in the electricity generation, transmission and distribution, presenting the current seasonal load curves and showing the currently used smart meters.

In the fourth chapter the economic analysis follows identifying networks and authorities that influence the market climate and defining the legal surrounding. The spot exchange Nord Pool will be presented investigating the relation between infeed shares and price developments. Different tariff models for end-customers are also introduced. Moreover, the topic of data collecting will be discussed.

Since the current technical and economic situation in the Åland energy market is known at that point, in the fifth chapter grid modernisation requirements will be identified and presented focussing on certain smart grid fields, such as smart homes, power reserve, energy storage, virtual power plants and others.

In the sixth chapter there will follow proposals for a new market model in Åland discussing different perspectives that come up along the previous chapters.

Finally, in the seventh chapter all results, future possibilities and modernisation requirements will be brought together in a comprehensive picture presenting an outlook what goals Åland can realistically reach and what needs to be considered in order to reach these goals.

2 Introduction

This chapter shall give an oversight over both the topic smart grid as such and the Åland energy market today. First the current situation in the local energy market is presented by identifying important facts and relevant data. Then a definition of the term smart grid is given to illustrate the required multi-level perspective. Afterwards, an insight is shared into the efforts taken by Åland on the way to a future smart grid so far to explain what characteristics make Åland so well-suited for establishing a smart grid project. Conclusively, the most important parties involved will be introduced pointing out their roles and influences.

2.1 Facts and Data about the Market in Åland with a Focus on the Energy Sector

Åland is an autonomous, demilitarised and Swedish speaking territory in the north of the Baltic Sea consisting auf 16 municipalities as can be seen in figure 2.1. In spite of the fact that Åland belongs to the Finnish nation the island group nevertheless enjoys several privileges. Since 1922 Åland has had its own democratically elected legislative assembly (lagtinget) nominating the Åland government as the executive power (landskapsregering). The fields of health, medical care, education, culture as well as police, traffic and infrastructure are all home-ruled.[1] The local energy market is also self-governed by the local government while, of course, international laws, regulations and rules must be observed as Åland is on the one hand regarding the electricity grid physically connected to the Nordic energy market and on the other hand like Finland an EU member since 1995.[2]

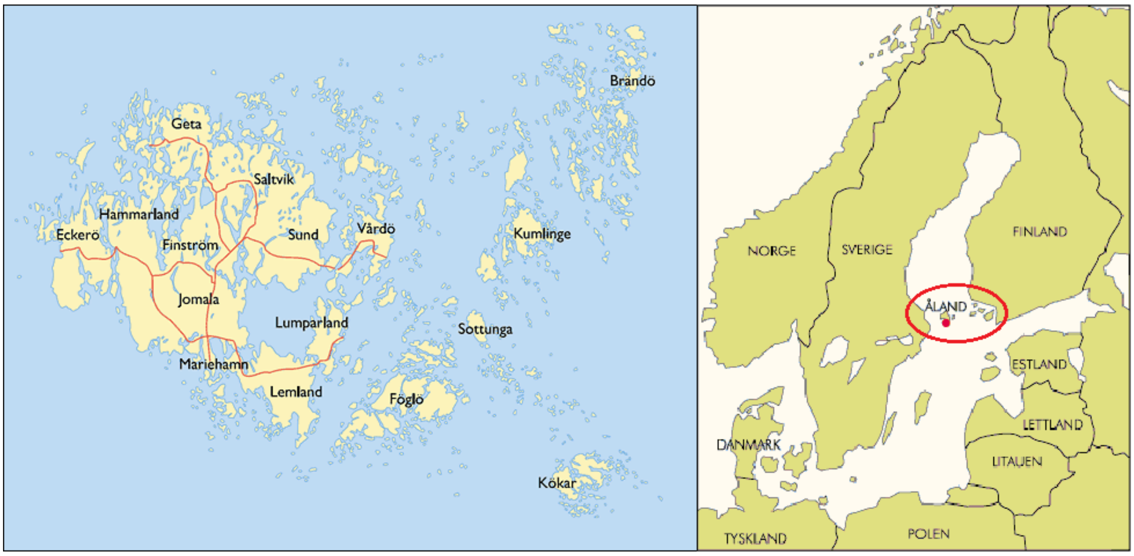

Figure 2.1: Åland by Municipalities and its Location in the Baltic Sea.[3]

[1] ÅSUB (2016): Åland in Figures 2016: About Åland, p.29.
[2] Mansén (2016): Expert interview with Robert Mansén, head of ÅTEC, on 09.06.2016.
[3] cf. Visit Åland (2016): Maps of Åland.

Because Åland is not part of the EU tax union, it has the right to sell tax-free on board of Ålands ships and ferries which creates a huge economy sector for the small society of only 28.983.[4,5] This is also mirrored in the local gross domestic product (GDP). It has to be acknowledged that there are no newer data published by the government and its statistic and research agency (ÅSUB) than from 2013 and further that there are no exact numbers known concerning the size of the energy sector. Figure 2.2 demonstrates that over three quarters of the Åland market value are created by industries, government, shipping and finance. Today trade and technical fields only cause a small impact of merely 10%.

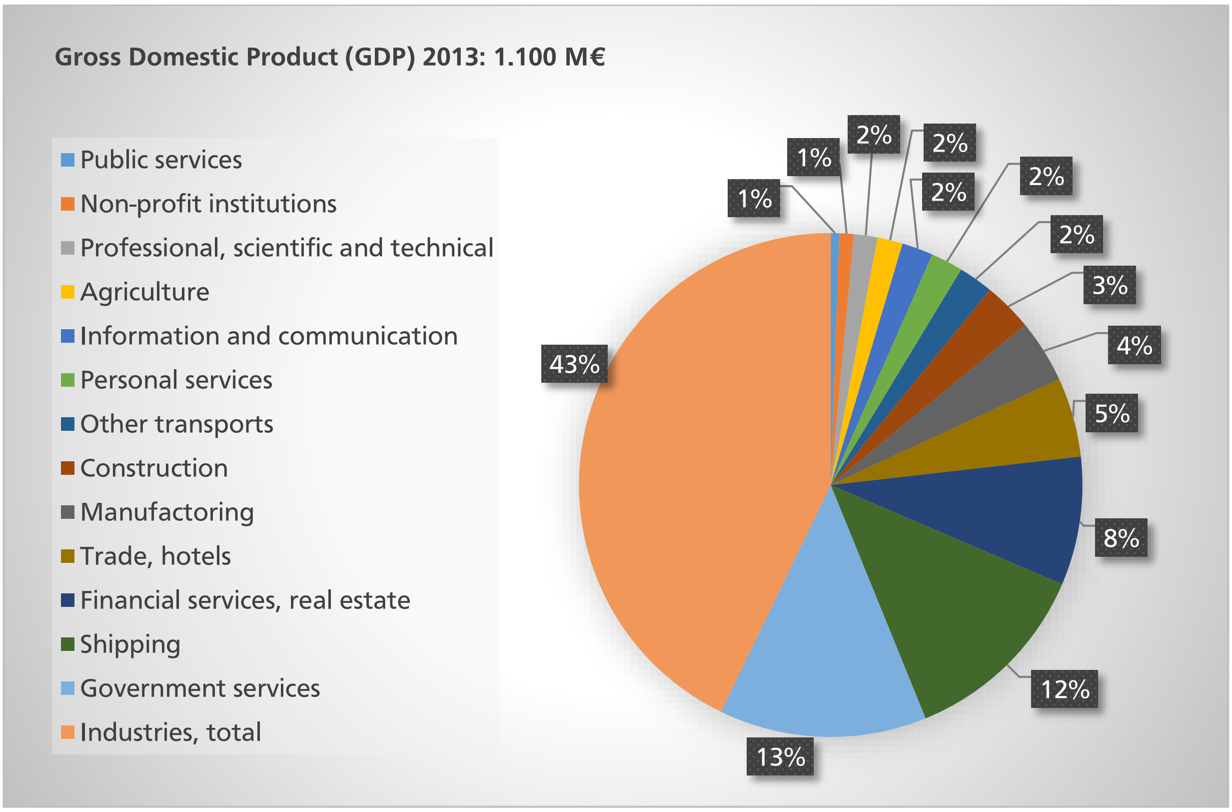

Figure 2.2: GDP of Åland 2013 by Sector.[6]

There are different ways to calculate the GDP. In order to receive an impression of the share of the energy sector in the GDP the income approach is chosen. This approach adds indirect business taxes, depreciation and net foreign factor to the national income[7]. Transferred to this situation, the turnovers 2015 of the big local energy companies must be summed up and set in relation to the GDP 2015 forecasted by ÅSUB. Actually the preliminary work has to be subtracted from the revenue in order to avoid double counting of the sales of another company but the exact data is not available, e.g. the bought oil for district heating or the imported electricity for local supply. So when looking at the shares it must be taken into account that the actual share is even a bit smaller than presented.

[4] Kinnunen; Lindström (2010): A Study of Cluster Impacts and the Future of the Shipping Industry in Åland Islands.
[5] ÅSUB (2016): Åland in Figures 2016: Population 31.12, p.3.
[6] cf. ÅSUB (2016): Åland in Figures 2016: Gross Domestic product 2013, p.19.
[7] cf. Thangavelu (2015): How To Calculate The GDP Of A Country.

Table 2.1 shows some financial figures of the energy market players in Åland to better assess the sector size. The production group Allwinds was 2015 in the red continuing the trend of the last years. The losses are caused by high maintenance costs, low electricity prices at the Nordic electricity spot market Nord Pool and decreasing governmental subsidies for wind power. Allwinds invested in wind measurements and the expensive project planning of a new huge wind park which cannot be built now because of withdrawn funding by the Finnish government.[8] DSO Ålands Elandelslag (ÅEA), however, could draw profits which shall partly be used as profit carry-forward for future investments and future dividends.[9] DSO Mariehamns Elnät made profits, too. Its board suggests to distribute 184.000 € dividends (18,40 €/share) and to use the rest for carry-forward.[10] City-owned Mariehamns Energi follows its zero-profit-strategy and, moreover, rebought own shares from minority owners.[11] TSO Kraftnät Åland (KNÅ), owned by the government, also follows a zero-profit-strategy and furthermore uses actual profits about 826.260,16 for depreciations for the new HVDC connection completed in 2015.[12]

Table 2.1: Financial Figures of the Big Energy Companies in Åland 2015.[13,14,15,16,17,18,19,20]

2015	relative to GDP / %	Turnover / €	EBIT / €	Annual Net Profit / €	Total Assets / €	Employees
Åland	100	1.125.000.000,00[21]				
Allwinds	0,38	4.327.971,81	-516.941,44	-454.300,10	14.377.911,23	6
Ålands Elandelslag	1,69	19.054.724,89	2.095.357,24	634.552,57	38.910.877,19	46
Mariehamns Elnät	0,83	9.365.875,98	1.152.617,54	190.104,59	12.850.269,30	16,5
Mariehamns Energi	1,02	11.473.369,00	613.376,00	0,00	17.061.555,00	20,4
Kraftnät Åland	0,82	9.217.334,54	2.199.412,86	0,00	108.762.123,88	15
Σ	4,75	53.439.276,22	5.543.822,20	370.357,06	191.962.736,60	103,9

Figure 2.3 shows the share of the turnovers of the big energy players both in relation to the predicted GDP 2015 and to each other. Obviously the impacts among these companies are quite similar while the total impact on the GDP is only slight.

[8] Allwinds (2016): Annual Report 2015.
[9] Ålands Elandelslag (2016): Annual Report 2015.
[10] Mariehamns Elnät (2016): Annual Report 2015.
[11] Mariehamns Energi (2016): Annual Report 2015.
[12] Kraftnät Åland (2016): Annual Report 2015.
[13] cf. Ålands Elandelslag (2016): Annual Report 2015.
[14] cf. Allwinds (2016): Annual Report 2015.
[15] cf. Åland s Vindenergi (2016): Annual Report 2015.
[16] cf. Åland s Vindkraft (2016): Annual Report 2015.
[17] cf. Mariehamns Elnät (2016): Annual Report 2015.
[18] cf. Mariehamns Energi (2016): Annual Report 2015.
[19] cf. Kraftnät Åland (2016): Annual Report 2015.
[20] cf. LeoVind (2016): Annual Report 2015.
[21] ÅSUB (2016): Konjunkturläget våren 2016. Rapport 2016:2, p. 23.

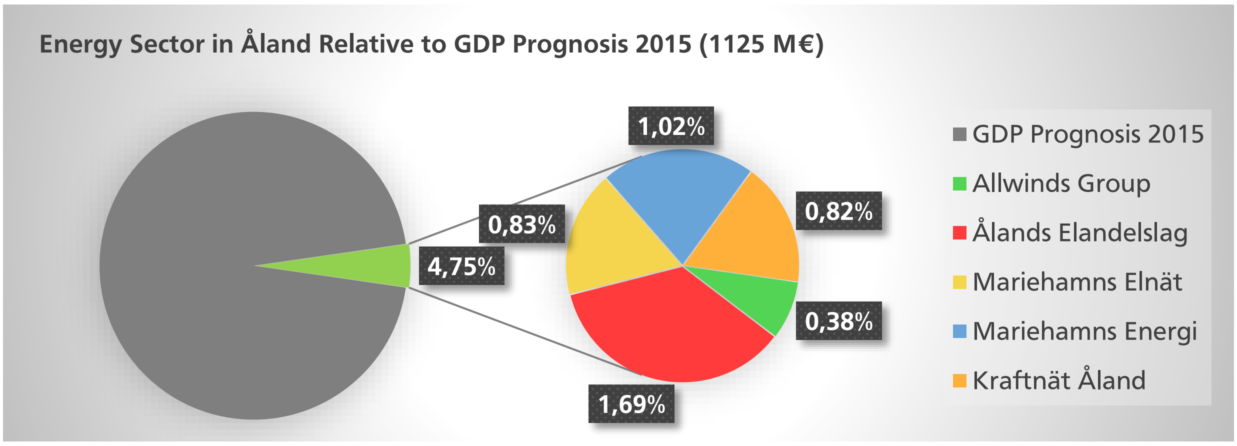

Figure 2.3: Shares of the Big Energy Companies in the Åland GDP 2015.[22,23,24,25,26,27,28,29,30]

Figure 2.4 shows a schematic representation of the load flow in the Åland electricity grid today.

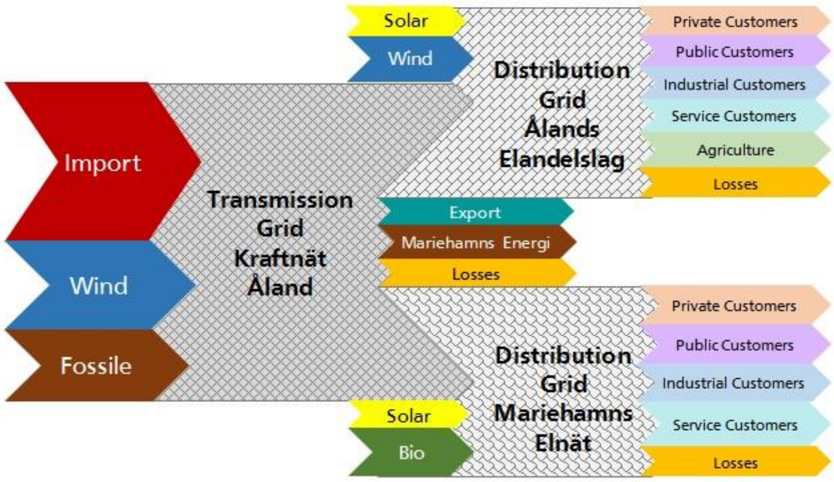

Figure 2.4: Schematic Representation of the Load Flow in Åland.[31,32,33]

The main part of electricity demand comes via the transmission grid from imports as well as local wind and fossil power plants. Mariehamns Energi, the local district heat operator and electricity producer, simultaneously consumes electrical energy. Beside very few exports and some losses, the rest of the load flows towards the distribution grid. It becomes obvious that decentralised generation by renewables causes additional infeed in the MV (wind and bio power)[34,35] and LV (solar power) [36,37] grid of the

[22] cf. ÅSUB (2016): Konjunkturläget våren 2016. Rapport 2016:2, p. 23.
[23] cf. Ålands Elandelslag (2016): Annual Report 2015.
[24] cf. Allwinds (2016): Annual Report 2015.
[25] cf. Åland s Vindenergi (2016): Annual Report 2015.
[26] cf. Åland s Vindkraft (2016): Annual Report 2015.
[27] cf. Mariehamns Elnät (2016): Annual Report 2015.
[28] cf. Mariehamns Energi (2016): Annual Report 2015.
[29] cf. Kraftnät Åland (2016): Annual Report 2015.
[30] cf. LeoVind (2016): Annual Report 2015.
[31] cf. Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[32] cf. Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[33] cf. Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag
[34] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[35] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[36] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[37] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.

DSOs.By decreasing today's immense import and by increasing solar power systems with micro-producers, expanding bio power plants and installing more wind turbines, the growing share of infeed sources into the MV and LV grid will challenge both the supply safety and the system stability itself. Hence, smart technology is needed to meet the future challenges of becoming a 100% renewable, self-sufficient society after net export.[38]

2.2 Definition of the Term Smart Grid

There is not one official definition standardised. Hence, this chapter will present some approaches to give an idea of what the term smart grid includes.

The energy product supplier ABB defines a smart grid as an intelligent, modern power transmission and distribution system that provides stable, secure, efficient and environmentally sustainable electricity supply crossing national and international borders. It is an observable, controllable automation and information infrastructure based on industry-wide standards integrating the whole supply chain from production to consumption and being able to detect and react automatically to disturbances and changes in the system, re-establishing balance and maintaining the stability. A sustainable smart grid integrates renewable, low carbon energy sources into the network as well as new technologies in order to enable the use of energy storage devices and the large scale use of electric vehicles (EVs). Moreover, it increases reliability and quality of power supply by accepting any power quality from any source delivering it bidirectionally to any consumer. It increases energy efficiency and meets the rising energy demand helping balance electrical consumption with supply. Hence, peak demand as well as emissions and pollutions are reduced by utilising the dynamic integration of consumption units to balance the load. With this comprehensive control energy costs, electrical losses, capital expenditures and maintenance costs can be minimised.[39,40]

The Smart Grid Architecture Model of the CEN-CENELEC-ETSI Smart Grid Coordination Group clarifies the requirement of a multi-level perspective illustrated in figure 2.5. There is, of course, the business level within a smart grid that builds the political and legal regulatory frame. A significant role plays ENTSO-E described in chapter 4. Then there is a function layer setting the agreed upon usage of a smart grid. Furthermore, there is an information level structuring data models. Additionally, there is also a

[38] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.
[39] ABB (2016): ABB's view of Smart Grids. How does ABB define a Smart Grid?
[40] ABB (2016): ABB glossary of technical terms. smart grids.

communication plane both to plan future correspondence between smart technologies and market participants and to follow up on it to let the system learn. The last level is the component level planning in detail the fielding of different smart products for each domain like generation, transmission and distribution, decentralised micro-production and smart homes. Beside the process of load flow, also further zones have to be considered as hierarchical levels when designing a smart grid: field, station, operation, enterprise and market. All these planes interoperate with each other.[41] Hence, the realisation of a smart grid is generally a very complex tasks that demands lots of analysis in many different areas and a very efficient cooperation between all levels.

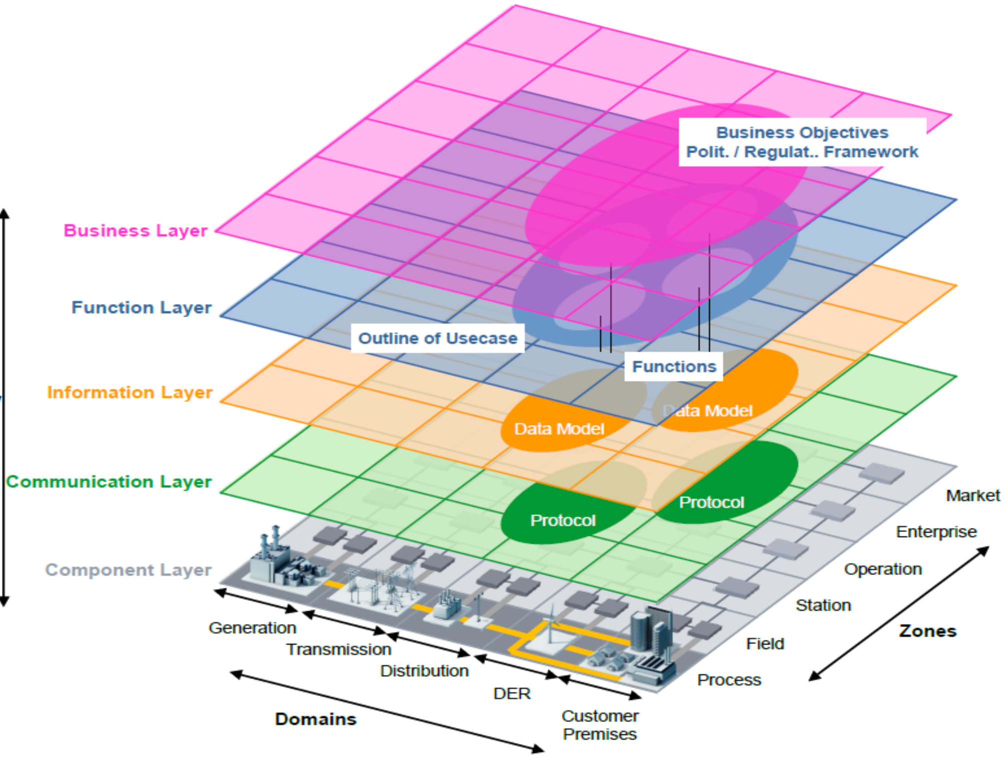

Figure 2.5: Smart Grid Architecture Model.[42]

For Åland this is a huge challenge since the market is so small and the rather conventional energy companies possess only a little know-how in modern smart technologies as well as in participating in international markets.

According to the Norwegian-German classification society DNV GL there are ten important technology trends for the future in the energy sector following below[43]:

1. increasing electrification (EVs),
2. new materials (semiconductor technology),
3. digitalisation (collecting and maintaining of consumption data),

[41] CEN-CENELEC-ETSI Smart Grid Coordination Group (2012): Smart Grid Reference Architecture.
[42] European Union Agency for Network and Information Security (2014): Smart grid security certification in Europe: Challenges and recommendations, p.26.
[43] van Eldik-Schoon (2016): Technology Outlook 2025: the 10 technology trends creating a new power reality. DNV GL.

4. bigger wind turbines (lighter materials lead to bigger diameters and therefore higher power),
5. cheaper solar systems (in many regions worldwide the most favourable),
6. optimised energy storages (for bulk power, system support, small batteries for smart houses),
7. bidirectional demand response management (smart house, dynamic price tariffs),
8. smart houses (smart meters, batteries, heat pumps, air-conditioning, e-vehicles),
9. data based smart grids (security as well as privacy matters) and
10. hybrid grids (AC and HVDC).

Basically the named future technology trends above are all somehow connected to the smart grid as defined before. Hence, by using more and more wind, solar and other renewable energies those technologies will improve and lower their prices due to economies of scale. But increasing the amount of volatile renewables significantly means consequently that there will be a need for solutions to stabilise voltage and frequency in order to guarantee electricity supply. Therefore storages will be utilised more and will be constantly developed further. Also electrical vehicles (EVs) can serve as balance power reserves and even help meet the international political ambitions to become greener and less CO_2 polluting. Due to increased micro-production in private households and in order to be even more flexible meeting both price shocks at the spot market and imbalance threats, it is a logical conclusion that bidirectional communication systems will be established connecting consumption and production units and coordinating load flow in the most efficient way. So digitalisation, data flow and data storage are essential topics, too.

This all raises ethical questions concerning how far privacy rights may be limited in such a transparent, omnipresent system or how far people want to give up control to adaptive computer systems and, moreover, who should own all the data and what the owner should be allowed to do with it exactly. While this thesis will not go into detail with ethical questions, these questions do, however, clarify the need of new laws dealing with these developments. Especially international legislation will be decisive since there will not be national borders in such an interconnected, always communicating future smart grid. Hence, a European solution is required. This again will not only affect technical, ethical and legal levels but also the market level in regard to more flexible price tariffs and changes in the spot market systems. This thesis tries to analyse the developments in chapter 4.4 using Åland as an example to give an outlook in future energy markets.

2.3 Considerations for a Smart Grid in Åland

After other European islands had started smart grid projects, such as Gotland in Sweden and Bornholm in Denmark[44], also Åland developed intentions to become a model area for future energy systems. Within

[44] VTT (2016): Åland Smart Energy Platform: Feasibility study results, p.8 et seqq..

the frame of the Åland Smart Energy Platform Finnish feasibility studies were done by Tampere University of Technology, by the technical research centre VTT and by Lappeenranta University of Technology which came to the conclusion that Åland has great possibilities to become an adequate test platform. The goal is to attract international companies to test their new leading technologies in a digitalised, sustainable power grid with a huge infeed of wind, bio and solar power. What makes Åland so special is not only the good local wind conditions and long sun hours during summer but most of all its size, location and submarine connection between Sweden and Finland which makes it possible to combine not only the testing of smart technologies but also the understanding of the consequences within an international market context.[45]

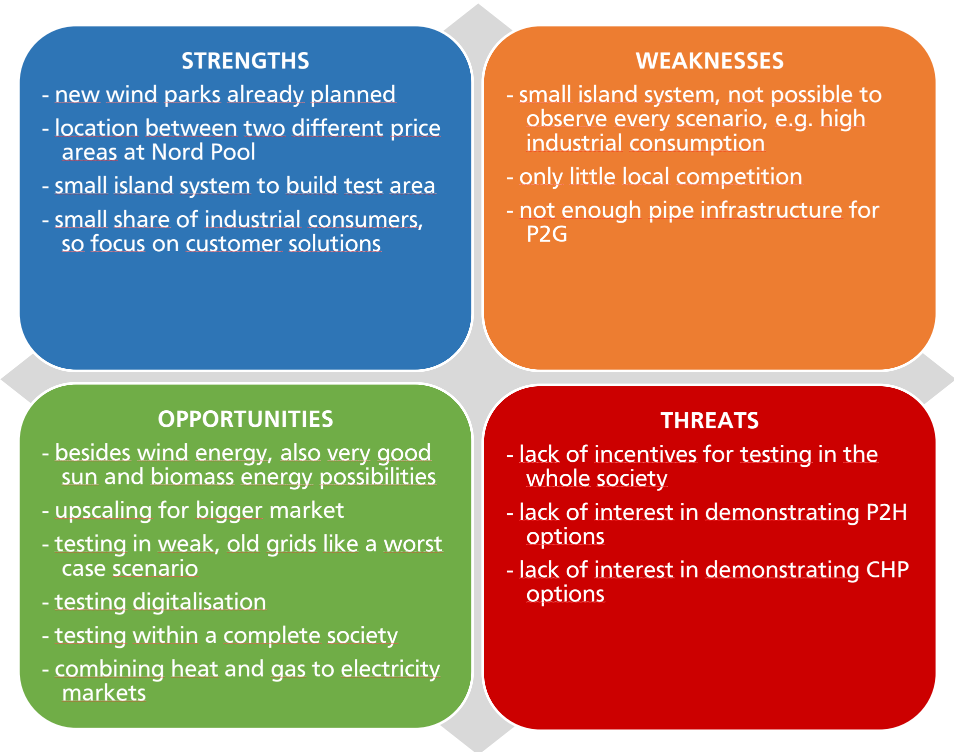

Figure 2.6: VTT SWOT Analysis.[46]

Part of these tools and communication platform are Ålands Technology and Energy Centre (ÅTEC), Ålands government, CLIC Innovation Ltd. (former Cluster for Energy and Environment (CLEEN) Oy) as well as big companies in the energy sector such as ABB Oy, Wärtsilä Finland Oy, Empower Oy and Fortum Oy. Moreover research institutions participate, such as Lappeenranta and Tampere University of Technology, the VTT and the local university Högskolan på Åland as well as the local energy companies Kraftnät Åland, Ålands Elandelslag, Mariehamns Elnät, Mariehamns Energi and Allwinds. There are intentions to build a smart grid with smart homes, a solar power park, electric transport, increasing the

[45] ÅTEC (2015): Press release: The world's most advanced flexible energy system of the future – Case Åland.
[46] cf. VTT (2016): Åland Smart Energy Platform: Feasibility study results, p.34.

share of biomass energy and energy efficiency in general due to modernisation measures. Figure 2.6 shows the results of the SWOT analysis done by VTT.[47]

While discussing many vague visions and catching key words real steps towards a smart grid have not been taken yet.

2.4 Directly and Indirectly Involved Parties of the Åland Smart Energy Platform

As it has already become obvious, there are many parties involved in the Åland energy market. This can be a benefit when every party provides their knowledge and strengths towards the common goal to create a smart grid in Åland. But it can also be of disadvantage when the competences are not clarified and powerful external forces suppress the local parties that might not possess the know-how nor the money but still know the local conditions best. In this chapter an introduction into the most important players in the Åland energy market shall follow to shape an image of the complexity.

2.4.1 Åland Government

After Sweden had lost Åland and Finland to Russia in 1809, Åland was part of the Finnish grand duchy. After Finland had gained independence in 1917, Åland attempted to be officially reunited with Sweden which was denied by Finland. Consulted by the League of Nations, Åland accomplished the right of self-government within the Finnish nation in 1921. Consequently, Åland was demilitarised and neutralised so that Sweden would not have to fear Finnish attacks from the island group in between. Since 1922 the parliament (Ålands landskapsregering) with its 30 members decides about matters such as the local energy market. Finland's primary responsibilities consider the fields of foreign affairs, judiciary, most of civil and criminal law, customs duties and taxes.[48] Åland's government receives an annual compensation sum for the taxes and charges paid to Finland which equals to 0,45% of the estimated annual revenues of the Finnish government, state borrowings excluded. Åland's government can split this sum self-assessed for its local matters.[49] Most of the money is usually spent on health and environment, then finance and after that education.[50] Åland's government founded the Åland Technology Centre (ÅTC) in 1989 and renamed it in 2015 in Åland Technology and Energy Centre (ÅTEC) which shall promote Åland's technological competence and innovation.[51]

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[47] VTT (2016): Åland Smart Energy Platform.
[48] Ålands landskapsregering (2012): Åland – eine selbstständige Region.
[49] Europe Information, Ministry for Foreign Affairs of Finland (2013): Åland in the European Union.
[50] ÅSUB (2016): Åland in Figures 2016: Expenditure of the Government of Åland, MEUR, p.21.
[51] Ålands landskapsregering (2016): Ålands teknologi- och energicentrum.

2.4.2 ÅTEC

The Åland Technology and Energy Centre (ÅTEC) is a governmental organisation supporting innovation and business development in Åland with a focus on sustainability and cleantech. While five employees was the maximum, today only two work for the unit. A huge project for ÅTEC is the Åland Smart Energy Platform formed in 2014 as a cooperation with the international innovation cluster CLIC Innovation Ltd. (formerly CLEEN). In 2015 a feasibility study was made as a cooperation between ÅTEC and VTT, the Finnish Institute for Technical Research, in order to formulate a roadmap for Åland becoming a smart energy demonstration platform. The study concludes that Åland's uniqueness is created by its manageable size, its location between Finland and Sweden as well as its good conditions to combine electricity with heat and even transport.[52] Regarding heating combined with electricity (CHP), it must be seen that it is not only a possibility but also a necessity considering cost efficiency especially in the vast archipelago.[53] According to this pre-study the fix and variable costs to establish a demonstration platform without components amount to 2 M€. ÅTEC cooperates with over fifteen local, Finnish and international companies, universities and organisations in the frame of the Smart Energy Platform.[54,55]

2.4.3 TSO Kraftnät Åland AB

Kraftnät Åland (KNÅ) founded in 1997[56] is the only transmission grid operator (TSO) of the island group and owned by the local government. The company maintains one 25 MW gas turbine for back-up power. The transmission grid (TG) includes 22 power stations and 512 km of electrical lines in total. As the local TSO connecting Åland with the Swedish synchronised grid KNÅ has the obligation to both ensure power supply for the inhabitants of the islands and the stability in the whole system from the in- and outside. As the Åland grid is part of Nord Pool's bidding zone SE3 KNÅ has balancing responsibility. An old system is still maintained in which contracts between the TSO and each of the two local DSOs as well as the electricity producer Allwinds are concluded as follows: These three act within certain balance power windows. The balance responsible companies have to predict their energy infeed into the grid and the estimated consumption day-ahead. If their prediction is wrong, Kraftnät will balance the power by buying energy from (if the prediction was too low) or by selling it to (if the prediction was too high) the Swedish TSO Svenska Kraftnät. The price of these interactions is regulated for a contractually settled price which equals to the current up-/down-price at Nord Pool. Beyond this window Kraftnät is allowed to sell (export) power for higher prices or buy (import) it for lower prices than the balance prices at Nord Pool. This approach shall lead to a more exact prediction and more supply security.[57]

[52] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.
[53] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[54] ÅTEC (2015): Åland Smart Energy Platform.
[55] Häggblom (2016): Email dated 09.09.2016 10:28: "concept developemtn".
[56] Kraftnät Åland (2016): Elverbrukning. En liten kort resumé på elhistorian på Åland.
[57] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.

2.4.4 DSO Mariehamns Elnät AB

One of the two DSOs in Åland is responsible for the area of Mariehamn, the capital of Åland, where about one third of all inhabitants live. The city-owned company emerged from former Mariehamns stads elverk (engl.: Mariahamn's city electric utility) in 2013 in order to separate the books between the company and the community. Today Mariehamns Elnät owns 120 grid stations, 341 km LV and 87 km MV grid as well as 8.626 metering points. The LV grid in Mariehamn is realised in strong lines that could bear a bigger micro-production infeed from roof-top solar panels.[58,59]

2.4.5 DSO Åland Elandelslag (ÅEA)

The other DSO, Ålands Elandelslag (ÅEA), owns the grid in the countryside and archipelago outside of Mariehamn, where about two third of the inhabitants live permanently or in cottages only during summer. The legal form is a cooperative so that every customer holds an equal share in the company. ÅEA owns 1.045 grid stations, 2.084 km LV and 1.186 km MV grid as well as around 14.886 metering points.[60,61]

2.4.6 Energy Producer Mariehamns Energi AB

Founded in 1977 the city-owned company produces both thermal and electrical energy. Mariehamns Energi possesses a heating grid in order to distribute district heat within the capital Mariehamn and, moreover, sell balancing service to Mariehamns Elnät that out-sourced the balancing responsibility to Mariehamns Energi. There are 886 customers while the other buildings use heat pumps. Mariehamns Energi owns two combined electrical and thermal power diesel generators and one electrical power diesel generator as an emergency reserve for the power plant itself. Furthermore, their daughter company Mariehamns Bioenergi AB which is jointly owned by the Åland forest industry (51%)[62] possesses a biogas turbine and a combined biomass generator. Its heat sink can store electrical power by transforming it into thermal power.[63]

2.4.7 Electricity Producer Allwinds AB

Allwinds founded in 2011 is the local wind park operator owning 21,16 MW wind power and maintaining 21,76 MW which represents the total amount of installed wind power in Åland. The company is equally owned by three firms: Ålands Vindenergi Elandelslag (founded in 1994), Åland Vindkraft AB

[58] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[59] Mariehamns Elnät (2016): Annual Report 2015.
[60] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[61] Karlsson (2016): Email dated 29.08.2016 13:07: "SV: metering points".
[62] Mariehamns Energi (2016): Bioenergi.
[63] Lindström (2016): Expert interview with Henning Lindström, CEO of Mariehamns Energi AB.

(1997) and Leovind AB (2003). Due to its huge share in the daily load curve and because Allwinds is an electricity supplier to end-consumers using the Åland grid, the company is also held balance responsible by TSO KNÅ.[64]

2.4.8 Finnish TSO Fingrid Oy

TSO KNÅ installed a 162 km long HVDC submarine cable (Ål-link) in 2015 connecting Åland Ytterby to Fingrid's transmission grid in Naantali, Finland. While financing started in 2008, the contracts were signed in 2012. The substation on Finnish mainland is owned by KNÅ.[65]

2.4.9 Finnish DSO Caruna Oy

TSO KNÅ has a 45 kV AC connection installed in 1991 between Åland Brändö and Kustavi on the Finnish mainland linking their grid to Caruna's distribution grid (DG). The cable is 16,6 km long and can usually carry 9 MW load.[66,67]

2.4.10 Swedish DSO Vattenfall AB

A 63 km long AC cable between Tellholm in Åland and Senneby in Sweden was taken in use in 1973 and renewed in 2000 connecting Åland's TG to the grid of Swedish DSO Vattenfall. Vattenfall built the grid connection on Swedish land between KNÅ's substation and TSO Svenska Kraftnät's 70 kV transmission grid and ever since charges contractually an annual usage fee of about 1 M€ which paid off any installation costs a while ago.[68]

2.4.11 Swedish TSO Svenska Kraftnät AB

KNÅ has sought for a direct connection to the near 220 kV grid of the Swedish TSO Svenska Kraftnät for many years. According to the TSO-TSO model by ENTSO-E, TSOs of EU member states are supposed to internationally exchange balance power exclusively by TSOs which requires a cross-border connections between TSO Kraftnät Åland and TSO Svenska Kraftnät[69]. Although KNÅ is willing to build and pay the connection it does apparently not meet the Swedish market concept.[70]

[64] Lindqvist (2016): Expert interview with Henrik Lindqvist, CEO of Allwinds AB.
[65] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[66] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[67] Kahlroth (2016): Email dated 30.08.2016 08:32: "SV: cable to Kustavi".
[68] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[69] ENTSO-E (2014): Network Code on Electricity Balancing. Version 3.0. Chapter 1: Definitions, p. 12.
[70] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.

2.4.12 ABB Oy

Supplying almost all the products needed in the field of energy supply, the company has a great interest in the Åland Smart Energy Platform. ABB considers a smart grid as the only imaginable future solution in an energy market that intends to install huge amounts of fluctuating renewable energy sources. The imbalance causing amount of renewables will force the market to integrate lots of smart communication and control technologies in order to coordinate power flows and stabilise the system. Åland has the right size to serve as a test area to learn from for bigger grids that plan on becoming smart in the future. Moreover, ABB already preserves business relationships with the island group as the HVDC submarine cable Ål-link as well as many other products and services are provided by ABB.[71] ABB also participates in the Åland Smart Energy Platform coordinated by ÅTEC.[72]

[71] Kärnä (2016): Expert Interview with Teijo Kärnä, Industry Segment Manager at ABB Oy.
[72] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.

3 Technical Analysis of the Åland Grid and Identifying Future Challenges

The focus of this chapter rests on the technical analysis of the electricity grid in Åland today pointing out the state of the equipment and its properties. Therefore the particular tasks in the electricity market are divided into generation, transmission and distribution as well as metering.

Before going into detail a general impression of the market size shall be given. Figure 3.1 and 3.2 present the share of input sources in the frame of production and import as well as the share of output sinks regarding consumption, export and losses.

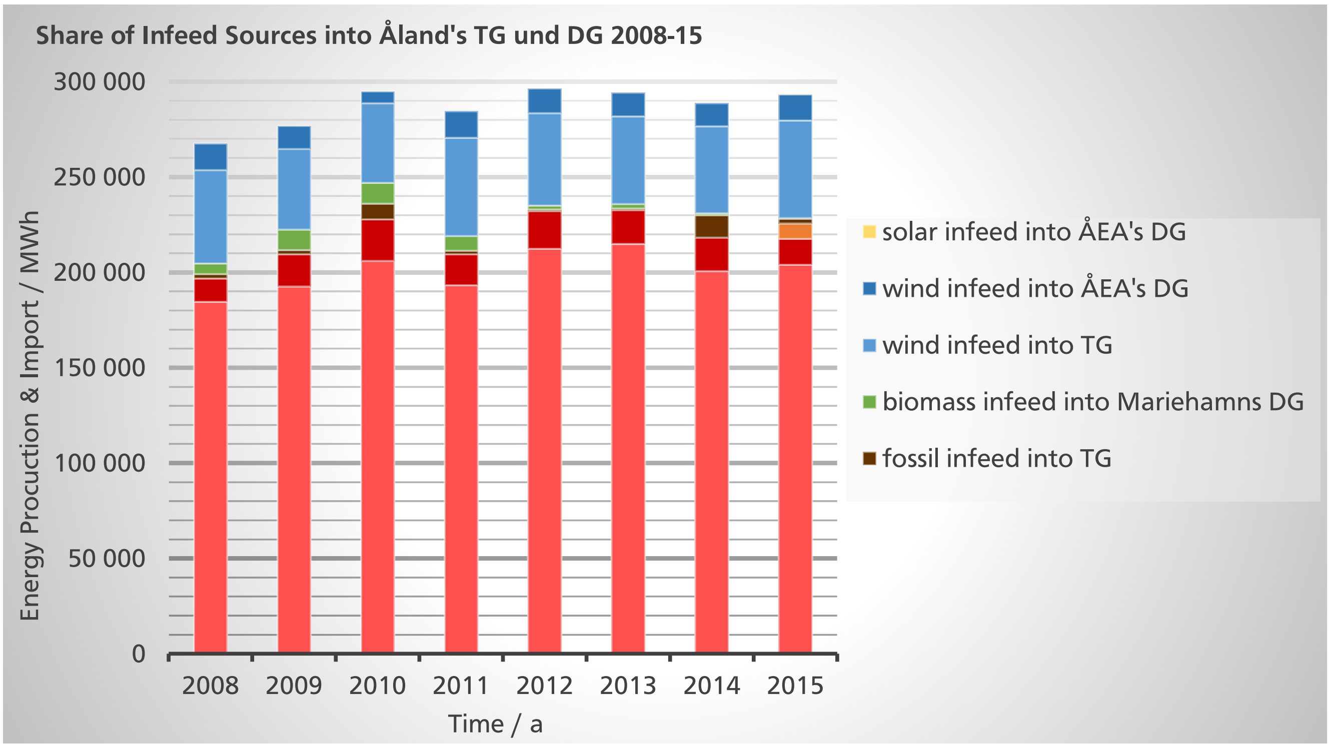

Figure 3.1: Shares of Energy Infeed Sources in Åland 2008-2015.[73,74,75]

Figure 3.1 shows the input side of the Åland grid. It becomes obvious that a significantly large part of the energy in Åland is imported from Sweden and, hence, bought from the Swedish DSO Vattenfall and Nord Pool. The imports from Finnish DSO Caruna, however, are clearly lower but also rather constant over the years. The AC connection to Finland aims to provide energy in the far Eastern archipelago. The losses are lower when importing the energy from Finland for the East of the Åland islands even though the spot market prices are higher than those in Sweden. The connection, however, has with maximum 12 MW not enough capacity to be used to a great extent. The HVDC cable to Finland taken into operation in 2015 caused comparatively high input rates from Fingrid whereas imports via the connection to Caruna decreased consequently.[76]

[73] cf. Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.
[74] cf. Ålands Elandeslag (2016): Grid input and output data 2008-2015.
[75] cf. Mariehamns Elnät (2016): Grid input and output data 2008-2015.
[76] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.

The fossil production shows peaks in 2010 and 2014. Since the winter of 2010 was rather cold and prices at Nord Pool were high, lots of electricity was produced by fossil power and exported to Sweden. In 2014 the new Ål-link (HVDC) to Naantali was tested and the substations of the AC connection to Senneby were maintained, so the AC cable was disconnected and replaced by local fossil generation. Biomass production used to have a small but steady input amount but in 2012 Nord Pool prices started to range so low that the biomass production has not been profitable and was therefore reduced.[77]

Infeed from solar power was measured in 2015 for the first time in the DG of ÅEA with a total amount of 40,86 MWh which is too small to be noticed in figure 3.1. Wind power, however, contributes around one fifth of the total infeed in Åland grid systems each year with only 20 wind turbines currently as will be presented in subchapter 3.1.1.1.

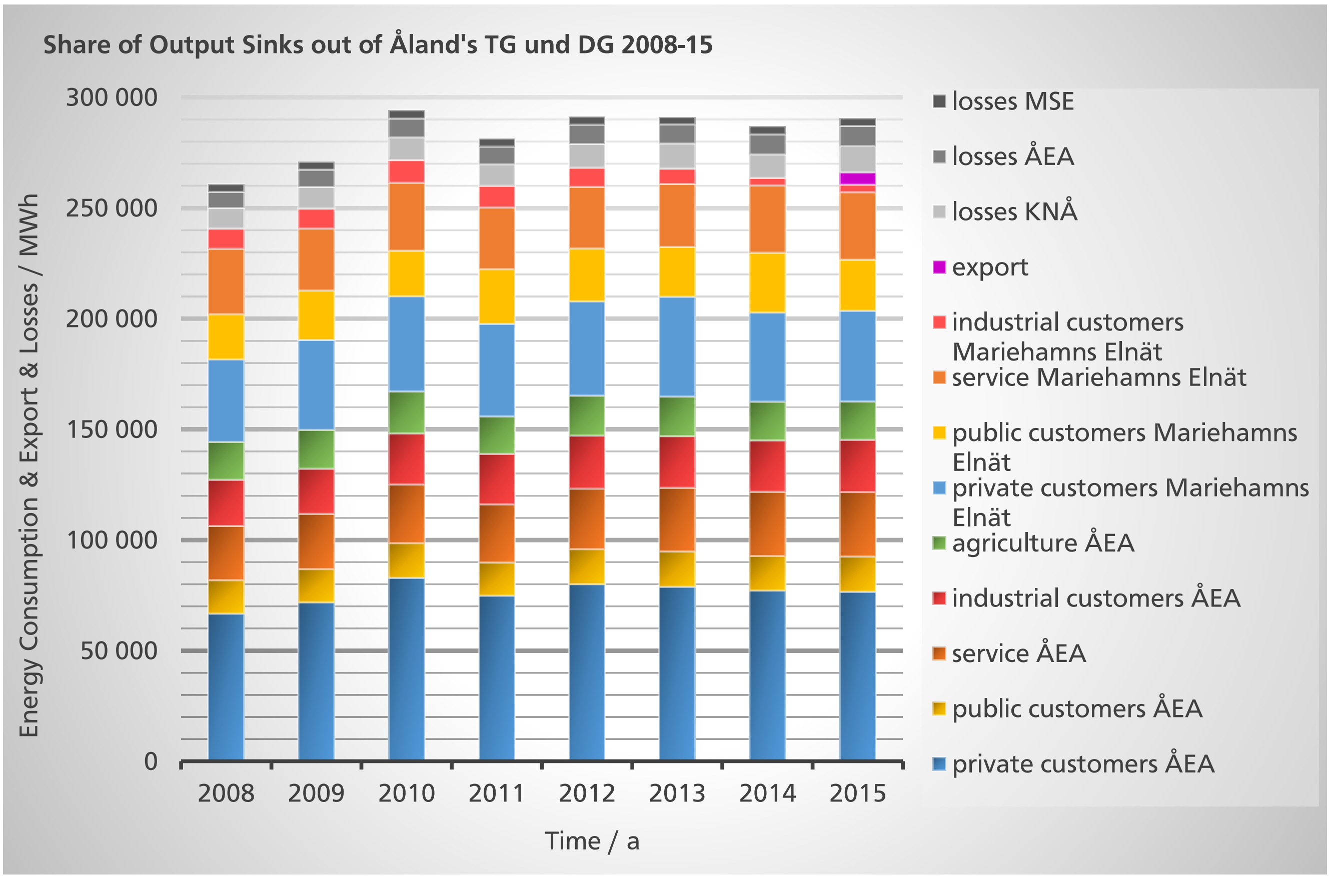

Figure 3.2: Energy Output in Åland 2008-2015.[78,79,80]

Figure 3.2 Figure 3.2 shows the output side of the Åland grid. Since about two third of the Åland inhabitants live in the countryside outside of Mariehamn about two third of the private consumption take place in the ÅEA grid, only one third in Mariehamns Elnät's grid. The public and service consumption share, however, is bigger in the capital because the government is located in the city as well as many hotels, restaurants and leisure facilities. This consumption, however, is exceeded by the industrial and

[77] Lindström (2016): Email dated 30.08.2016 10:04: "SV: Input Shares".
[78] cf. Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.
[79] cf. Ålands Elandeslag (2016): Grid input and output data 2008-2015.
[80] cf. Mariehamns Elnät (2016): Grid input and output data 2008-2015.

agricultural consumption in the rural area of ÅEA's grid where most of industries and agriculture are located. The losses in the transmission grid with the three submarine cables and the losses in the distribution grid of ÅEA spreading all over the vast archipelago are of course higher in comparison to the local distribution grid of Mariehamns Elnät. All in all, the losses are in average almost 8% which is basically high but reasonable for many sea cables. The lower losses in Mariehamn show the difference when considering a small area without long distribution ways. This can serve as an outlook to a future smart grid where the energy is produced more locally and nearer to its consumption location so that consequently losses can be minimised significantly.

3.1 Current Situation in Åland and Developments

In this chapter the technical equipment and properties of the current power supply system in Åland are introduced. First there will be a presentation of the local generation with a specially detailed focus on wind power. Then the transmission and distribution systems shall be examined. In the end the current metering network shall be analysed.

3.1.1 Generation

Since Åland (2015: 269,4 GWh[81]) is no huge energy consumer compared to its big neighbours Finland (2015: 82,5 TWh[82]) and Sweden (2015: 136 TWh[83]), it does not take so much local energy production to be self-sufficient. But it does take technologies to stabilize the volatile infeed of the increasing share of renewable energy sources. In the following the different energy sources in Åland today will be presented pointing out future trends and opportunities.

3.1.1.1 Wind Power in Åland

The figures of this subchapter create a clear picture of what the wind situation in Åland looks like and how it is used by the local wind power operator Allwinds AB. Figure 3.3 shows the weather stations in a map of the archipelago that collect data for operational planning of future wind park locations and for balancing forecasts.

[81] Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.
[82] Energiateollisuus (2016): Energy Year 2015 Electricity: Carbon dioxide emissions from power generation at record low.
[83] Energimyndigheten (2016): 2015 var ett år med stor elproduktion och rekordstor export av el.

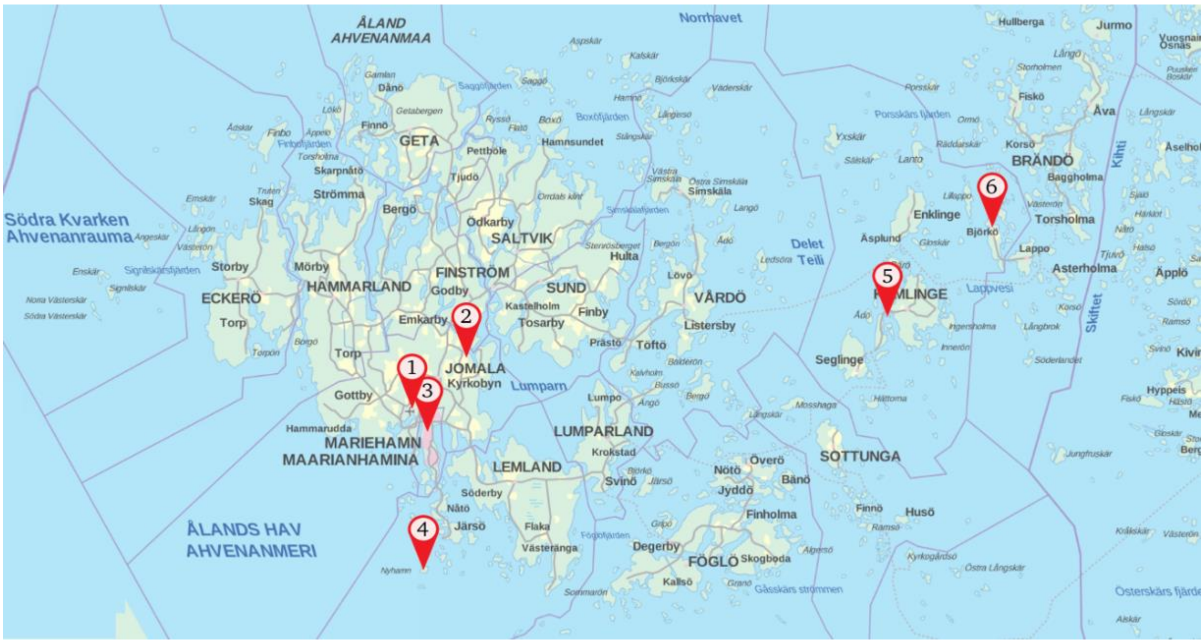

Figure 3.3: Map of Åland with the Wind Measuring Weather Stations: [1]: Mariehamns Airport, [2]: Jomalby, [3]: Svibyviken, [4]: Nyhamn, [5]: Kumlinge, [6]: Björkö/Kolholms bottnen.[84,85]

The data these weather stations provide are collected and analysed by WindFinder.com GmbH & Co. KG. The three-hourly wind forecast calculated for the next days are used by Allwinds to create a daily day-ahead forecast which they have to send to TSO Kraftnät Åland. The historical data from WindFinder can demonstrate the good wind performance in Åland. In figure 3.4 the average wind speed is shown and it strikes how prominently the location at Nyhamn, south of the capital, stands out. But also the location in Kumlinge offeres a quite constant strong wind over the whole year.

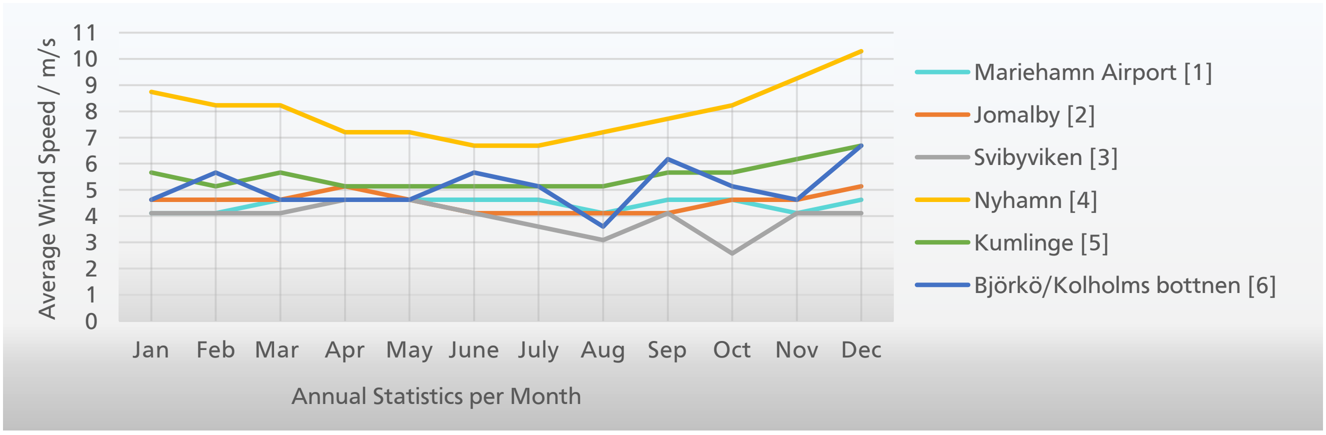

Figure 3.4: Average Wind Speed in Åland.[86]

Beside the average wind speed WindFinder also offers statistics about the average wind probability at different locations illustrated in figure 3.5 which is essential to an energy market that intends to be 100% renewable and will consequently have high balancing efforts. In a system so volatile it is important to

[84] cf. Paikkatietoikkuna (2016): Karttaikkuna.

[85] cf. WindFinder (2016): Wind, waves and weather for kitesurfers, windsurfers, surfers and sailors.

[86] cf. WindFinder (2016): Wind, waves and weather for kitesurfers, windsurfers, surfers and sailors.

have a realistic estimation how much wind can be reckoned with. Again Nyhamn is very prominent while other locations such as Jomalby and Svibyviken do not perform as well as expected. So in order to set up a huge wind power plant in the future it must be taken into account that the plant works much more efficient at an almost off-shore location somewhere on a small rock island in the vast archipelago like at Nyhamn.

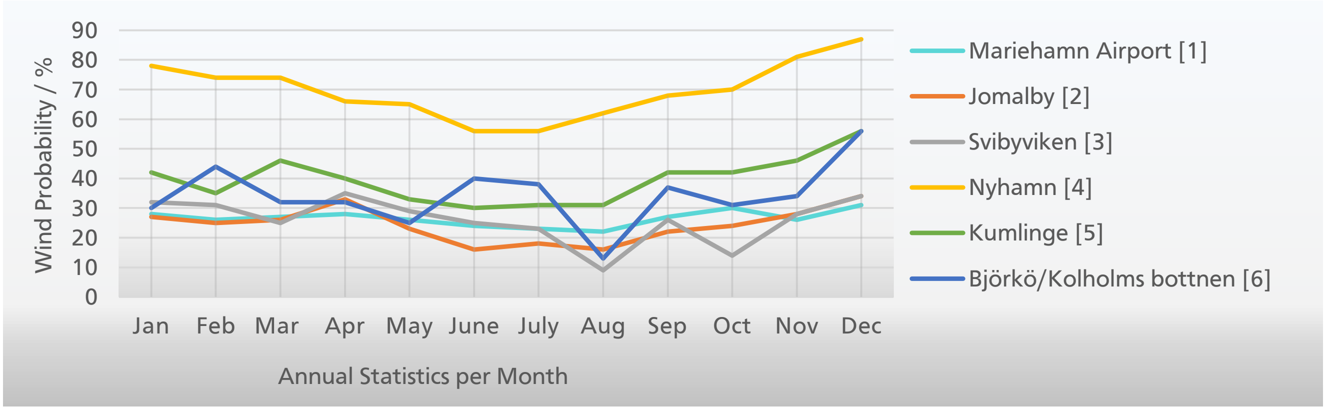

Figure 3.5: Wind Probability in Åland.[87]

Table 3.1 demonstrates a list of the currently operating wind turbines in Åland maintained and mostly owned by the local electricity producer Allwinds.

Table 3.1: List of Wind Turbines Installed in Åland in 2015.[88]

	Name	Location	Power / MW	Manufacturer	Model	Owner	Connection	Installation
1	Konrad	N Stora Båtskär	2,3	Enercon	E-70	LEO	KNÅ	2007
2	Donatus	V Stora Båtskär	2,3	Enercon	E-70	LEO	KNÅ	2007
3	Leo	Ö Stora Båtskär	2,3	Enercon	E-70	LEO	KNÅ	2007
4	Trefanten	Lilla Båtskär	2,3	Enercon	E-70	LEO	KNÅ	2007
5	Anna	Kummelpiken, Båtskär	2,3	Enercon	E-70	LEO	KNÅ	2007
6	Wendela	Ryssklubben, Båtskär	2,3	Enercon	E-70	LEO	KNÅ	2007
7	Preciosa	Eckerö	0,5	Vestas	V-39	ÅVA	ÅEA	1995
8	Frans	Knutsboda, Lemland	0,6	Vestas	V-44	ÅVA	KNÅ	1997
9	Fredrika	Knutsboda, Lemland	0,6	Vestas	V-44	ÅSF	KNÅ	1997
10	Freja	Knutsboda, Lemland	0,6	Vestas	V-44	ÅVK	KNÅ	1997
11	Fortuna	Knutsboda, Lemland	0,6	Vestas	V-44	ÅVA	KNÅ	1997
12	Oskar	Sottunga	0,66	Vestas	V-47	ÅVK	ÅEA	2004
13	Albert	Föglö	0,6	Enercon	E-44	ÅVA	ÅEA	1999
14	Mika	Kökar	0,5	Enercon	E-40	ÅVA	ÅEA	1997
15	Altai	Vårdö	0,5	Enercon	E-40	ÅVA	ÅEA	1998
16	Fursten	Pettböle, Finström	0,5	Enercon	E-40	ÅVK	ÅEA	1998
17	Gideon	Pettböle. Finström	0,5	Enercon	E-40	ÅVK	ÅEA	1998
18	Svea	Pettböle, Finström	0,6	Enercon	E-44	ÅVK	ÅEA	1999
19	Astrea	Lumparland	0,6	Enercon	E-40	ÅVA	ÅEA	2003
20	Amalthea	Lumparland	0,6	Enercon	E-40	ÅVA	ÅEA	2003
all			21,76					

[87] cf. WindFinder (2016): Wind, waves and weather for kitesurfers, windsurfers, surfers and sailors.
[88] Allwinds (2016): Production data of all wind turbines in 2015.

It becomes obvious how much more power younger turbines possess in comparison to older ones. One reason of that is the bigger diameter of the rotor blades. The second reason and precondition in order to make them bigger is that lighter, more robust materials are continually created and improved. The third reason is the technically possible height that increases with better materials. However, legal height and diameter restrictions must be considered. Besides, sometimes deeper locations are windier depending on local conditions so that higher turbines are not always the optimum. Generally, there are three options in case of old, inefficient turbines:

1. to tear them down,
2. to tear them down and exchange them with new technology or
3. to upgrade them to save costs, increase their efficiency and extend their life span.[89]

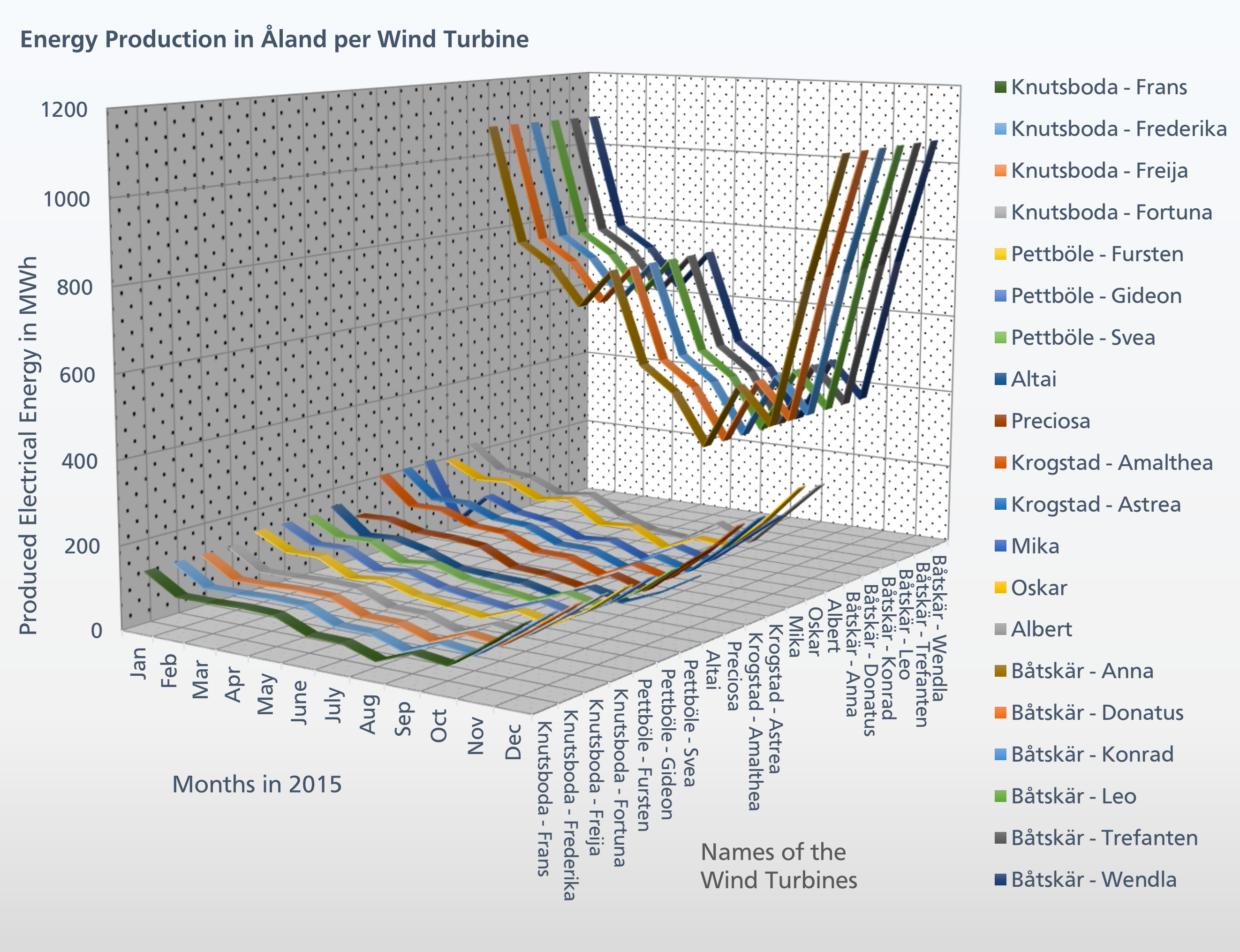

Figure 3.6: Åland's Electricity Generation by Wind Power for each Turbine in 2015.[90]

Figure 3.6 shows the local electricity generation from wind power in 2015. It has to be acknowledged that turbine Preciosa was shipped away in May 2016[91] and that there are not more detailed production

[89] Kärnä (2016): Expert Interview with Teijo Kärnä, Industry Segment Manager at ABB Oy.
[90] Allwinds (2016): Production data of all wind turbines in 2015.
[91] Aaltonen (2016): Email dated 05.07.2016 8:43: “SV: double-check and further information needed”.

data of each turbine of a wind park than the production data of them all together. Since the generator power in each wind park is in most cases evenly spread but at least very similar, as table 3.1 indicates, a good approximation of the production of each turbine is possible. All of the listed turbines belong to balance responsible Allwinds AB except for turbine Fredrika which is owned by Ålands Skogsindustri[92].

As it becomes easily obvious wind park Båtskär produced by far more energy than the others, in detail 2,57 times as much as the rest which represents 72 % of the total production share of wind power in 2015. The first reason for that lies in a very wind favourable area located South of Mariehamn close to the weather station in Nyhamn where both wind probability and wind speed reach remarkably high values as the earlier analyses showed. The second reason is the technical condition of the quite new wind turbines which are younger, work more efficiently and have – because of their larger rotor surface – a five times bigger power compared to the older turbines. Less surprising is the rather similar generation profile of the other turbines for they have not only almost the same power like table 3.1 shows but also similar wind speed and probability profiles as figure 3.4 and 3.5 indicate.

This analysis demonstrates the possibilities of what could be achieved by installing some more wind turbines with the latest technology in Åland. Easily huge amounts of power could be provided and lots of local renewable infeed could be reached in order to become a self-sufficient, green smart grid.

3.1.1.2 Biomass Power in Åland

Mariehamns Bioenergi AB is the daughter company of Mariehamns Energi AB 51% owned by local forest industries and 49% owned by Mariehamns Energi (which is owned by the capital). Mariehamns Bioenergi possesses a biogas turbine with 5 MW thermal power and a combined biomass generator which has 9 MW thermal and 2,1 MW electrical power. Its heat sink (98 °C) is able to store 0,4 MW electrical power as thermal power which afterwards cannot be converted into electrical energy anymore but only used as heat.[93] Wood chips, sawdust and bark are used as fuels. The annual sum of used bio fuels in Åland equals to 140.000 m^3 which corresponds to 55.000 m^3 timber volume. So about 8.500 t of oil imports and 27.000 t of CO_2-emissions can be saved.[94] Due to low spot market prices at Nord Pool generation with biomass power has not been profitable during the last few years so that the share in total infeed has decreased a lot as shown in the beginning of this chapter.[95]

[92] Aaltonen (2016): Email dated 05.07.2016 9:37: "SV: double-check and further information needed".
[93] Lindström (2016): Expert interview with Henning Lindström, CEO of Mariehamns Energi AB.
[94] Mariehamns Energi (2016): Bioenergi.
[95] Lindström (2016): Email dated 30.08.2016 10:04: "SV: Input Shares".

3.1.1.3 Solar Power in Åland

Connected to the distribution grid of ÅEA 16 households have installed solar power in form of PV panels on roof tops representing 110,83 kW with the option to feed in energy in case of a surplus.[96] Since 2016 there is a solar infeed into the distribution grid of Mariehamns Elnät by nine households with PV installations. Since 2015 almost 13 MWh solar power has been fed into the network. In March 2016 the infeed was almost 400 kWh, in April almost 1 MWh, in May, June and August about 1,7 MWh and in July even around 2,7 MWh.[97]

3.1.1.4 Fossil Power in Åland

Since July 2016 Mariehamns Energi operates a combined 15,8 MW electrical and 13 MW thermal power diesel generator, a combined 8 MW electrical and 19,8 MW thermal power diesel generator and a 2,5 MW electrical power diesel generator as an emergency back-up power reserve for the power plant itself. Before that, two 12,3 MW gas turbines provided additional ancillary service to the TSO but those have not been profitable anymore. Because all these generators will reach their end of life until about 2020 the future of fossil electricity production in Åland is terminated. However, a new generator for district heating is supposed to be installed. The non-customers of Mariehamns Energi use combined heat power (CHP).[98]

3.1.2 Transmission

Figure 3.7 displays the total electricity transmission grid in Åland managed by the governmentally-owned Kraftnät Åland AB. It becomes obvious that there are only two connections to the Nordic mainland market. KNÅ owns a AC connection from Åland's shore in Tenneby to Senneby in Swenden (including the substation) where it is connected to the grid of DSO Vattenfall. Installed in 2000 the 110 kV AC cable is thermally designed for 80 MW but it is contractually agreed upon to use only 54 MW, from 2017 on 58 MW. Between Åland Brändö and Finnish Kustavi there is a 45 kV AC connection to the DSO Caruna. The 16,6 km long AC cable possesses about 9, for short bottlenecks even 12 MW capacity. Additionally, in 2014 a 162 km long HVDC submarine cable designed for 100 MW (125 MW possible for about 30 min) was installed to link Ytterby to Naantali, Finland. Kraftnät Åland owns the 110 kV HVDC cable as well as the substation in Naantali, where it is connected to the Finnish TSO

[96] Karlsson (2016): Email dated 10.08.2016 15:42: “SV: solar”.
[97] Tommiska (2016): Email dated 30.08.2016 10:15: ”SV: Data_repl.”.
[98] Lindström (2016): Expert interview with Henning Lindström, CEO of Mariehamns Energi AB.

Fingrid. Since KNÅ is the owner of the network including the substations on the mainland, the company has to pay for the losses and consequently, due to fees passed on, each inhabitant of Åland.[99]

It becomes clear when looking at figure 3.7 and table 3.1 that the transmission grid in Åland might not have many connections but quite long cable distances in relation to the island size caused by the geographical situation. The connections at each voltage level can be found listed in table 3.1. Kraftnät Åland's grid is all in all 512 km long spreading all over the most important dwelling areas as figure 3.7 illustrates.

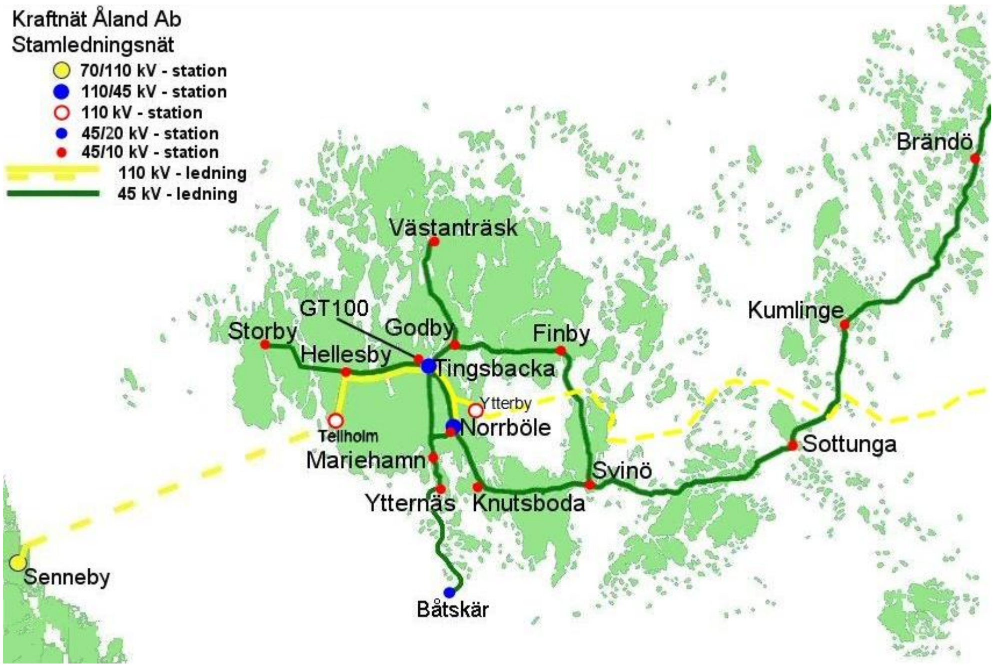

Figure 3.7: Voltage Levels of Åland's Electricity Transmission Grid.[100]

Table 3.2: Transmission Grid in Åland 2015.[101]

Lines	Voltage Level / kV	Length / km
HVDC cable to FI	+/- 80	161,8
AC cable to SV	110	62,9
overhead lines	110	26,4
cable	45	96,8
overhead lines	45	164,1

3.1.3 Distribution

In Åland there are two DSOs. The smaller DSO Mariehamns Elnät AB owns the grid in the capital area and a bit further outside of the city borders. The DSO has already installed bigger dimensioned cables

[99] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[100] Kraftnät Åland (2016): TSO in landskapet Åland.
[101] Kraftnät Åland (2016): TSO in landskapet Åland.

in the low voltage system to be able to withstand an increasing bidirectional load flow due to the infeed of micro-producers with solar panels on their roof tops.[102]

The bigger DSO is Ålands Elandelslag (ÅEA) owning the grid in the whole rural area of Åland and connecting even remote small islands to the grid. ÅEA's 10 kV grid can be seen in figure 3.8. Due to its legal form as a cooperative (every customer owns an even share of the total company) ÅEA is obliged to connect each and every new cottage to the DG. Although a new customer must pay the initial grid connection, all subsequent maintenance and support costs have to be borne by the DSO which is equal with the entirety of all customers. This expensive system may cause major financial struggles for the company in the long run.[103]

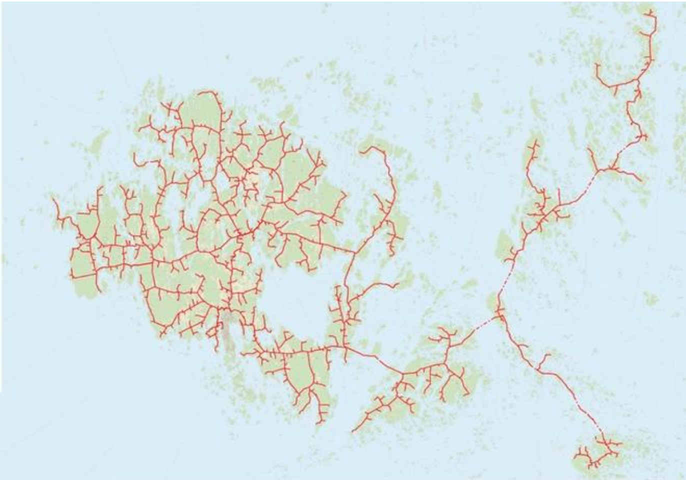

Figure 3.8: Ålands Elandelslag's 10 kV Distribution Grid on 20.06.2016.[104]

Table 3.3 and 3.4 show the distribution grids in Åland. The small grid in the capital area, Mariehamns Elnät, is 428 km long of which around 20% is medium voltage level and 80% low voltage level. ÅEA's rural distribution grid is with 3.269 km length 7,6 times longer using 36% in the medium voltage and 64% in the low voltage level. While only 12% of the connections in Mariehamns Elnät's grid are led over ground, 84% of ÅEA's grid are laid over ground. The rest are underground and submarine cables. In Mariehamns Elnät's network only 2,5% are submarine connections while in ÅEA's system it's 3,3% of the whole grid.

In Mariehamns Elnät's grid the 2015 interruption time per customer was 1:10 h and the interruption time per customer per failure 8,64 s.[105] In ÅEA's grid 2015 the interruption time per customer was 1:42 h and the interruption time per customer per failure 30 min which is caused by many overground cables and a scattered network in the archipelago which can be hard to reach in some cases.[106] In comparison, on the Finnish mainland the interruption time per customer in 2013 was 5:43 h (1:36 h in

[102] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[103] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[104] Karlsson (2016): Email dated 20.06.2016 09:46: "Ålands Elandelslag material".
[105] Mariehamns Elnät (2016): Annual Report 2015.
[106] Ålands Elandelslag (2016): Annual Report 2015.

2009) in the DG mainly caused by weather and animal incidents since 85% of the middle voltage grid consists of overhead lines.[107]

Table 3.3: Distribution Grid in Mariehamn 2015.[108]

Voltage Level	Lines		Length / km
10 kV	suspension cable	copper	1,814
	submarine cable	aluminium	5,926
	underground cable	copper	0,471
		aluminium	71,434
	overhead line	aluminium	6,876
0,4 kV	suspension cable	steel aluminium	42,172
	submarine cable	copper	2,616
		aluminium	2,321
	underground cable	copper	162,265
		aluminium	131,792

Table 3.4: Distribution Grid in Åland's Rural Areas.[109]

Voltage Level	Lines		Length / km
10 kV	suspension cable	copper	49
		aluminium	22
	submarine cable	copper	10
		aluminium	73
	underground cable	copper	7
		aluminium	88
	overhead line	aluminium alloy	103
		steel aluminium	653
		jacketed (each phase)	180
0,4 kV	suspension cable	MMJK[110] (roped in steel)	2
	spiral suspension cable	AMKK[111]-AMKA[112]	1740
	submarine cable	copper	2
		aluminium	22
	underground cable	copper	162
		aluminium	156

3.2 Load Curves and Balance Challenges

The data set from Kraftnät Åland consists of the hourly energy values from 01.01.2008 until 31.05.2016, average load values per hour. According to the calendrical seasons, an analysis for spring (21.03.-

[107] Energiavirasto (2015): National Report 2015 to the Agency for the Cooperation of Energy Regulators and to the European Commission, p. 21.
[108] Mariehamns Elnät (2016): Annual Report 2015.
[109] Ålands Elandelslag (2016): Annual Report 2015.
[110] M Muovi eristys (ulkoinen) (plastic insulation (external)) M Muovia eristys (johtimet) (plastic insulation (conductors)) J Johdin (conductor) K Kannatinköysi (suspension rope)
[111] A Alumiinia johtimet (aluminium conductor) M Muovia eristys (plastic insulation) K Kaapeli (cable) K Kannatusköysi (suspension rope)
[112] A Alumiinia johtimet (aluminium conductor) M Muovia eristys (plastic insulation) K Kaapeli (Cable) A Avojohto (open wire)

20.06.), summer (21.06.-22.09.), autumn (23.09.-21.12.) and winter (22.12.-20.03.) was accomplished. It has to be notified that statistical outliers have been excluded to not falsify the conclusions. Beside very few low load hours due to network failures, single high load hours were eliminated when the new HVDC cable was tested in summer and autumn 2015.

In figure 3.9 the load curve for spring is illustrated as an average of the last nine years. By looking at the minimum and maximum values and under consideration of the statistical figures standard variation and variance, it can be concluded that the load development on a typical spring day in Åland is quite well predictable. The average load moves around 30 MWh while in the deep night hours when most people sleep and industrial consumption is reduced, it drops to around 25 MWh and during the morning hours when the inhabitants wake and business starts it increases to about 35 MWh. The maximum values move around 15-20 MWh above average whereas the minimum values stay closer with about 10 MWh below average except for one outlier. While the standard variation is constantly about 5 MWh the squared variance shows some higher divergences during the morning hours as well as during the evening hours. This is probably caused by the fact that people never plan hundred percent accurately when to wake up in the morning or to come home in the evening in order to go to bed while the rest of the daily consumption is rather steady.

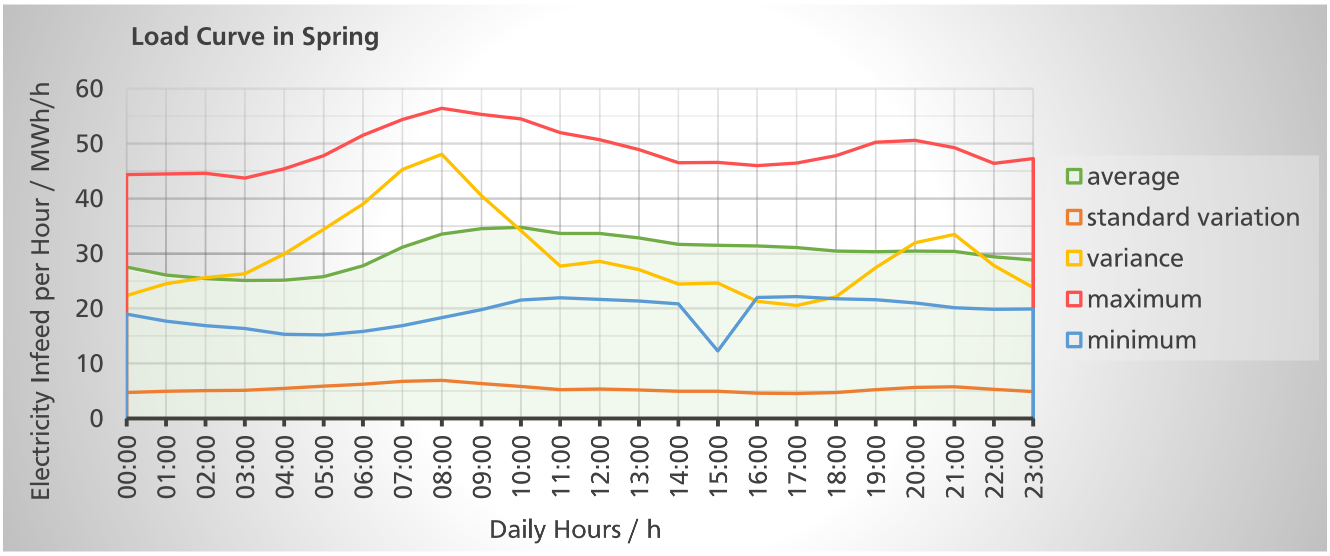

Figure 3.9: Average Hourly Load Curve for Åland in Spring between 2008-2016.[113]

When analysing the last eight summers in Åland illustrated in figure 3.10 it becomes obvious that the maximum values behave even less surprising than in spring with values around 5 MWh at night and 10 MWh at day higher than the average caused by usually constant weather during summer. Also the minimum values move only circa 5 MWh, during day 10 MWh below average. The low average load itself is 20 MWh at night and 25-30 MWh at day caused by higher temperatures and people going more outside[114]. The standard variation at averagely 2 MWh points out that the load during summer is very well

[113] Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.
[114] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.

predictable. The variance reacts strongly in the morning hours while the long Nordic evenings smoothen it in the evening.

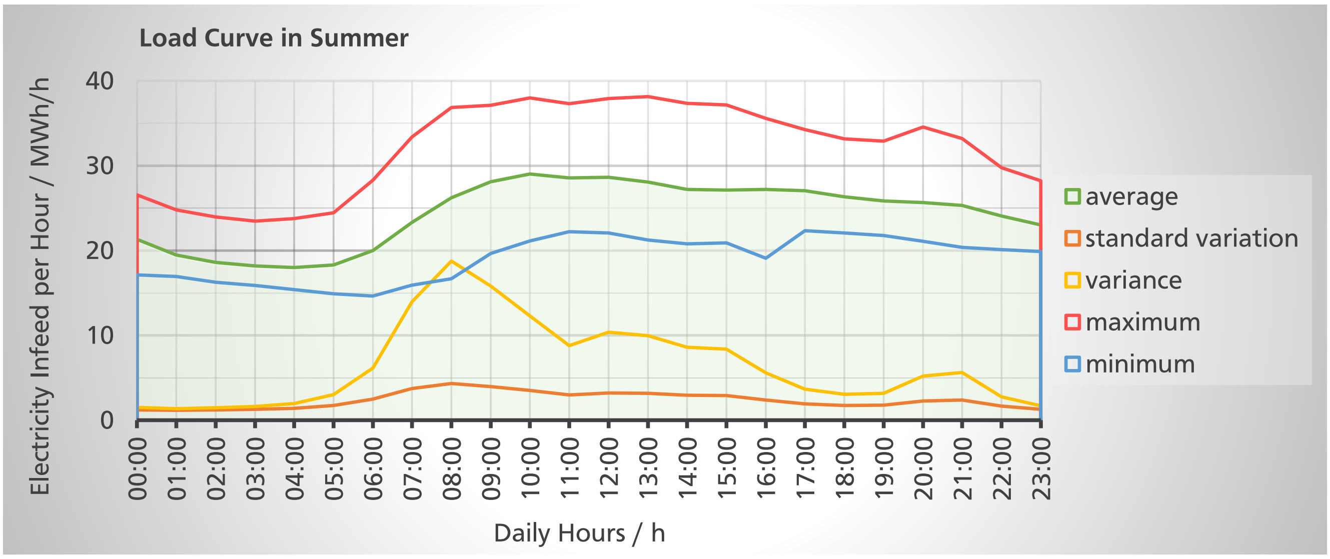

Figure 3.10: Average Hourly Load Curve for Åland in Summer between 2008-2015.[115]

The load curve for autumn for the last eight years in Åland is illustrated in figure 3.11. The maximum values move rather constantly about 20 MWh above average while the minimum values are around 10 to 20 MWh below average. The average load itself is 30 MWh during night and during day 40 MWh, so all in all quite steady. The average in autumn increases compared to summer due to colder temperatures and less sun hours. The standard variation moves around 5 MWh. The variance shows a peak in the morning and another one in the evening following the same pattern like in spring.

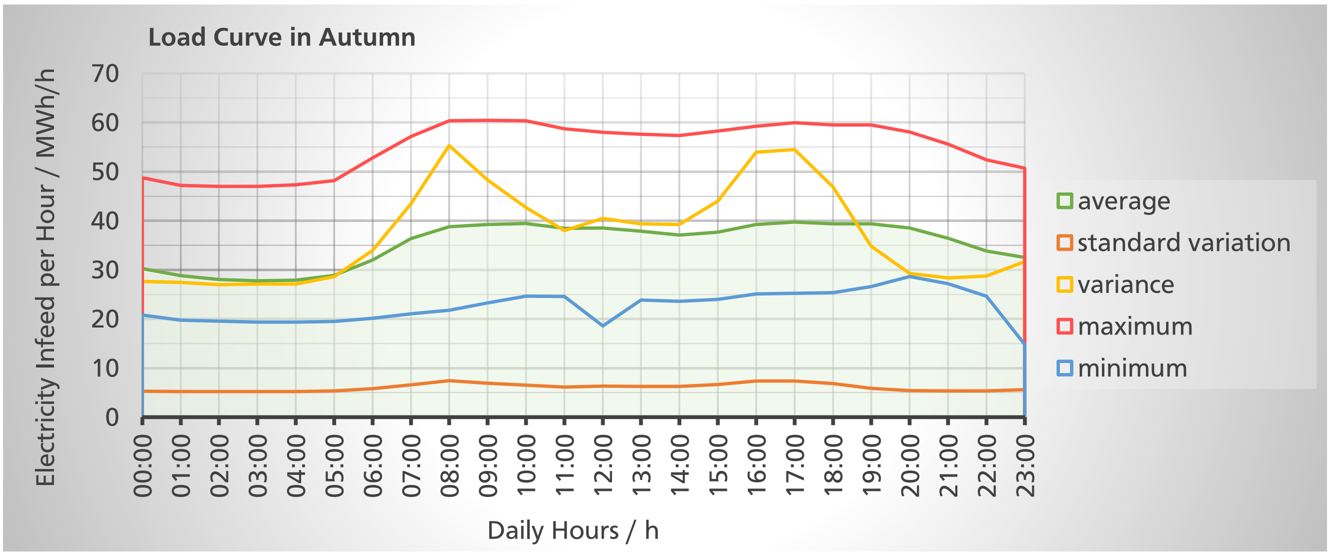

Figure 3.11: Average Hourly Load Curve for Åland in Autumn between 2008-2015.[116]

[115] Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.
[116] Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.

Figure 3.12 illustrates the average winter statistics for the last nine years. The average load is circa 35 MWh at night and 45 MWh during the day so the highest compared to the other seasons. The maximum values move steadily about 20-25 MWh above and the minima constantly around 10-15 MWh below average. The standard variation is 5 MWh or a bit more while the variance shows some peaks in the morning hours and early evening hours picking up the usual pattern caused by daily working rhythms.

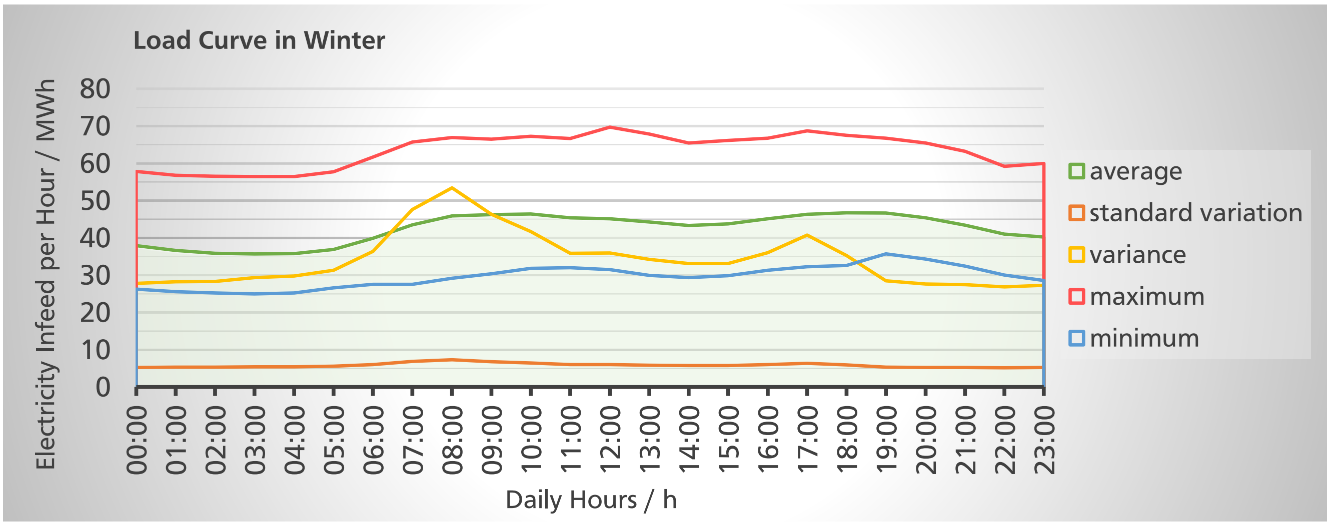

Figure 3.12: Average Hourly Load Curve for Åland in Winter between 2008-2016.[117]

In order to keep the system stable it must be identified how much reserve capacity there is needed to balance the maximum values (positive reserve power) and minimum values (negative reserve power). Chapter 5.2 will analyse in detail how much reserve capacity there is required in today's grid and also for a future scenario. But before using and buying reserve power the balance responsible companies in Åland attempt to stick their consumption forecasts closely with the real consumption using this experience curves and weather forecasts. To further improve the forecasts and secure the system stability TSO Kraftnät Åland holds contracts with the three balance responsible companies allowing failure predictions in regard to day-ahead consumption up to a certain degree as can be seen in table 3.5.[118]

Table 3.5: Balance Power Windows of the Balance Responsible Companies.[119]

Company	Balance Power Window
Allwinds AB	13,9 MW
Ålands Elandelslag Cooporative	7 MW
Mariehamns Energi AB	4 MW

If the producers and DSOs predict the energy consumption too low, KNÅ will buy (import) balance power at the Nord Pool balance price. The company that was mistaking must refund the sum afterwards. If the wrong prediction expands the window KNÅ can even charge a higher price as a penalty. In reverse,

[117] Kraftnät Åland (2016): Grid input and output data for 01.01.2008 until 31.05.2016.
[118] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[119] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.

if the balance responsible companies predicted the energy consumption too high, KNÅ will sell (export) balance power at the Nord Pool balance price. If the prediction expands the window KNÅ will only refund part of the earnings to the company as a penalty. This system shall incite the three companies to improve their predictions.[120]

3.3 Metering

Ålands DSOs exchanged all analogue meters with the smart meters listed in table 3.6 including also serial and substation meters.

Table 3.6: Smart meter integrated in the distribution networks.[121,122,123]

Ålands Elandelslag's grid				
Smart meter	**System**	**Amount**	**Sending frequency / h**	**Generation**
Kamstrup	Omnia Power	ca. 8.000	1	1
Hunt Technologies Inc.	Turtle	ca. 7.000	1	1
Mariehamns Elnät's grid				
Smart meter	**System**	**Amount**	**Sending frequency / h**	**Generation**
Aidon 551x, 5530 and 5550	MActor	6.268	1	2
AEM cst0420	MActor	1.658	1	2
L+G E350	MActor	617	1	2
L+G E650	MActor	48	1	2
EMH	MActor	21	1	2

Mariehamns Elnät uses the smart metering system MActor by Metrima. This bidirectional communication system uses several communication media to achieve a secure data transport at any time, such as IP/ethernet, PLC A-band, radio, cell radio, signal cable, GPRS/GSM. Amongst others the system manages hourly values, alarms, street lightning and traffic control as well as network supervision, energy optimisation and integration with a billing system. Partly the listed smart meters are of the first generation, partly of the second. The smart meters of the first generation are able to send the consumption data every 15 minutes but this is still not economically reasonable so it is only send once an hour. The data from the second generation can be accessed each two minutes and also more inexpensive.[124,125,126] With a upcoming system update Mariehamns Elnät intends to increase the communication bandwidth to gather almost real-time consumption data and power quality values.[127]

ÅEA already installed the Turtle system between 2004 and 2006 which works only unidirectionally. The meter data is transmitted via the powerline until it reaches the middle voltage grid. Then the data is sent over fiber cable or 3G net. The Kamstrup smart meter is newer and could handle bidirectional five minute

[120] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[121] Karlsson (2016): Email dated 07.09.2016 08:10: "SV: Smart Meter".
[122] Karlsson (2016): Email dated on 08.09.2016 15:07: "Smart Meters".
[123] Tommiska (2016): Email dated 06.09.2016 19:29: "AMR system and meter types".
[124] Tommiska (2016): Email dated 06.09.2016 19:29: "AMR system and meter types".
[125] Tommiska (2016): Email dated 06.09.2016 23:55: "SV: AMR system and meter types".
[126] Metrima (2016): MActor.
[127] Tommiska (2016): Email dated on 26.10.2016 01:30: "SV: Urgent: Smart Meter Generation".

intervals if necessary. It has a breaker to cut the grid connection in case of default of payment. By 31.12.2018 all smart meters in ÅEA's grid are expected to be of that kind.[128]

The consumption data measured in the meter is send via both cell radio and fiber cables to Consilia Solutions AB. This local service company provides an enterprise resource planning programme automatically creating invoices that are directly send to the end-costumers. Consilia Solutions developed a future model for the Åland energy market. In that model all electricity customers share their consumption data anonymously in the already existing platform called my page where Finnish energy costumers can check their own consumption. But this future platform would not only collect consumption data but also information about the housing situation (e.g. walls and insulation (wood, stone etc.), single-family house, apartment building, amount of persons living there). Today such information may not be passed over by the city or the government due to Finnish customer rights. However, the data could be given voluntarily for the customers could profit from the comparison to similar households. Moreover energy enterprises could even integrate their recommendations where and how energy could be saved according to the personal data. The greater goal is to motivate people in comparing energy consumption, competing in energy saving and consequently improving the energy efficiency of Åland.[129] The most efficient customers could be honoured publicly within the close community. Furthermore the most efficient municipality could receive a price by the government to also increase the competition on a regional-political level. The system could one day even send information to people's smart phone about spot price developments and accordingly recommend to start or stop using bigger loads[130]. The active intervention in the current energy consumption via smart phone is considered to belong to the topic smart home respectively part of a smart grid. The term smart home will be presented in chapter 5.1.

All local companies agree upon separating the measurement of consumption and the active control of it both contractually and technically. According to the local telecommunication company Ålands Telefonandelslag, the energy platform Åland and cooperating companies plan to integrate new smart meters for communicating consumption data bidirectionally and discuss to install a future control device communicating via the router in the smart house having access to the internet. The transmission of the remote control information would be the role of the communication company. It is assumed that electricity grid operators will never control private consumption actively from the outside due to personal self-determination laws. It is, however, estimated that people will willingly change their consumption behaviour when they get messages by the service company providing the control device regarding strong

[128] Karlsson (2016): Email dated on 08.09.2016 15:07: "Smart Meters".
[129] Lönnqvist (2016): Expert interview with Mikael Lönnqvist, Debuty CEO of Consilia Solutions AB.
[130] Lönnqvist (2016): Expert interview with Mikael Lönnqvist, Debuty CEO of Consilia Solutions AB.

price fluctuations.[131] This way, load peaks could be smoothened more easily than possible today. Moreover the so called demand response would create a direct answer to spot price shocks and, hence, stabilise even those shortly after.

Smart meter also enable more options for price tariff models. This topic shall be discussed more deeply in chapter 4.5.

[131] Sundborg (2016): Expert interview with Jonas Sundborg, CEO of Ålands Telefonandelslag Cooperative.

4 Economic Analysis of the Åland Energy Market and Market Opportunities

In this chapter relevant national and international laws and regulations will be introduced showing the framework and limits of any possible project and even market scope for Åland. Important organisations and authorities and their roles shall be described in the following. With the environmental conditions clear, different financing options will be presented and analysed. Afterwards, the energy exchange Nord Pool is introduced analysing the relation between infeed shares and spot prices. Also the current tariffs for end-customers in Åland will be presented in this chapter. In the end a discussion follows about the collection of private consumption data.

4.1 Networks and Authorities

This subchapter shall provide an overview over the most decisive organisations in the Nordic countries influencing the Åland energy market directly or indirectly. Therefore the relevant networks and authorities are presented in the following.

4.1.1 Nordel

In 1963 the network between the Nordic TSOs in Denmark, Finland, Iceland, Norway and Sweden named Nordel entered into force. Its goal was to harmonise the common electricity market and improve efficiency through information exchange, cooperation and recommendations. In 2007 the Nordic Grid Code was published that will be presented in chapter 4.2.3. In 2009 Nordel was replaced by the European Network of TSOs (ENTSO-E).[132]

4.1.2 European Network of Transmission System Operators for Electricity (ENTSO-E)

Within the frame of further liberalisation of the European Energy Markets, the EU's Third Legislative Package for Internal Energy Market came in force in 2009 focusing on the main goals:

- to separate energy supply from grid operation ("unbundling"),
- to intensify the independence of regulators by establishing the Agency for the Cooperation of Energy Regulators (ACER),
- to improve the cross-border cooperation between TSOs by creating ENTSO-E and
- to increase transparency in retail markets to benefit consumers.[133]

The European Network of Transmission System Operators for Electricity (ENTSO-E) consists of 42 TSOs from 35 European countries, including Finland. The TSOs increasingly significant role as a coordination

[132] ENTSO-E (2015): News & Events: Former Associations: Nordel.
[133] European Commission (2016): Energy: Markets and consumers: Market legislation.

platform helps interact between all market players.[134] Kraftnät Åland, however, is no member of the network. Instead KNÅ has a proxy at Fingrid, the Finnish TSO that is ENTSO-E member.[135] Goal of ENTSO-E is to form one functioning European energy market respecting the EU's energy and climate aims. The biggest challenge in that lies in the integration of an increasing amount of renewable energies into the grid.[136]
ENTSO-E's mission is to use their legal mandates for the benefit of electricity customers and the whole society regarding changes within the system security, the electricity market and environmental sustainability by finding the adequate development for an integrated European energy market. Its vision is to become the professional body consulting und guiding European and national policy makers and market participants as well as preparing proposals and objective assessments for technical, market and policy issues related to the European electricity systems.[137]

ENTSO-E considers TSOs in charge of the development of the grid infrastructure. Hence, Kraftnät Åland as a TSO plays the central role in transferring the Åland electricity grid into a smart grid and coordinating the grid usage of the other players according to non-discriminatory and transparent rules.[138]

Extending beyond the basic TSO activities, ENTSO-E's tasks include the development of European standards settled in network codes and a common grid model as well as a common system operation channel called Electronic Highway. Another task is the protection of critical infrastructure systems. In order to guarantee grid stability, a methodology for dealing with operational reserves is defined. Moreover, operational incidents are classified and followed up. By cooperating with regional service providers ENTSO-E supports a coordinated system operation.[139]

ENTSO-E promotes the technical cooperation between the TSOs and publishes reports about electricity generation twice a year. Moreover, the body develops long-term pan-European network plans such as the Regional Investment Plan 2015 for the Baltic Sea region and the Ten-Year Network Development Plan 2016.[140] While the Regional Investment Plan for the Baltic Sea region does not consider Åland as such there is, however, a development in this area expected that affects Åland: the decommissioning of nuclear and thermal power plants in Sweden and Finland until 2030 which would cause a certain risk for the surrounding grid stability.[141] Some nuclear reactors in both countries will reach their end of life between 2025 and 2035. Additionally, three reactors will be shut down until 2020.[142] As can be seen in figure 4.1, Finland cannot meet its electricity demand during high load hours and has consequently

[134] ENTSO-E (2015): About ENTSO-E: Who is ENTSO-E?
[135] Kahlroth (2016): Message on 11.08.2016.
[136] ENTSO-E (2015): About ENTSO-E: Who is ENTSO-E?
[137] ENTSO-E (2015): About ENTSO-E: Inside ENTSO-E: Mission and Vision.
[138] ENTSO-E (2015): About ENTSO-E: Inside ENTSO-E: Member Companies.
[139] ENTSO-E (2015): About ENTSO-E: System Operations: What we do.
[140] ENTSO-E (2015): About ENTSO-E: Who is ENTSO-E?
[141] ENTSO-E (2015): Regional Investment Plan 2015 Baltic Sea region, p.6.
[142] ENTSO-E (2015): Regional Investment Plan 2015 Baltic Sea region, p.19.

negative net exports of almost 20 TWh a year. In order to supply the needed power and to prevent supply bottlenecks between Finland and Sweden and between Swedish bidding zones SE2 and SE3 as well as SE3 and SE4[143] (see figure 4.3) it is reasonable either to improve the infrastructure to intensify imports or to install more reserve power to back-up directly where the energy is needed and, hence, where the losses are the lowest, e.g. on Finland's coast and in Åland. However, it must be taken into account that Åland is part of bidding zone SE3 und that there is consequently no price difference if Finland imports energy from Swedish mainland or any other part of SE3. But there are, indeed, some advantages to import from Åland instead of from Sweden, such as:

1. the transmission losses will be lowered due to a shorter import distance which contributes to a more efficient and environmentally conscious dealing with energy resources.
2. the received tax payments from Åland will rise and therefore the Finnish state budget.
3. the Finnish GDP will rise due to the economy growth in Åland.

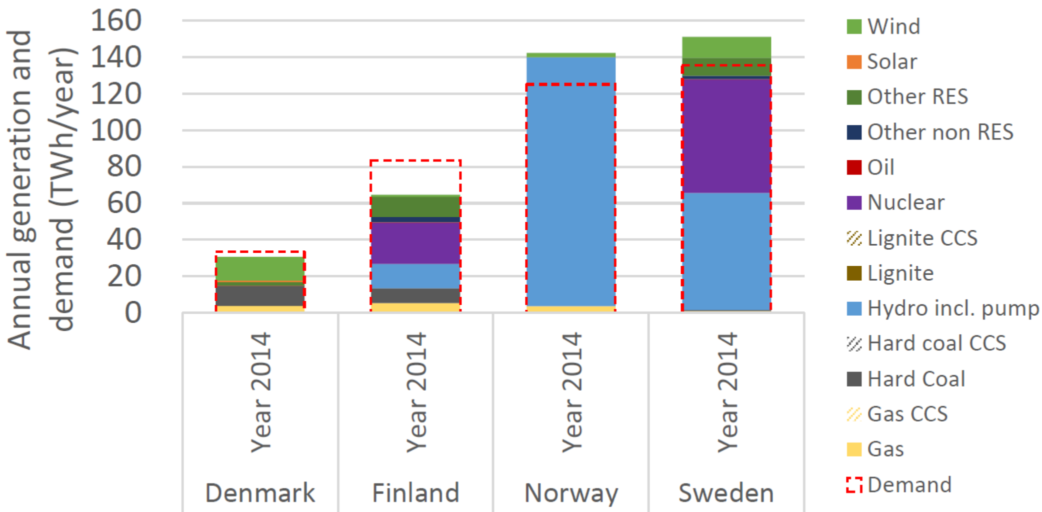

Figure 4.1: Annual Generation and Demand in the Northern Baltic Sea Region.[144]

ENTSO-E also coordinates and participates in R&D like the programme Horizon 2020 which is a financial instrument with a funding volume of 80 billion € between 2014 and 2020 in order to invest in future innovations that are able to improve the European market growth.[145,146] The Ten-Year Network Development Plan 2016 is not final yet but already published for consulting reasons. It discusses which of the projects suggested in the frame of the regional investment plans can and should be realised. One of the presented project possibilities is the option of a new trade-based connection between Finland and Norway as well as a third AC submarine cable between Finland and Sweden. Furthermore project 239 is in discussion which intends to renew the older of the two HVDC submarine cables: the 400 kV connection Fenno-Skan 1 between Sweden (SE3) and Finland promoted by the TSOs Svenska Kraftnät und Fingrid

[143] ENTSO-E (2015): Regional Investment Plan 2015 Baltic Sea region, p.17.
[144] ENTSO-E (2015): Regional Investment Plan 2015 Baltic Sea region, p.15.
[145] ENTSO-E (2015): About ENTSO-E: Who is ENTSO-E?
[146] European Commission (2016): Horizon 2020: What is Horizon 2020?

where 500 MW today shall be updated to 800 MW at some point in the future[147]. ENTSO-E intends to await the common feasibility study by the both TSOs until further steps are taken[148].[149] This could mean competition for Åland.

4.1.3 NordREG

NordREG is an organisation for energy regulation in the Nordic countries. Its members are the Danish Energy Regulation Authority, the Finnish Energy Authority (Energiavirasto), the National Energy Authority in Iceland, the Norwegian Water Resources and Energy Directorate and the Energy Markets Inspectorate in Sweden. Exchanging knowledge and perspectives the issues of the energy market shall be analysed to afterwards develop reports to guide the countries into an efficient, transparent internal electricity market. The goal is to improve competitiveness and efficiency by creating a common market where customers can freely choose their electricity supplier beyond national borders (except Iceland). One part of the tasks is nourished by the cooperation with market participants. Another part of the tasks comes in the field of concrete measures through cooperation with the Electricity Market Group (EMG) that is a working group under the Nordic Council of Ministers. The council will be presented the next subchapter. The last task field is caused by the every project touching cooperation with the Council of European Energy Regulators (CEER) and the Agency for the Coordination of the Energy Regulators (ACER). NordREG's strategy combines matters in different task fields. In regard to the retail market the organisation intends to continue working on a common Nordic end-user market by supporting co-functioning data hubs representing Nordic interests on EU level and exchanging information on earlier recommendations while further recommendations shall be ceased. Regarding the wholesale market, NordREG plans to continue publishing its reports, to perform capacity calculations, to follow up on ENTSO-E's work and to finish the Nordic project to implement a common cross-border balance settlement (NBS) between the TSOs and the spot market in order to create a Nordic body called Settlement Responsible (SR) that handles the operative management of NBS[150]. Another strategic field is network regulation. Within this framework, international studies and recommendations are observed, Nordic interests are identified and harmonisation initiatives focussing regulations and tariffs are forwarded to the Electricity Market Group. Another field is demand side flexibility where current discussions are observed, barriers for demand response are analysed and possible Nordic interests shall be represented.[151,152]

[147] ENTSO-E (2016): Project 239 – Fenno-Skan 1 renewal.
[148] ENTSO-E (2016): TYNDP 2016 – Consultation review of Project Candidate list and Regional Inventment Plans 2015, p.24.
[149] ENTSO-E (2016): TYNDP 2016 Map.
[150] Fingrid (2016): Customers: Balance Service: Nordic Balance Settlement.
[151] NordREG (2016): About NordREG.
[152] NordREG (2016): Work Program 2016. Report 1/2016.

4.1.4 Nordic Council

The Nordic Council consists of 87 elected representatives from Åland (2), Denmark (16), Faroe Islands (2), Finland (18), Greenland (2), Iceland (7), Norway (20) and Sweden (20).[153] The council intends to intensify and improve the cooperation between the Nordic countries in order to attract people to live and work there.[154] At the end of October 2016 the council will convent to debate about the implementation of the UN's Sustainable Development Goals which are:

1. no poverty,
2. zero hunger,
3. good health and well-being,
4. quality education,
5. gender equality,
6. clean water and sanitation,
7. affordable and clean energy,
8. decent work and economic growth,
9. industry, innovation and infrastructure,
10. reduced inequalities,
11. sustainable cities and communities,
12. responsible consumption and production,
13. climate action,
14. life below water,
15. life on land,
16. peace, justice and strong institutions and
17. partnership for the goals.[155]

The goals 7, 8, 9, 11, 12 and 13 are directly related to the energy sector. The council will carry the findings to the prime ministers of the Nordic countries in the 2016 session of the council[156] and, hence, make an impact on politics.

The Nordic Council also publishes proposals, for instance, espousing the funding of refuelling stations for zero-emission vehicles[157] and the research in energy storage technologies[158]. The Nordic Council plays consequently an important consulting and communicating role between the Nordic countries, their politicians and global sustainability goals affecting all societies.

[153] Norden (2016): Behind the Nordic Council: Members of the Nordic Council.
[154] Norden (2016): The Nordic Council.
[155] UN (2016): Sustainable Development Goals.
[156] Norden (2016): High level discussion on the role of the Nordics in implementation of the Sustainable Development Goals.
[157] Norden (2016): Medlemsforslag om samarbeid om utbygging av energistasjoner.
[158] Norden (2014): Utvalgsforslag om energilagring som instrument i klimapolitikken.

4.1.5 The Åland Energy Authority

According to the local law Landskapslag (2015:103) the Energy Authority Åland is has the right and duty to supervise and monitor the local electricity market, all matters of energy as such and the trading of emission gasses. Moreover, the authority follows up on developments and initiates legislative proposals consulting the government on all energy related issues.

4.2 The Legal Framework and the Political Agenda

After the previous presentation of important market forces their work is introduced in the following. Beside the local laws in Åland, there is also a Finish influence on the island group. In fact, Nordic strategies and regulations change the market rules for Åland. Moreover, the European power embraces all developments giving the future strategies for all member states directly or indirectly. The most important legislation and strategies shall be presented in the following.

4.2.1 Åland Electricity Laws

Valid since May 2016, the law Landskapslag (2015:102) replaces the previous Electricity Act (1982:38). The law handles the production, transmission and distribution as well as ex- and import of electricity. It also applies to network operations, balance responsibility, balance power and network tariffs. Furthermore, it declares that the Åland parliament accepts most of the Finnish Electricity Market Act but changes it regarding the local requirements. The law demands certain outage times and makes it easier to access electricity and to change suppliers listing several deviations in §4 Landskapslag (2015:102) concerning technical dimensions which do not apply to the small island market. The most important change coming along with the Finnish Electricity Market Act 2013 is the new definition of transmission grid. The TG used to be a national, looped network with a voltage of 110 KV or more. Now the TG also includes individual, radial cables of a sufficiently high voltage supplying large consumption centres in the DG what results in responsibility changes, discussions and new network fees passed on to the customers.[159] This part, however, does not apply to the situation in Åland: Kraftnät Åland's TG starts at 45 kV as shown in chapter 3.1.2 and there are no large consumption centres to be supplied by higher voltage connections than those realised.

It is common to adopt Finnish laws since it is easier and faster for the small island legislation to simply change fully developed laws, as on the mainland there are much more resources and qualified personnel. So the Åland legislator adds paragraphs according to local conditions and erases other contents which do not apply to Åland, as in this case.[160]

[159] Fingrid (2013): New Electricity Market Act changes the rules of the game.
[160] Juslin (2016): Expert interview with Henrik Juslin, Inspector of the Unit Electricity and Energy at Åland Government.

4.2.2 Finnish Energy and Climate Roadmap 2050

In 2014 the Finnish Government published the Energy and Climate Roadmap 2050 which is a report of the Parliamentary Committee on Energy and Climate Issues. This roadmap explores alternative scenarios to reach the given goals instead of dictating specific steps and mirrors the EU energy policy setting the primary concern on security of supply, environmental sustainability and support of competitiveness. Below the six described scenarios are shortly introduced:

1. Growth Scenario – quick development and adoption of new technologies and wide spread of smart solutions
2. Stagnation Scenario – trade barriers, slow technical development, no global climate agreement
3. Save Scenario – EU saving goals reached early, more investments in energy efficiency than in development of new technologies
4. Change Scenario – radical and quick change of technological development and society structures towards a faster achievement of the goals
5. Baseline Scenario – complying with the Energy and Climate Strategy (2013) until 2025 followed by a trend-like development
6. Base -80% Scenario – like Baseline Scenario with emissions reaching the target levels

According to this report, published by the Ministry of Employment and the Economy (MEE), About 80% of all greenhouse gas emissions are caused by energy production and consumption, including transportation energy. Until 2050 all emissions shall be reduced by 80-95% compared to 1990. Since in 2012 Finland's cleantech sector grew by 15%, the on-going transition to a low-carbon society becomes obvious. Nevertheless acceptable energy prices are crucial for energy-intense Finnish companies to remain competitive on the international market.[161]

To fight global warming and to face the proceeding electrification energy efficiency is supposed to improve significantly to reduce end-consumption at best clearly below 250 TWh by using smart technologies and demand response. Hence, by the end of the 2020s it is aimed to achieve usage of more than 50% emission-free, renewable energy as well as an increase of self-sufficiency to more than 55%, including peat.[162] The degree of self-sufficiency is calculated by putting domestic energy sources as primary energy in relation to the total national energy consumption. Depending on the used methodology, in each scenario Finland is expected to reach 45-65% (nuclear power considered as imported energy) or 70-80% (nuclear power considered as domestic energy) energy self-sufficiency in 2050. Since Finland is connected to the Nordic and European grid trading electricity bidirectionally, economic understanding enforces that the variable production costs must be lower inside Finland than outside to achieve total self-sufficiency.[163] In that matter this roadmap differs significantly from the European roadmap in so far

[161] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. Chapter 1: Central premises, p.13 et seqq..
[162] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. The committee's comments, p.70 f.
[163] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. Chapter 2: Energy production and energy system.

as the EU intends to create one united European energy market whereas Finland plans on increasing its energy autarky.[164]

Furthermore coal shall no longer serve as energy source and the oil imports for domestic needs shall be halved. By 2030 the share of renewable transport fuels is intended to reach 40% at least. In general the Finnish government is supposed to establish support programmes for renewable energy based on technological neutrality and ranking of priorities.[165]

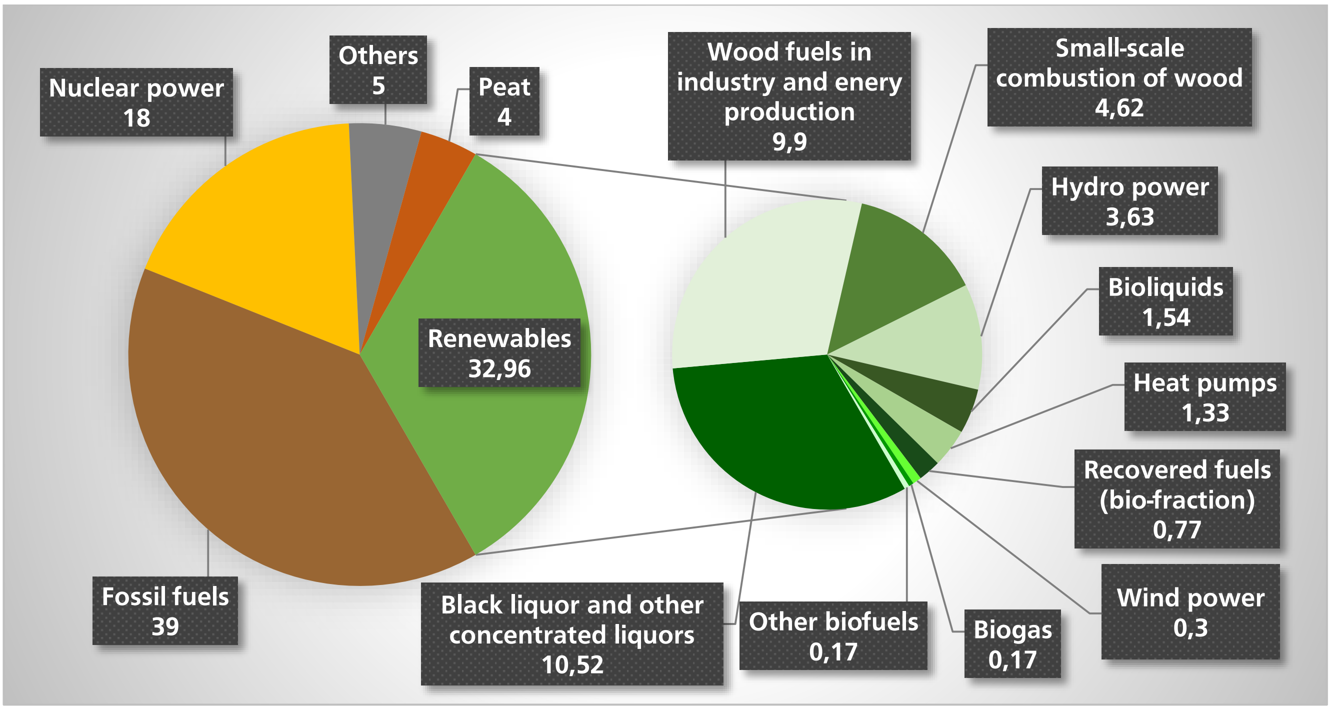

Figure 4.2: Percentage Shares of Sources in the Primary Energy in Finland in 2014.[166,167]

Figure 4.2 illustrates the shares of the different primary energy sources for Finland in 2014. It becomes obvious that wind power does not enjoy a very significant status with only 0,3% while the focus lies on burning fuels that are considered renewable by the Finish government. Carbon dioxide neutral solutions like hydro, wind and solar appear to be rather unimportant.

In electricity production, the biggest share of sources are the renewables with 39%, followed by nuclear power with 35%, hard coal with 11%, natural gas with 8%, peat with 5 % and 2% others.[168] The renewables are subdivided in 52% hydro power, 21% black liquor, 20% other woos fuels, 4% wind power and 2% others.[169] Also this fugures intensify the impression that wind power does not play a very significant role in the Finnish energy transition.

[164] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. The committee's comments, p.70.
[165] Ministry of Employment and the Economy (2015): Current issues. Pending projects. Key projects. Energy and Climate Strategy 2016.
[166] Statistics Finland (2015): Share of renewables of total primary energy 2014.
[167] Statistics Finland (2015): Electricity generation with renewables 2014.
[168] Statistics Finland (2015): Electricity generation by energy source 2014.
[169] Statistics Finland (2015): Electricity generation with renewables 2014.

In fact, due to an unexpectedly good development the Finnish government even limited the support of wind power to save subsidy costs in the amount of 70 up to 80 M€ by 2020. With a new feed-in tarif system a 2,5 GW cap of wind power shall be restrained while there have been installed up to around 3,3 GW by now. Every wind power plant operator must apply for a share in this cap. After authorisation, the plant owner has to apply to be part of the new tarif system until November 2017. Since wind power received 65 % of the annual 214 M€ budget for renewables in 2015 the massive financial support is not considered cost-efficient or market-oriented by the Ministry of Employment and Economy anymore.[170]

By contrast, the German-Finnish Chambre of Commerce financed by the German Ministry for Economy and Energy presented an analysis of wind power development in Finland which come to the conclusion that the investments in wind power plants are in accordance to the 2020 goal of the government likely to meet 50% of the annual consumption by renewables. It must be seen that investments of 500 M€ helped wind power plants produce 2,3 TWh energy in 2015 which equals the double amount of the previous year.[171]

So while the relative growth of wind power in Finland has been, indeed, huge, over the last few years, the total amount of wind power regarding the shares of the other energy sources is still rather small compared to Åland. Consequently the Finnish understanding of the importance of wind power for the island group is not given as strongly as desired by the Åland government in order to receive subsidies. However, the total amount of MW needed for Åland to become self-sufficient by wind power is tiny compared to the development on the mainland.

4.2.3 Nordic Grid Code

Nordel, a collaboration consisting of the transmission system operators in Denmark, Finland, Norway and Sweden, published the current version of the Nordic Grid Code in 2007. The code contains several more specific codes such as the Planning Code and Connection Code which shall be respected as well as the binding Operational Code and Data Exchange Code. The document is updated once a year or more often if needed aiming the rule harmonisation of the numerous national grid operators in the Nordic countries.[172] In the long term a functioning, transparent and effectively integrated Nordic power market shall be achieved and further developed in order to both control the market interaction of established energy enterprises and to make clear statements about the requirements and conditions for new market entries.[173] Beside a few HVDC cables to link subsystems to each other including voltage levels from 285 kV up to 400 kV, there are mainly AC lines installed in the Nordic grid with a common frequency of 50

[170] Hirtenstein (2015): Finland to Limit Wind Power Development, Reduce Subsidy Costs.
[171] Jaanti (2016): Zielmarktanalyse Finnland mit Profilen der Marktakteure. Zukunftsmarkt Windenergie Finnland.
[172] cf. Nordel (2007): Nordic Grid Code. Preface.
[173] cf. Nordel (2007): Nordic Grid Code. Chapter 1: Introduction.

Hertz and voltage levels as table 4.1 shows. Voltage stability, angle stability and thermal stability are the primary goals in this synchronised integrated grid.[174]

Table 4.1: Transmission Voltage Levels of the TSOs in the Former Nordel Member States.[175]

Member Country	TSO	Transmission Voltage Levels / kV
Denmark	Energinet.dk	132 / 150 / 220 / 400
Finland	Fingrid Oy	110 / 220 / 400
Norway	Statnett SF	132 / 300 / 420
Sweden	Affärsverket Svenska Kraftnät	220 / 400

4.2.4 Network Access Conditions for Cross-Border Exchanges

Regulation (EC) No 714/2009 on conditions for access to the network for cross-border exchanges in electricity clearly states how significant cooperation and non-discriminatory network access between European TSOs are for a secure technical development of a competitive internal market carried out by ENTSO-E with a focus on regional efficiency. In that concern it raises the question why the AC connection between Åland and Sweden is still not used to the full technically possible amount restricted by not quite contemporary contractual agreements having their origins in a time long before Nord Pool and such increased shares of renewables in the system[176]. Article 11 also states that a TSO should be compensated for the costs hosting the transmission from one TSO to another one. Not only highlights this the speciality that KNÅ is not connected to the Swedish TSO but to DSO Vattenfall, it also means that for Svenska Kraftnät (SE) and Fingrid (FI) the submarine connection Fenno-Skan[177] is the cheaper option to trade than transmitting the energy via Åland. In order to become a trading platform Åland needs to increase the local production to become more relevant in the picture between those big TSOs.

Furthermore Article 16 claims transparent and non-discriminatory network fees for interconnecting lines between TGs and the capacity of those line is supposed to secure the system stability. So if Åland's installed power grows the cross-border connections will need to be adapted. This legal foundation pointing out an important technical requirement might open a door for KNÅ to finally receive the permission to build a direct grid connection to the TG of Svenska Kraftnät and consequently avoid both Vattenfalls' high connection fee and the contractual limitations of power flow (58 instead of 80 MW)[178].

[174] cf. Nordel (2007): Nordic Grid Code. Chapter 2.3: The electrical characteristics of the Nordic electric power system.
[175] cf. Nordel (2007): Nordic Grid Code. Chapter 2.3: The electrical characteristics of the Nordic electric power system, p.9.
[176] cf. Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[177] ENTSO-E (2016): Project 239 – Fenno-Skan 1 renewal.
[178] cf Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.

4.2.5 Network Code on Electricity Balancing

ENTSO-E's answer to Regulation (EC) No 714/2009 lies in the Network Code on Electricity Balancing 2014 submitted to the European Commission for a revision. Pursuant to article 1 the network code sets common rules for procurement and settlement of frequency containment reserves, frequency reserves and replacement reserves applying to all TSOs and interconnections in the EU.[179] Kraftnät's TG is located on an island but is, indeed, connected to another TSO (Fingrid) and, hence, not excluded from the code.

Moreover, the code defines the TSO-TSO-Model in article 2 as a standard exchange model for balancing services exclusively by TSOs. Moreover, the exchange of balancing capacities and balancing energy from frequency restauration reserves and replacement reserves is exclusively with TSOs.[180] Exclusively means the connection between Kraftnät Åland's TG and Svenska Kraftnät's TG should be permitted in order to achieve a transparent, competitive, internal electricity market as intended by, for instance, the European Commission and ENTSO-E.

4.2.6 Network Code on Demand Connection

The European Commission's Demand Connection Code came into force in September 2016 and has to be transferred into national law within the following two years[181] setting the ground for a harmonised legislation in all European member states for demand facilities and distribution systems to be connected to the grid. In accordance to article (3) the goals are to secure the system, to integrate more renewables, to improve the competition, to use the network resources more efficiently and to benefit the end-customers. According to article (7) this code does not apply to existing demand connections but to new TG-connected demand and distribution facilities as well as new DGs and demand units used by those in order to provide demand response services to TSOs.[182] If Åland is supposed to possess much more volatile renewable power plants in the future, there should, in fact, be taken political steps in order to create incentives for local demand response providers to offer such service. Hence, Åland government might adapt the Finnish law on that regulation in regard to local conditions.

4.3 Financing

There are basically four different financing methods in the books. First it must be differentiated whether the monetary aid comes from inside (equity financing) or from outside (debt financing) of the investing economic unit. When speaking about equity financing it must then be distinguished between internal and external equity financing. This also applies for debt financing where there is both an internal and

[179] ENTSO-E (2014): Network Code an Electricity Balancing.
[180] ENTSO-E (2014): Network Code an Electricity Balancing.
[181] VDE FNN (2016): Network Code on Demand Connection.
[182] European Commission (2016): Network Code on Demand Connection.

an external way.[183] In the following subchapters those four finance sources shall be analysed for the Åland case. Besides, also project finance is a reasonable approach worthy to be analysed to finance especially several milestones along the way towards a smart grid in Åland. Finally, the Finnish Mankala company, another option to ease the financing, as well as GO^2 funding will be presented.

4.3.1 Internal Equity Financing

Internal equity financing works by using retained profits or hidden reserves.[184] As shown in chapter 2.4, most companies in the Åland energy market are owned by the city of Mariehamn, by the government or by the customers themselves and, hence, are not profit-oriented. According to their annual reports analysed in chapter 2.1 there are no profits huge enough to finance for example the planned wind park in the Eastern archipelago. Consequently this finance source is exhausted.

4.3.2 External Equity Financing

External equity financing still means the usage of company resources but this time coming from the outside. The easiest way for listed companies is the increase of capital stock, so called seasoned equity offerings.[185] Since none of the energy companies in Åland is listed at the spot market the only possibility to use this kind of financing is to increase the deposits of the shareholders.[186] Since those shareholders are, as mentioned, mostly governmental institutions or the citizens themselves in their role as customers, there is no option for most of the Åland companies here. Only the profit-oriented wind farm owner Allwinds could without obstacles consider getting an external associate on board but would then, of course, forfeit influence and decisional power.

4.3.3 Internal Debt Financing

Internal debt financing works by creating accruals for future claims unknown in height and maturity. Hence, company money is accumulated to pay back debts at some point.[187] For there is not much money left to be saved for future debts this is not quite a reasonable financing option for Åland's green smart grid intentions.

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[183] Napp (2015): Sides of the lecture Projektfinanzierung, ch. Investition und Finanzierung – Grundlagen: Systematisierung von Finanzierungen: Finanzierungsalternativen, p.13 f..
[184] Gabler Wirtschaftslexikon (2016): Selbstfinanzierung.
[185] Schiereck (2015): Script of the lecture Corporate Finance I, ch. Seasoned Equity Offerings: definition, reasons and types, p. 299.
[186] Gabler Wirtschaftslexikon (2016): Beteiligungsfinanzierung.
[187] Gabler Versicherungslexikon (2016): Finanzierung auf Rückstellungen.

4.3.4 External Debt Financing

External debt financing means receiving money from an external party in a short, medium or long run usually with performance-based interests and repayments.[188] So beside these obvious incentives, external investors need to believe in an Åland smart grid project in order to provide the money for projects such as bigger wind, solar and battery parks and to support the usage of EVs and the necessary infrastructure for them. Consequently it could either be a politically motivated investment by Finland (to support the show case) or an EU initiative to support the European technology lead or it could be a business motivated investment by a cluster[189] of technically leading companies to test future products within a manageable island frame.

4.3.5 Project Finance

All previous financing options have direct impact on the balance sheet of a company. A different approach is project finance where a project corporation is founded just for the purpose of the specific project situation. The risks are allocated flexibly between all participants, the liability is limited, the repayment is made by future cash flows and the only insurance are the assets of the corporation.[190] So for instance, an Åland energy association consisting of ÅTEC and at least the five big energy companies Kraftnät Åland, Ålands Elandelslag, Mariehamns Elnät, Mariehamns Energi and Allwinds could coordinate the whole Åland smart grid programme. In that programme there could be smaller projects for new renewable power plants, energy storages, new infrastructures and more. Each project could get external sponsors on board to share know-how and risks.

4.3.6 Mankala Company

In Finland there is a cost-price model for energy companies called Mankala named after the first of their kind: the Oy Mankala AB founded in the 1960s. After World War II energy companies were not able to secure electricity supply alone so they cooperated in a limited company creating economies of scale and improving efficiency by combining resources. In the Mankala model a power company sells electricity and heat to its shareholders without any profit while the shareholders pay the company's costs proportionally to their share without any dividend. The owners can, however, sell the bought electricity or heat forward. Hence, competences, financial resources and risks are shared. Due to the Mankala company's low risks and broad risk allocation it is quite easy to find further external investors.[191]

[188] Gabler Wirtschaftslexikon (2016): Fremdfinanzierung.
[189] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.
[190] Napp (2015): Sides of the lecture Projektfinanzierung, ch. Projektfinanzierungen: Projektfinanzierung, p.2.
[191] Pohjolan Voima (2016): The Mankala cost-price model increases competition in power production.

The Supreme Administrative Court allowed the Mankala model since the owner's obligation to buy the energy at cost-price is not a so called concealed distribution of dividends – which would be illegal – but is, in fact, a necessity for the Mankala company to survive. Besides, the cost-price can be both below and above the market price, so the shareholders do not make profits inevitably. Moreover, the National Board of Taxes permitted the model for the Mankala company itself does not aim at any profits and – if the owners sell the energy profitably – they pay the full tax anyway. Also the Competition Authority consented to the Mankala model because it does promote competition and market diversity by enabling even small energy companies to participate in new power projects which would be too big for them alone. But as long as the Finnish government does not pass a specific law permitting Mankala the model is vulnerable to international criticism.[192]

Beside the fact that the Mankala model owes its presence only to case law, its advantages have become clear. Since the Åland energy companies fulfil different task fields (production (electricity and heat), transmission, distribution) they could, indeed, create a common Mankala company to build for instance a new wind or solar power park. They would all profit from the development towards a self-sufficient smart grid in Åland. However, in their current financial situation they would probably have to take in external companies as well.

4.3.7 GO^2

According to directive 2009/28/EC (52) with the general goal to intensify the increase of renewables, EU member states are obliged to establish a national register for electricity produced from renewable energy sources. More precisely, with every MWh produced from renewables the corresponding power plant owner receives a Guarantee of Origin (GO). In Finland GOs are issued by the national TSO Fingrid, member of the Association of Issuing Bodies[193,194]. Electricity suppliers can then buy GOs to make their provided energy mix transparent and more promotional. Even end-customers can buy GOs to make sure green electricity is produced because of their direct demand for it. A GO certificate lasts one year. During that time it must be devalued either by marking usage or by selling it to the next link in the supply chain; otherwise it just ends. Trading GO certificates at the spot market between EU countries as well as Switzerland and Norway both strengthens the increase of renewables and offers new marketing opportunities for power plant owners. [195,196]

A new European financing system for renewable power plants (bio, geothermal, hydro, solar and wind power) is given by a loan-based funding combining GO and project finance named GO^2. The GO^2 system

[192] Schröder; Pirttilä (2011): Mankala energy production model under threat?.
[193] Energiavirasto (2016): Etusivu: Energy Authority: Industry Professionals: Renewable energy: Guarantees of origin of electricity.
[194] Association of Issuing Bodies (2016): Facts: AIB Members.
[195] Energiavirasto (2016): Etusivu: Energy Authority: Industry Professionals: Renewable energy: Guarantees of origin of electricity.
[196] EEX (2016): Herkunftsnachweise für Grünstrom: EU-Richtlinie 2009/28/EG zum Handel mit Herkunftsnachweisen.

covers up to 15% of the total costs for a new power plant by triggering a domino effect. A GO² financed project is required to be ready-planned which is given in the case of the 100 MW wind park in the Eastern archipelago of Åland[197]. GO² United, where several companies invest in a project, allocates 0,60€/MWh to the ECOHZ Renewable Energy Foundation. GO² Signature, where one sponsor invests exclusively in a project, allocates at least 80% of the sales price to the foundation. Since the GO² funding is loan-based the first financed projects will refinance the next generation which will refinance the generation afterwards and so on.[198,199]

So the only task for Åland is to ensure that their 100 MW wind park project is, in fact, ready planned and then apply. This financing opportunity may only cover 15% of the total costs to build and connect the wind power plant to the grid, it does, however, create a perspective for the Åland energy market.

4.4 Energy Exchange at Nord Pool

Beside the regulated spot market there is also an off-market called over-the-counter market (OTC). At the OTC usual trade rules do not necessarily apply but contractual partners agree upon their own contract conditions in order to increase risks and chances and the return. Because of this vast field of financial instruments and the flexibility of regulations this thesis will not consider the OTC market in any more detail but instead analyse the situation at the Nordic spot market for energy: Nord Pool.

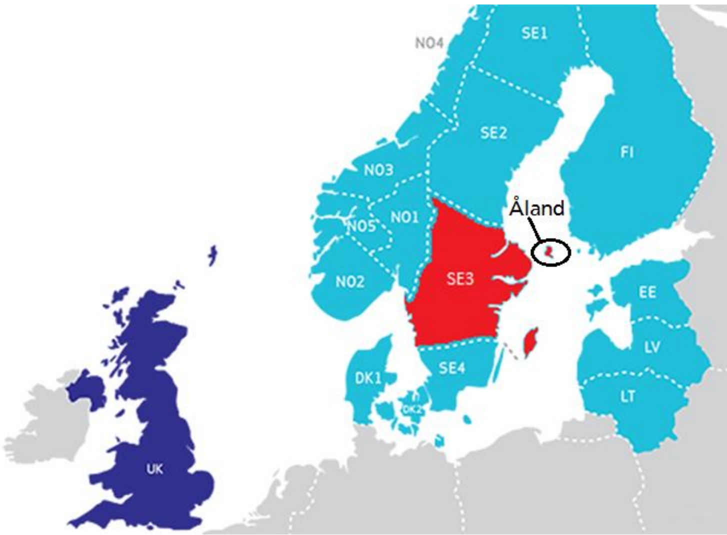

Figure 4.3: Nord Pool Bidding Zones with Åland marked in SE3 coloured red.[200]

Nord Pool is the Nordic energy spot market divided in several bidding areas. Åland is part of the Swedish bidding zone SE3 as can be seen in figure 4.3. The spot market's origins go back to 1991. Nord Pool is owned by the Nordic TSOs Statnett SF (NO), Svenska kraftnät (SE), Fingrid Oy (FI) and Energinet.dk

[197] Lindqvist (2016): Expert interview with Henrik Lindqvist, CEO of Allwinds AB.
[198] ECHOZ (2016): GO².
[199] TÜV Rheinland (2016): Certificate C-07-2016-21236063 for GO².
[200] cf. Nord Pool (2016): Bidding areas.

(DK) as well as by the Baltic TSOs Elering (EE), Augstsprieguma tikls (LV) and Litgrid (LT). TSO Kraftnät Åland, however, is no shareholder of the spot market. In 2015 the total annual trade volume in the Nordic and Baltic day-ahead market was with 374 TWh record, 5 TWh in the Nordic, Baltic and German intraday market and 110 TWh in the day-ahead market in the United Kingdom.[201]

Nordpool is considered a Nominated Electricity Market Operator (NEMO) according to Capacity Allocation and Congestion Management (CACM).[202] CACM, ENTSO-E's second network code, came into force in August 2015 in order to secure the supply, to create a competitive internal energy market and to decarbonise the electricity sector in Europe.[203] According to Commission Regulation (EU) 2015/1222 article 4 each member state electrically connected to another member state of the EU shall designate a NEMO in every bidding zone to perform the single day-ahead and/or intraday coupling. In compliance to article 7 Nord Pool's role as a NEMO is to cooperate with the TSOs in trading, meaning, to take and allocate orders so that they match, to publish prices as well as to settle and clear the contracts between the market participants.

There are basically two different trade markets at Nord Pool but all trade takes place at central European time (CET): The day-ahead market Elspot and the intraday market Elbas. Most of the power is traded at Elspot where orders for the next day are taken. Seller and buyer agree upon a price for the power provided one day later by concluding a contract of sale. Bids can be submitted until 12:00 CET. Afterwards a computer programme calculates the hourly market price for the next day which is where demand and supply meet. Not only do demand and supply determine the price but also the transmission capacities do. To reduce the demand in bidding areas where transmission capacity is needed the price is risen.[204]

The rest of the power trading takes place continuously 24 hours a day at the intraday market Elbas up to one hour before delivery. Because of increasing volatile electricity production from renewables Elbas is expected to grow compared to Elspot and become more important.[205]

To get an impression of the price development in SE3 the Elspot prices were analysed. For Elbas there is no SE3 specific data available. Figure 4.4 shows the average price development for one day in 2015. The curve is similar to the KNÅ electricity consumption curves in chapter 3.2. Of course, Åland is too small to have a huge impact on the Swedish bidding area SE3 but load curves are from experience mostly everywhere rather similar. Obviously the day-ahead prices are strongly influenced by the average load curve. During night the price is the lowest followed by a steep ascent in the morning. Around noon the price relaxes again and then rises during evening before it lowers again for the night.

[201] Nord Pool (2016): About Us.
[202] Nord Pool (2016): About Us.
[203] ENTSO-E (2015): Capacity Allocation and Congestion Management (CACM).
[204] Nord Pool (2016): Day-ahead market.
[205] Nord Pool (2016): Intraday market.

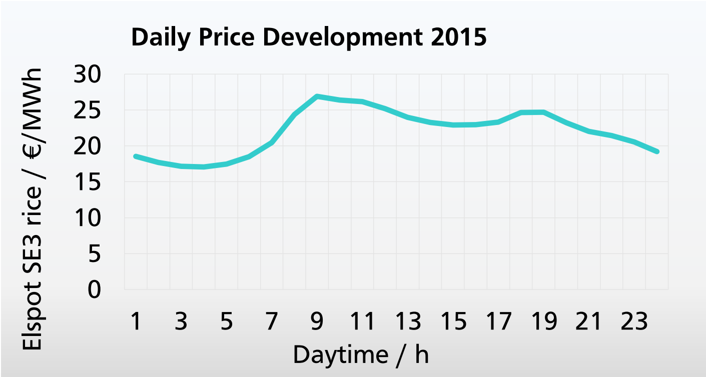

Figure 4.4: Daily Elspot Price Development after Hourly Average Prices at Nord Pool's SE3 in 2015.[206]

To receive a better impression of the price fluctuation during one year the weekly average prices of 2015 are shown in figure 4.5. It becomes clear that the prices are on average higher during winter than during summer. This could be caused by the higher energy demand during winter in general. But it could also indicate increased infeed fluctuations from especially wind power that raise the spot price.

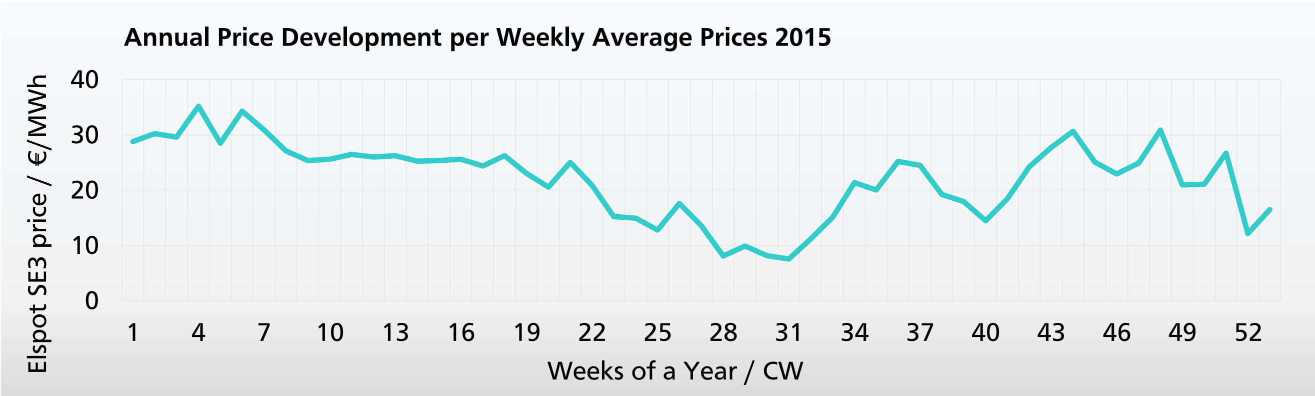

Figure 4.5: Annual Elspot Price Development per Weekly Average Prices at Nord Pool's SE3 in 2015.[207]

To show how unpredictably the prices develop on a daily average price basis, figure 4.6 illustrates some strong peaks. An daily average price over 60 € in the winter of 2015 is, in fact, significantly over the annual average of 22,04 €. Assuming a case in which Allwinds overpredicts the infeed from wind power it becomes easy to imagine how huge the costs can get for a small company when they need to buy much power from Nord Pool at the wrong time. Those costs can only be passed on to end customers at the end of the invoice year what can be a long time to wait for a small company to cover costs.

[206] Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
[207] Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.

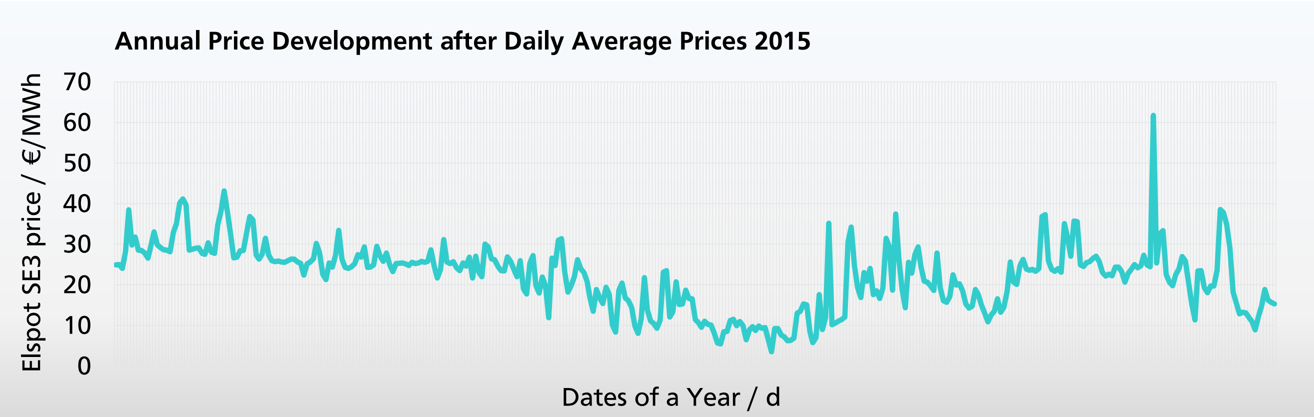

Figure 4.6: Annual Elspot Price Development after Daily Average Prices at Nord Pool's SE3 in 2015.[208]

In order to better classify the price development at Nord Pool's SE3, figure 4.7 shows the monthly average prices from January 2011 until October 2016. After each year there is a gap in between the curve. Neglecting the peaks it becomes obvious that the price is all in all decreasing as the trend line (dots) indicates.

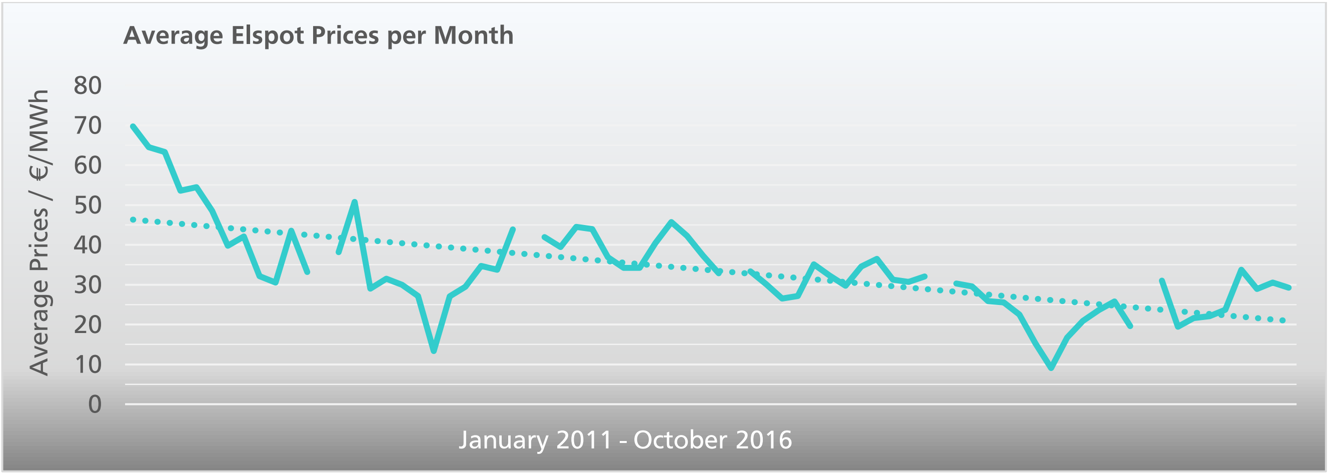

Figure 4.7: Average Elspot Prices per Month for Bidding Zone SE3 at Nord Pool.[209,210,211,212,213]

In order to improve the understanding of peaks, figure 4.8 shows the weekly average prices from January 2011 until October 2016 also leaving gaps between each year. The data for previous years are not available for SE3. The price fall during 2011 is significant starting over 80 € and ending under 30 €. In January 2012 the year started with a strong peak while in summer there was an intense price fall under 10 € on average. 2013 and 2014 were comparatively unspectacular except for the very low price during late summer 2014. In the beginning of 2015 there was a radical peak again. While the previous years show small or large price falls during summer the average prices in 2015 were rising.

[208] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
[209] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2011.
[210] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2012.
[211] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2013.
[212] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2014.
[213] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.

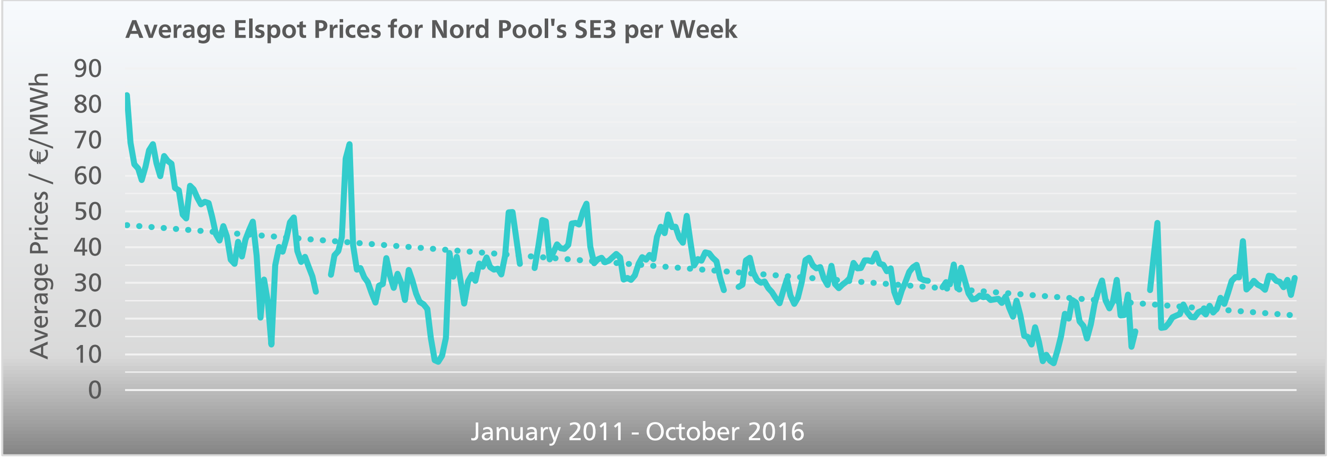

Figure 4.8: Average Elspot Prices per Week for Bidding Zone SE3 at Nord Pool. [214,215,216,217,218]

In fact, there is no typical annual price curve noticeable repeating itself each year. To improve the insight into the annual price development over the last few years, figure 4.9 illustrates the hourly price data each year for 2011 until 2016. In 2012 the peak price in the beginning of the year reached over 250 €. Also the hours around this peak were not cheap which again picks up the challenge for small energy companies to survive only a few expensive hours after a wrong prognosis of the wind speed or the sun hours when their customers help carry those costs only after several months. In the beginning of 2016 the price went over 200 € as well after some other smaller peaks before. Also during the summer 2015 there was a high price peak of about 170 €. At the end of the year there are again peaks visible. Those can be found in almost all of the data series. All in all it becomes obvious that the grey price curve in 2011 moves over the blue one from 2012. 2013 is again situated higher than 2014 which is higher than 2015. 2016 started with the same pattern except for the comparatively highly-priced summer as already mentioned.

So this data show clearly that there are some few extremely high peaks which can cause economic struggles for smaller companies like the ones in Åland. Moreover it points out a generally decreasing price trend over the last 6 years. And it also makes clear that there seem to be vague time windows where price peaks become more likely such as winter and sometimes even the usually calm time in the middle of the year while spring and autumn do show peaks but rather small ones especially in the last three years.

[214] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2011.
[215] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2012.
[216] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2013.
[217] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2014.
[218] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.

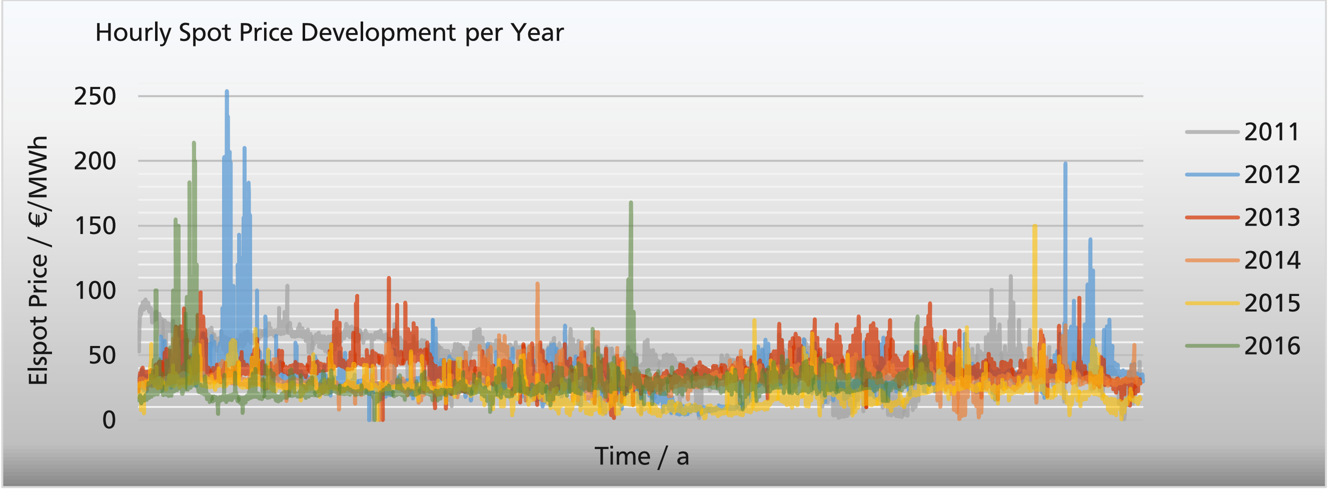

Figure 4.9: Hourly Elspot Price Development 2011-16 at Nord Pool's SE3. [219,220,221,222,223]

After looking only at Elspot prices the next four figures add Svenska Kraftnät production data for SE3. Considering only 2015 there has been made a seasonal distinction like with the Kraftnät Åland load data in chapter 3.2.

While the covariance analysis for the whole year could not show impressive findings as table 4.2 makes clear it does show the negative relation between the price and wind power, solar power and net export. It sounds reasonable that the price decreases due to the oversupply caused when volatile wind and solar power shares grow. It is also plausible that the price falls when there is so much load in the grid that exports exceed imports. Hydro, thermal, nuclear and fossil power have consequently a positive correlation to the price because those energy sources are plannable and will, hence, follow the price development and even create the prices.

Table 4.2: Correlation between Elspot Prices and in SE3. [224,225,226,227,228,229]

Production per Energy Source / Net Export / Consumption	Correlation between Elspot Price and Energy Source
hydro power	0,3326
wind power	- 0,0774
nuclear power	0,3065
thermal power	0,6059
fossil power	0,1886
solar power	- 0,0250
net export	- 0,5050
total consumption	0,6427

219 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2011.
220 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2012.
221 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2013.
222 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2014.
223 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
224 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2011.
225 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2012.
226 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2013.
227 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2014.
228 cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
229 cf. Svenska Kraftnät (2016): Statistik per timme och elområde 2015.

Since winter time in 2015 expands over two separate periods figure 4.10 shows a break in the end of the time line. The left part of the data if from January and February 2015, the right part is from the next winter starting in December 2015. When looking at the price peaks it becomes obvious that in some cases nuclear production rapidly decreased shortly before the peaks and the other way round: after price peaks often nuclear generation was increased because it is a quite inexpensive energy source. Moreover it becomes visible that the price reacts with a fall to lots of wind power infeed at the end of the year. Fossil and solar power infeed is here too small to be considered while the continuous hydro and thermal power seem to cover a certain load at all times due to their plannable operation and nuclear power obviously covers the base load.

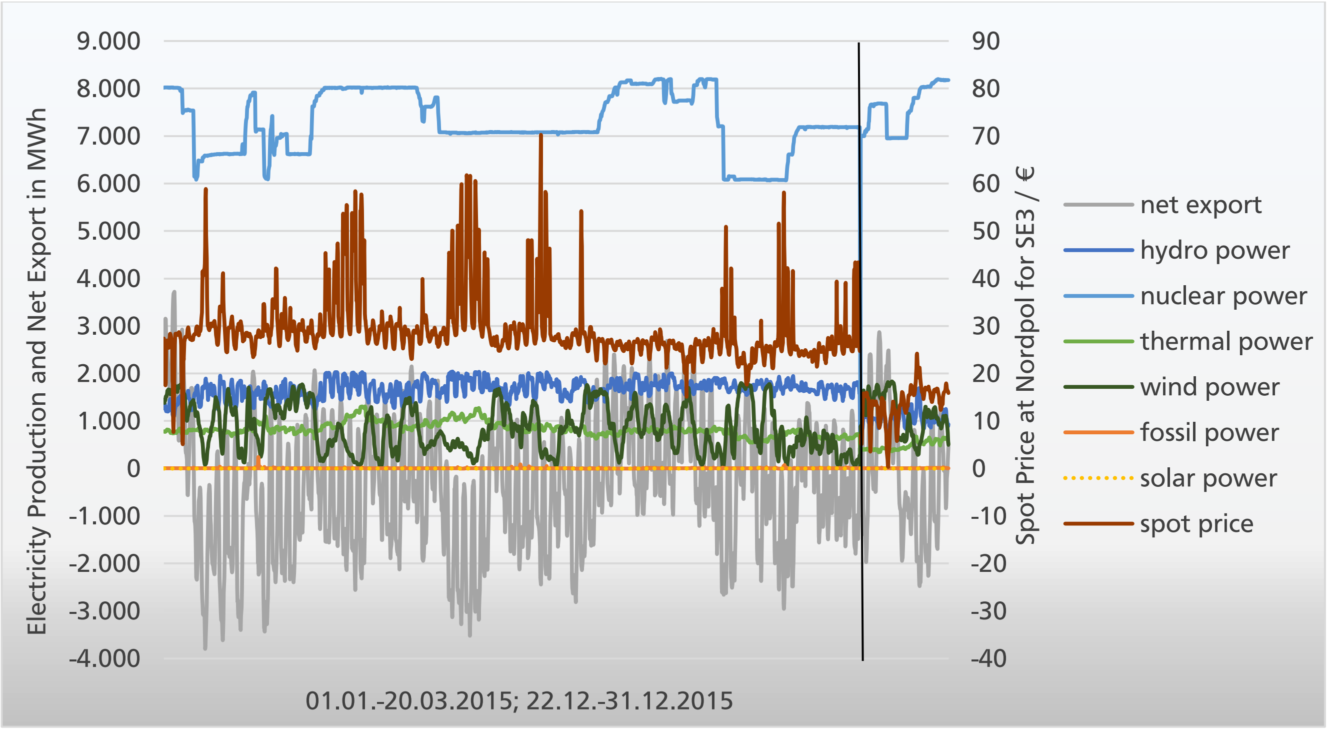

Figure 4.10: Electricity Production Shares in Winter and Spot Price Development in Nord Pool's bidding zone SE3 in 2015.[230,231]

Figure 4.11 illustrates the data for SE3 in spring 2015. It is easily noticeable that the imports rise when nuclear power infeed sinks because the base load has to be covered. Wind power infeed again shows a very volatile performance. At some wind peaks the spot price clearly drops. All in all there are less price peaks than during winter. Hydro, thermal, solar and fossil power behave in spring similar to winter.

[230] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
[231] cf. Svenska Kraftnät (2016): Statistik per timme och elområde 2015.

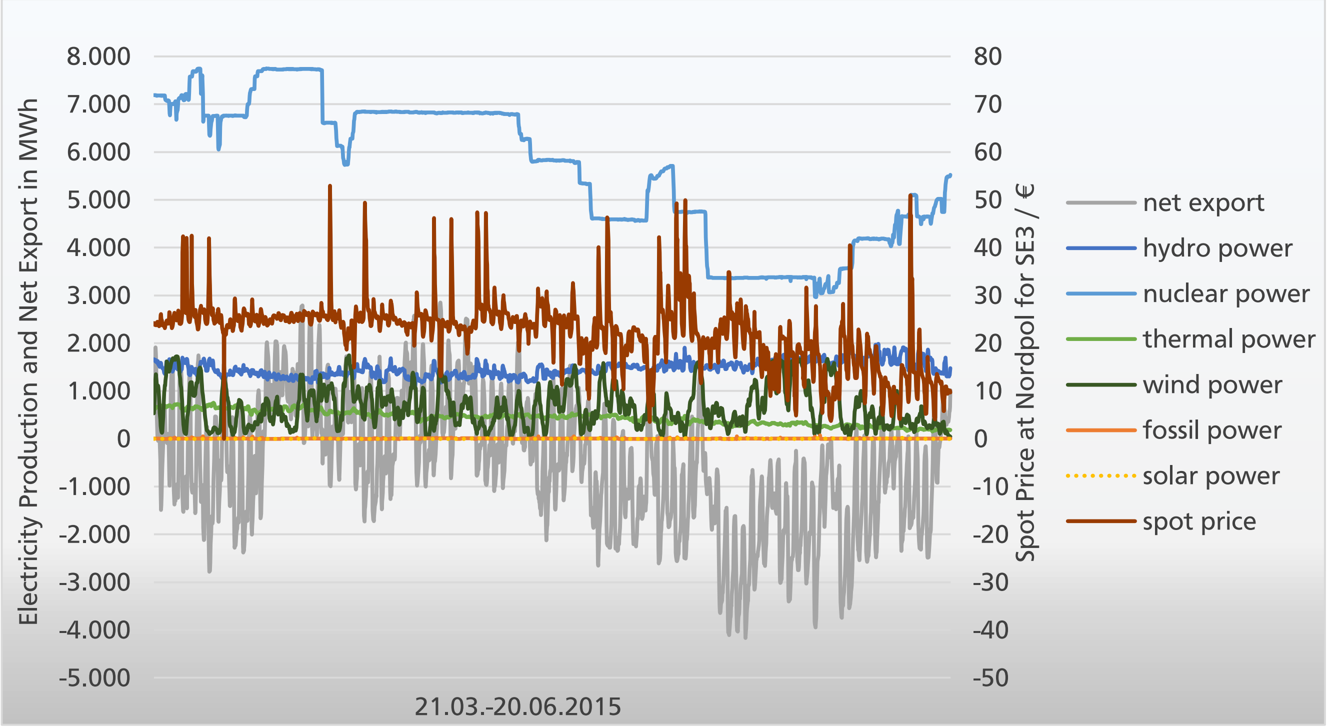

Figure 4.11: Electricity Production Shares in Spring and Spot Price Development in Nord Pool's SE3 in 2015. [232,233]

Figure 4.12 shows the electricity production in summer adding the price development into the picture. In the first half of the period the price is remarkably stable while the exports and hydro power infeed are higher than before and after. In the second half of this period when a lot of energy is imported the price often shows extreme peaks. Again it is a pattern that the price falls when wind power share increases which becomes clear especially in the second half.

[232] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
[233] cf. Svenska Kraftnät (2016): Statistik per timme och elområde 2015.

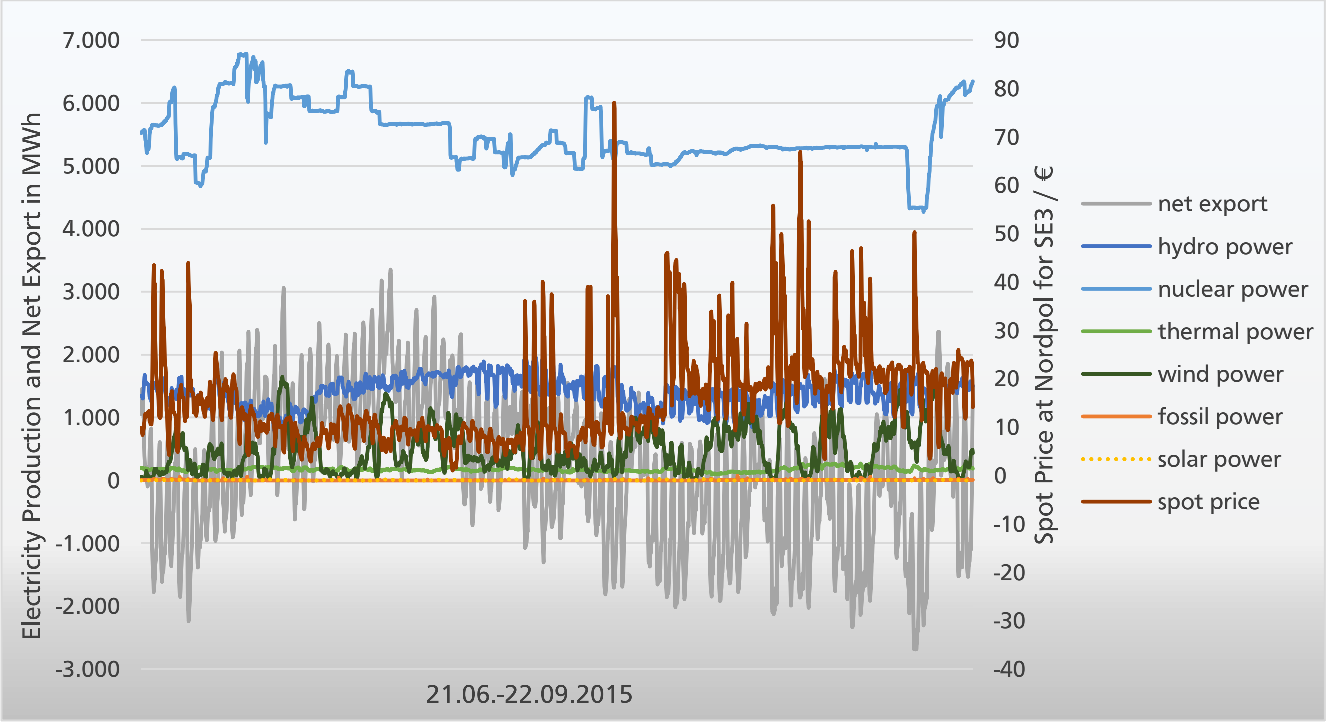

Figure 4.12: Electricity Production Shares in Summer and Spot Price Development in Nord Pool's SE3 in 2015. [234,235]

When looking at figure 4.13 showing the situation in autumn the huge price peak after two thirds of the period strikes. When there is a high demand for electricity but not enough supply so that the imports increase, the price goes up rapidly as can be seen here exemplarily. During the end of autumn there is a short phase with lots of wind power infeed followed by a recession and another increase. Conclusively, it can be said that when there is usual nuclear power production, much wind infeed and positive net export, the spot price should fall. When, however, there is less wind power infeed and negative net export, the price rises according to the calculated correlations shown in the beginning of this analysis.

[234] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
[235] cf. Svenska Kraftnät (2016): Statistik per timme och elområde 2015.

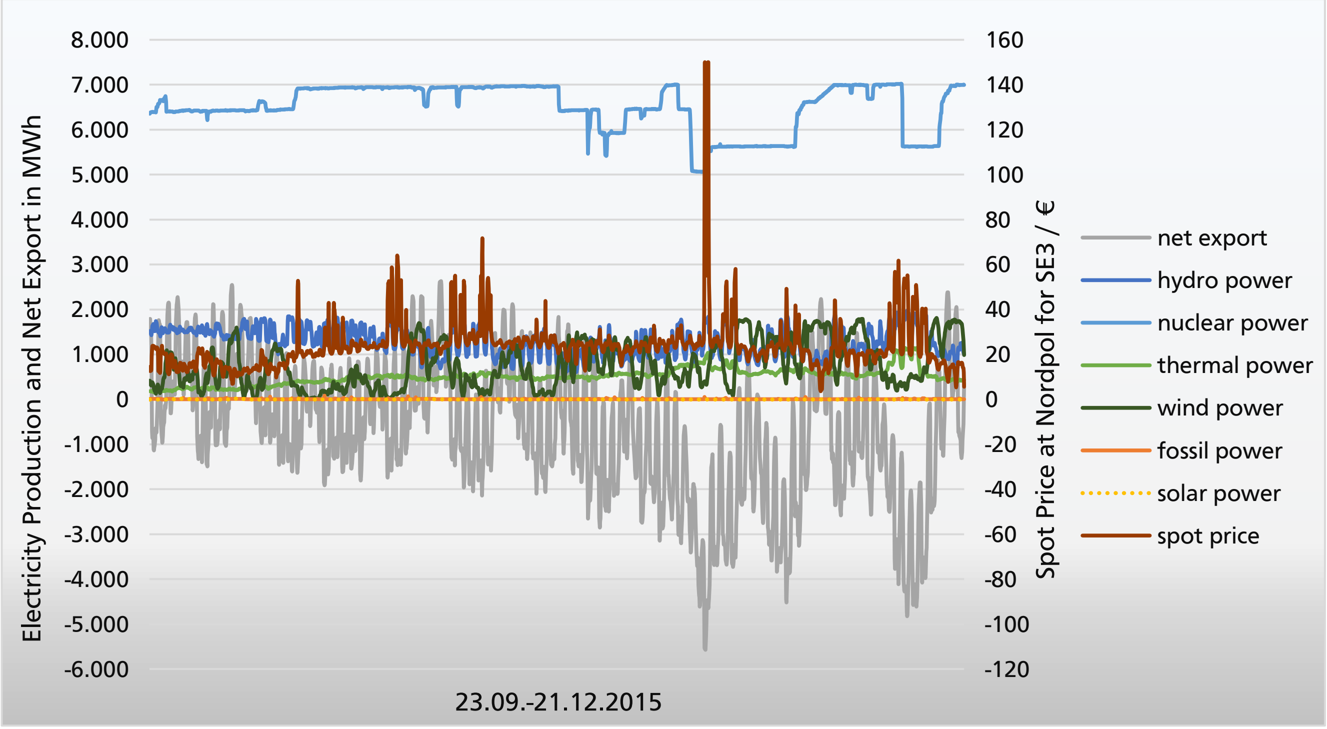

Figure 4.13: Electricity Production Shares in Autumn and Spot Price Development in Nord Pool's bidding zone SE3 in 2015. [236,237]

Summing up the findings for Nord Pool's bidding area SE3 it can be concluded that hydro (0,3 correlation with the price) and thermal power (0,6 correlation with the price) do not cause a visible impact on the price development although thermal power has a empirically indicated positive relation to the Elspot price. Fossil (0,2 correlation) and solar power (-0,02 correlation) do probably not feed in enough electricity into the system for a noticeable influence which matches their tiny correlation values. The base load covering nuclear power (0,3), however, plays a key role especially when it comes to the net export which is more visible in the figures than proven by the statistical values calculated. Consequently high import rates (net export: -0,5 correlation) increase the price which matches the curves whereas the correlation pointing out a negative relation does not prove a great influence. Wind power is the biggest volatile infeed source and even though the correlation (-0,08) is not significant, the unpredictable changes in production clearly show price leaps in the figures.

For Åland striving for significant electricity exports from wind power that means on the one hand the possibility to influence the price at the spot market but on the other hand the risk – assuming wind power in general increases in SE3 – of rapid price shocks when the wind suddenly lacks and the price skyrockets causing immense costs for – today – small local companies.

[236] cf. Nord Pool (2016): Stockholm-prices in Elspot per hour 2015.
[237] cf. Svenska Kraftnät (2016): Statistik per timme och elområde 2015.

4.5 Different Tariff Models

The end-prices for electricity customers in Åland consist of several parts as following:

- 24% VAT,
- 0,703 cent/kWh energy tax for industrial customers and greenhouses (exclusively VAT),
- 2,253 cent/kWh energy tax for all others (exclusively VAT),
- annual connection fee,
- annual basic fee for main fuse,
- network fee per transmitted MWh,
- electricity price per transmitted MWh. [238,239]

There are different tariff models offered by the Åland DSOs Mariehamns Elnät and Ålands Elandelslag for pricing the electricity consumption listed below:

Mariehamns Elnät:

- normal tariff,
- day/night tariff,
- seasonal day/night tariff (spring/summer/autumn/winter),
- load tariffs for HV customers (reactive/active power),
- load tariffs for LV customers (day/night; reactive/active power),
- spot price tariff,
- micro-production tariff,
- temporary meter tariffs (for construction works).[240]

Ålands Elandelslag:

- normal tariff,
- tariff for electric heating customers,
- time tariff (working days / weekend and nights; Jan.-Apr./May-Sep./Oct.-Dec.),
- load tariffs for HV customers (reactive/active power),
- load tariffs for LV customers (reactive/active power),
- tariff for aerial companies, line amplifiers and similar facilities,
- micro-production tariffs,
- production tariff (HV/LV; Nov.-Mar./Apr.-Oct.),
- temporary meter tariff (for construction works).[241]

[238] Mariehamns Elnät (2016): Elavgifter 2016.
[239] Mariehamns Elnät (2016): Elavgifter 2016.
[240] Mariehamns Elnät (2016): Elavgifter 2016.
[241] Åland s Elandelslag (2016): Elavgifter 2016.

While the end-customers can choose between the listed tariffs according to their requirements the local suppliers cannot but have to buy their electricity from Vattenfall Eldistribution AB and their balance power at Nord Pool. In fact, Kraftnät Åland has to buy a tariff (L1, Södra Sverige) of Vattenfall and pay an annual grid fee for the connection to the Swedish TSO.[242]

Shown in chapter 4.4, energy spot prices on average do have a certain daily curve and they also show seasonal tendencies. It consequently does make sense to adapt the normal end-customer tariffs to the fluctuations at the spot market because more dynamic price models offer cost-saving opportunities for end-customers and enable suppliers to pass on price shocks and, hence, scatter entrepreneurial risks. It might even minimize the risk to establish a monthly (instead of annual) invoice system so that such price shocks could be smoothened promptly. Such a system, however, would cause fluctuating costs for the end-customers who might not want such debt uncertainty. So a compromise could be an incentive model in which customers who possess a monetary security margin can decide voluntarily for a monthly invoice by receiving some kind of price discount.

In Consilia Solution's future model presented in chapter 3.3 to create a data hub consisting of metering and customer data is approved by many local energy companies. The idea is to let this information network grow. So there could be added a function sending the spot price development to customers so that they can adjust their consumption accordingly – in other words: demand response.[243,244,245,246] Grid operators supplying electricity should, however, investigate which relation is reasonable between scattering price shocks by demand response measures and balancing the load by experience curves.

4.6 Collecting Data

Software communication tools are the core of a smart grid as presented in chapter 2.2. But before data can be communicated, it must, indeed, be collected in a so called data hub. According to NordREG's status report 2016, Fingrid is already working on a data hub project for electricity meter data and market processes which is supposed to be in operation until August 2019. Meanwhile, the Finnish Ministry of Employment and the Economy adapts the legislation so no legal obstacles will stand in the way. A customer council (DSOs, suppliers, organisations) consults the working group, monitors the project development and communicates updates towards the stakeholders. Some of the many functionalities of the future Finnish data hub are:

- meter point management (run by DSO),
- customer data management (run by supplier with a new contract),

[242] Kahlroth (2016): Email dated 30.10.2016 18:23: “SV: Urgent: Tariffs”.
[243] Lönnqvist (2016): Expert interview with Mikael Lönnqvist, Debuty CEO of Consilia Solutions AB.
[244] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[245] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[246] Häggbloom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.

- contract management (run by supplier, confirmed by DSO),
- meter value management (run by DSO, stored for 6 years),
- third party access to meter,
- market monitoring,
- compiling statistics,
- billing (will be run by supplier, today still two bills for electricity and network each),
- dis- and reconnection and
- handling of customer's handling of attorney. [247]

Åland appears to be in the comfortable situation to await the new Finnish laws on collecting customer data for a future electricity market and adapt them according to the local plans described in chapter 3.3. The Finnish Competition and Customer Authority regulates consumer rights while Åland has no possibility to adjust these laws[248]. In order to create the best possible surroundings for a smart grid in Åland the legal development should be observed closely. The combination of consumer rights and energy laws might give room for legal creativity, if required.

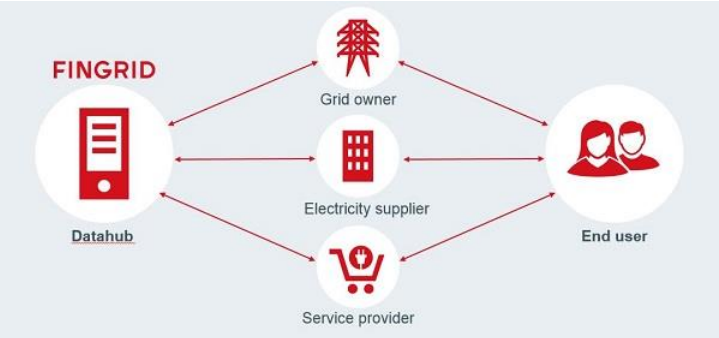

Figure 4.14: Finnish Data Hub Project.[249]

Figure 4.14 shows how Fingrid presents themselves as the centre of the data hub storing the information equally and simultaneously accessible for all suppliers, DSOs and service providers enabling also demand response options – another step towards a future smart grid.[250] It does, however raise the question who will own the information stored in the hub. Will it be the TSO? In Åland's case this would be a publicly accountable governmental institution. In Finnland's case it would be the company Fingrid Datahub Oy[251]. Adapting the data hub model from Finland or not, Åland should take a minute to think ahead and discuss between all the affected people the both ethical and legal questions of:

1. who should own the information added by the data hub users and
2. what should that person or body be allowed to do with the information?

[247] NordREG (2016): NordREG's status report.
[248] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[249] Fingrid (2016): Information about datahub.
[250] Fingrid (2016): Information about datahub.
[251] Fingrid (2016): Company.

5 Grid Modernisation Needs and Recommendations for a Åland Smart Grid

This chapter will describe the actual technical needs for establishing a green smart grid in Åland under the given circumstances and considering all analysed technologies and all proposed ideas.

As a smart grid consists of many different parts, there shall be analyses and discussions of the technical requirements in different fields, such as smart meter and smart house. Moreover, a reserve power analysis is presented comparing the situation today to the optimum future scenario. Then the possibility to upgrade old wind turbines shall be discussed. The advantages and requirements of the technology of CHP and energy storages will be presented as well. Furthermore, the possibilities and requirements of a changeover towards EVs will be discussed. And finally, the virtual power plant (VPP) is introduced as the core of a future smart grid.

5.1 Smart Meter and Smart Home

As presented in chapter 3.3, DSO Ålands Elandelslag needs to update the first generation smart meter while Mariehamns Energi already plans on updating the second generation meters in use in order to create a platform like imagined by Consilia Solution.

To create a fully integrated smart home which is capable of demand response, the Internet of Things and digitalisation are the key words. The Internet of Things means the new generation of devices connected to the internet and, hence, able to communicate and be controlled. Already existing smart home services work by connecting several devices in the household and extending the network later if needed. The central remote control happens via an app on a smart phone or a tablet. The information is saved in a cloud which is a service that has to be paid for. A smart home can improve the security at home by putting the lights on as a prevention of burglary. It can increase the comfort by automating the household and thinking for the dwellers. And it can even measure the health of the dwellers, identify possible threats and send these data to the respective doctor. Smart homes also increase the efficiency of the energy use by turning devices on only when needed. The service to install the smart home system is often provided by DSOs while the cloud service is often offered by other providers. The internet itself is provided by a communication company.[252]

Thinking further, controlling a smart home in accordance with current energy prices can be a time-consuming work. Hence, it is probable that many people will outsource this work to professional control service providers.[253] Those might cooperate with balance responsible companies in order to secure the system functionality.

[252] cf. Wyllie; Maier (2016): Haussteuerung per Smartphone: Die besten Smart-Home-Lösungen für Einsteiger.
[253] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.

5.2 Future Generation and Reserve Power

Basically there are two different approaches to calculate the required reserve power of an electricity system. Either it takes the amount of Megawatt missing if the biggest production unit is disconnected or it takes three percent of the peak load. The latter approach's result, however, should not be smaller than the biggest share of infeed.[254]

Since the peak load in Åland is evidentially very small compared to bigger countries Kraftnät Åland uses a different approach: Either the TSO calculates with the power of the biggest production unit which they consider to be the AC connection to Sweden with its 54 MW (from 01.01.2017 on 58 MW) or KNÅ calculates with a factor of 1,25 of the peak load which will be around 75 MW in the up-coming winter (usually 70 MW) resulting in a reserve power of 93,75 MW. The latter way is the one preferred.[255]

In order to receive an oversight the already in chapter 3.1 described generation and connection situation in Åland follows in a nutshell. Today there are about 22 MW wind power, less than 1 MW solar power, 26,3 MW diesel power and 2,1 MW biomass power installed in Åland. The AC cable to Sweden has a thermal capacity of 80 MW and a contractual one of 58 MW (from 2017 on). The AC cable to Finland has got 9 MW and the new HVDC connection 100 MW. Table 5.1 summarises everything for an improved understanding.

Table 5.1: Today's Electricity Production Sources in Åland.[256,257,258,259,260]

Energy source	Generator Power / Installed Power / Capacity
Diesel power	26,3 MW
Wind power	21,76 MW
Biomass power	2,1 MW
Solar power	< 1 MW
HVDC cable to Finland	100 MW (125 MW for 30 min)
AC cable to Sweden	58 MW (only 54 MW until 2017)
AC cable to Finland	9 MW (12 MW for 30 min)

There are, indeed, many ways to pave the road towards a smart grid in Åland. To compare the current situation not just with any future scenario a scenario is chosen that neglects finance challenges but imagines the 100% renewable, self-sufficient smart grid the local companies and authorities dream of focussing only on technical feasibility. The consideration of this optimal future scenario enables a clear statement about the opportunities showing steps which have to be taken but also leaves room for compromises due to funding shortfalls.

[254] Timbus (2016): Expert interview with Adrian Timbus, Technology and Solution Manager Smart Grids and Wind Power at ABB Schweiz AG.
[255] Kahlroth (2016): Email dated 21.10.2016: "SV: Urgent: Reserve Power".
[256] Kahlroth (2016): Expert interview with Jan Kahlroth, CEO of Kraftnät Åland AB.
[257] Allwinds (2016): Production data of all wind turbines in 2015.
[258] Karlsson (2016): Email dated 10.08.2016 15:42: "SV: solar".
[259] Tommiska (2016): Email dated 30.08.2016 10:15: "SV: Data_repl.".
[260] Lindström (2016): Expert interview with Henning Lindström, CEO of Mariehamns Energi AB.

So in the considered optimal future scenario there is an additional 100 MW wind park built in the Eastern archipelago[261]. ÅEA has finished plans to build two 18 MW wind parks so those will be added to the future scenario as well.[262] There are 15.400 houses in Åland: mostly small and private but also huge and public or industrial.[263] Assuming 7 kW photovoltaic installation each roof top in average, highly distributed solar power reaches about 100 MW all over the islands. Moreover there might be built two solar parks on small, rocky islands[264] each assumptively 5 MW.

Since the intention is to become 100 % renewable diesel power will not be considered in any future scenario. At the moment only the biomass generator covers the district heat demand in Mariehamn due to high diesel prices and low electricity prices. Usually a small scale combined biomass generator can produce about 20% electricity, 65% heat and 15% exhaust gas losses. (In comparison: A combined diesel generator produces about 42% electricity, 40% heat and 18% exhaust gas losses.)[265] So if the current 14 MW thermal power are enough to supply the capital with district heat and only 20% of one of the two generator's input can be transferred into electricity (resulting in 2,1 MW electrical power) the future of biomass-based electricity generation seems to be economically limited especially considering the economic growth of heat pumps[266].

The optimal future scenario is summarised in table 5.2.

Table 5.2: Optimal Future Scenario's Electricity Production Sources in Åland.

Energy source	Generator Power / Installed Power / Capacity
Wind power	140 (22 + 100 + 18) MW
Biomass power	2,1 MW
Solar power	100 MW
HVDC cable to Finland	100 MW (125 MW for 30 min)
AC cable to Sweden	80 MW
AC cable to Finland	9 MW (12 MW for 30 min)

The maximum load in Åland under normal conditions (neglecting the few tests of Ål-link) happened during winter. The usual peak load is 70 MW and is assumed to reach 75 MW this up-coming winter.[267] According to ÅSUB statistics the population growths is unremarkable[268] and according to KNÅ data the electricity consumption has not increased significantly over the last few years, so a peak load of 75 MW will be presumable for this optimal future scenario.

According to the usual approaches in bigger grids it must be compared which value is the higher one: The power of the biggest production or three percent of the peak load which is 2,25 MW. Assuming that

[261] Lindqvist (2016): Expert interview with Henrik Lindqvist, CEO of Allwinds AB.
[262] Karlsson (2016) Email dated 05.09.2016 13:47: "SV: MW today and tomorrow".
[263] Häggblom (2013): Bostäder och boendeförållanden 2012, p.1.
[264] Lindqvist (2016): Expert interview with Henrik Lindqvist, CEO of Allwinds AB.
[265] Lindström (2016): Email dated 24.10.2016 08:01: "SV: Urgent question about a system change in my future scenario".
[266] cf. ehpa (2016): European Heat Pump Mareket and Statistics Report 2015: Executive Summary.
[267] Kahlroth (2016): Email dated 21.10.2016: "SV: Urgent: Reserve Power".
[268] ÅSUB (2016): Åland in Figures 2016: Increase in population, p. 5.

the 100 MW wind park has at least two separate and equally loaded grid connections the biggest production unit will still be the AC cable to Sweden. Since 2,25 MW is far too small with this approach the reserve power would be 80 MW for the optimal future scenario.

According to the preferred current methods of the TSO in Åland to calculate the reserve power it must either be equal to the power of the biggest production unit which will be the AC cable as well or 1,25 times the peak load of 75 MW resulting in 93,75 MW. For the latter value is higher a reserve power of almost 94 MW will be needed in this optimal future scenario.

In conclusion, the question that needs to be asked is where and how to install or import almost 100 MW reserve power for a future energy market that still has to be built. When planning the reserve capacity it must be noticed that there is directly working primary reserve and secondary reserve which usually has longer response times. Because storage and maintenance costs have to be compared carefully to ancillary service and import costs, also the submarine cables have to be considered as reserve capacities.[269]

If 15.400 houses would add a battery storage of averagely 4 kW to each solar panel installation there could be a distributed storage system of 61,6 MW as primary reserve. Battery parks near the bigger solar or wind power plants are imaginable contributing 20 MW primary. Moreover, Allwinds intends to use the old mine as a gas storage[270] which could be used as secondary reserve. About 2,1 MW can be contributed from Mariehamns Bioenergi as secondary reserve. The 80 MW AC connection to Sweden and the 12 MW AC cable to Finland can provide primary reserve.

The 100 MW HVDC cable possesses Light technology using self-commutated voltage sourced converter (VSC) with immediately reacting transistors (instead of thyristors). So the Ål-link can provide 125 MW (30 min) primary reserve and is, moreover, able to adjust both frequency and active and reactive power independently from the grid and, thus, helps stabilise the system after a failure.[271,272]

Depending on the amount of local battery parks, Åland has to buy reserve power and ancillary services from elsewhere in order to import it in case of need via the submarine cables. It consequently has to be calculated how much all small and big battery units (in households and in parks and bearing in mind their lifetimes) cost in both installation and maintenance. The result needs to be compared to three aspects combined. First, the stand-by costs of primary reserve power providers in Finland or Sweden have to be identified. Second, the electricity prices in a no-up-to-little-wind-power-infeed situation must be calculated and it has to be notified that the prices will be higher than average as shown in chapter 4.4. And last but not least, the costs of transmission losses have to be taken into account when importing the electricity from an external provider.

[269] Timbus (2016): Expert interview with Adrian Timbus, Technology & Solution Manager Smart Grids and Wind Power at ABB Schweiz AG.
[270] Lindqvist (2016): Expert interview with Henrik Lindqvist, CEO of Allwinds AB.
[271] cf. Spahic (2010): Der Beitrag von HVDC Light® zum zukünftigen Stromsystem.
[272] cf. Hanson; Sandeberg (2005): Internationaler ETG-Kongress 2005: Selbstgeführte Umrichter im elektrischen Versorgungsnetz.

5.3 Updating Old Wind Turbines

When aspiring an Åland smart grid with a new 100 MW wind park among other new generating units from renewables it raises the question if it is profitable to update old wind turbines. 70% of the 20 existing turbines listed in table 3.1 are 13 years old or more. Due to lacking funding, Allwinds intends to maintain and keep them in operation as long as possible but has no plans on updating them. The authorised height of the old turbines does not allow more powerful turbines with larger rotor blades. Also, the cable connections are only designed for the given 0,5-0,66 MW generator power. As long as the funding situation stays the way it is today there are no updates reasonable.[273] Since the European average wind turbine has about 2,5-3 MW onshore and 3,6 MW offshore[274,275] it might be a more efficient and also more effective solution to concentrate on the development of a new wind park located somewhere in the archipelago where height limitations might be less restrictive, designing the cables and substations with a power buffer for possible later upgrades.

5.4 Combined-Heat-Power

Considering combined heat and power (CHP) used in power plants, Finland's district heating is almost 80% based on CHP.[276] Mariehamns Energi is a classic example minimising the losses by using CHP as mentioned in chapter 5.2. By 2020 the company's existing diesel power plants will have reached their end of live. Despite higher installation costs, cogeneration units are cheaper in the operation compared to corresponding separate generators for heat and electricity. When establishing a green smart grid in Åland it should nevertheless be taken into account that the cleaning of a biomass CHP unit is more expensive compared to a diesel generator for the boilers need to be cleaned from ashes monthly and must be controlled daily which is consequently more expensive. The reason in that lies in the often changing compositions and more impurities in the mass.[277]

Considering a future smart grid with lots of micro-producing smart houses and regarding all the remote households in Åland and its vast archipelago district heating is not the solution but instead micro-CHP. An integrated solution is given by the complementary boiler alternative micro-CHP which is honoured a key innovation (uniting applicability, simplicity and affordability) in the frame of smart cities by the Smart Cities Stakeholder Platform. Producing heat and cold like a heat pump the micro-CHP technology maximises the efficiency and by minimising potential transmission losses considering district heating. Today mirco-CHP units have an electrical output up to 50 kW permitted by the European Commission and there are different technologies:

[273] Lindqvist (2016): Expert interview with Henrik Lindqvist, CEO of Allwinds AB.
[274] EWEA (2016): Wind energy's frequently asked questions (FAQ): Electricity: How much electricity can one wind turbine generate?.
[275] Kärnä (2016): Expert Interview with Teijo Kärnä, Industry Segment Manager at ABB Oy.
[276] Energiateollisuus (2016): Energy and the Environment: Combined Heat and Power Generation (CHP).
[277] Lindström (2016): Expert interview with Henning Lindström, CEO of Mariehamns Energi AB.

- internal combustion engines: relatively large emissions (low power range),
- stirling (external cumbustion) engine: suitable for domestic applications (low power range),
- micro turbine: suitable for many application, e.g. EVs and reserve power,
- fuel cells: still under development (large power range).[278]

In order to establish a comprehensive smart grid in Åland with a focus on efficiency and environmental sustainability, updates of simple heat pumps towards micro-CHP units should be considered.

5.5 Energy Storage

When speaking of micro-production and also large renewable power plants, the uncertainty of delivery strikes. To become more independent from external ancillary services potential electricity surpluses have to be stored by transferring the electricity in another energy form in order to transfer it back later when needed.[279]

Considering large storages, battery parks can be used as primary balance reserve. They produce DC but with the right converter (VSC) the semiconductors in the power electronic can feed in AC immediately. There are many different types of electro-chemical storages: Due to economic reasons the most popular batteries are based on lithium-ion technology offering a good cycle stability and life span.[280] Such a solution is well-imaginable on a rocky island near to future wind and solar power plants.[281]

But also for small prosumers batteries in households are an option to help stabilise the system and save costs in the long term. There are grid-connected systems with the option to feed in electricity into the LV grid and sell it to suppliers[282]. And there are off-grid solutions which are, indeed, interesting for houses in the vast archipelago where grid connections are error-prone and expensive in both construction and maintenance[283].

There are, in fact, two challenges in the matter of private batteries. First: A financial incentive must be given otherwise private people will not make a still not cheap investment. Second: If someday there are demand response options so that the whole of private batteries contributes to the system stability in a relevant share and if there are service providers for smart homes to manage their consumption in accordance to the spot price, it might get even harder for the DSOs to balance their LV grids.[284]

[278] Smart Cities Stakeholder Platform (2013): Key to Innovation Integrated Solution: Heat pump and micro.CHP as complementary boiler alternatives.
[279] cf. ABB (2016): Battery Energy Storage Systems (BESS).
[280] Energyload (2016): Stromspeicher: Großspeicher-Batterieparks.
[281] Karlsson (2016): Expert interview with David Karlsson, CEO of Åland s Elandelslag.
[282] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[283] Karlsson (2016): Expert interview with David Karlsson, CEO of Åland s Elandelslag.
[284] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.

5.6 E-Vehicles and Solar Panels

The Åland car statistic illustrated in figure 5.1 shows the huge car density in the round about 30.000 inhabitant strong island group and points out the obvious need of the inhabitants to be mobile and flexible. Petrol is, indeed, no electricity but nevertheless could a change towards EVs improve the environmental sustainability as one goal of the Åland green smart grid idea. A changeover, however, requires a well-developed network of recharging stations. Today there is one station on the main island[285]. Not only smart houses would need a connection to load their cars at home but also the capital would require several stations for in Mariehamn is the most traffic.

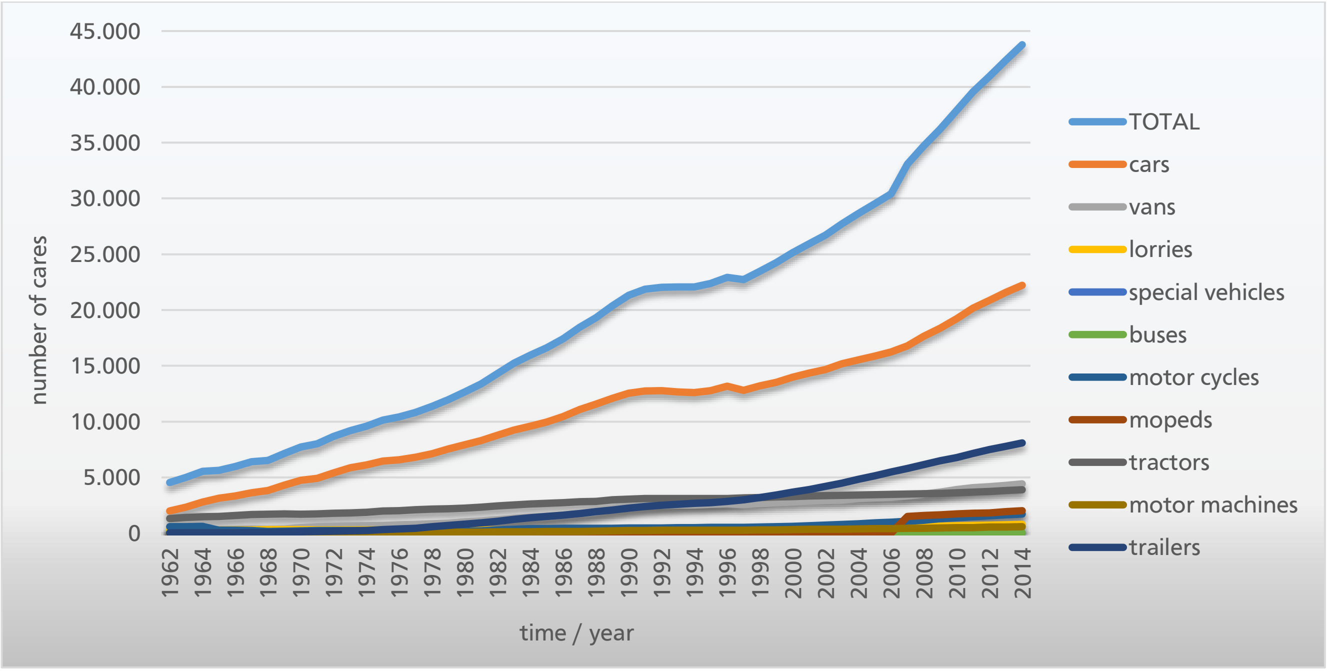

Figure 5.1: Åland Car Statistic on Stock Development 1962-2014.[286]

Beside the intention to install as much solar panels on roof tops as possible, this new consumption sources and sinks in the LV grid require cables designed for higher loads than before. If the LV network could withstand all possible solar power infeed with the existing cables, there could alternatively be laid new cables designed only to supply the EVs all over the islands offering charging stations not in the smart house but on the street in front. It has to be calculated whether or not to install several cables for certain purposes or rather two (n-1 criterion) big-sized cables to withstand all future loads in a green smart grid.

[285] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.
[286] cf. ÅSUB (2015): Development of vehicle stock 1962-2014.

5.7 Virtual Power Plant

In the course of the energy transition the share of renewables increases constantly and so does the energy mix. Hence, many small and often decentralised production units requires a central control system gathering all the information of many small units in the network and operating them remotely. A VPP is such a control system. Digitalisation is the key to coordinate producers, consumers, prosumers and storages in order to balance the load and secure the supply. Although there are VPPs available already today, in a future with the upcoming 5G net and the Internet of Things the communication will be much improved, accelerated and facilitated forming the core of a smart grid.[287]

[287] Saliba (2016): Expert interview with Dr. Sleman Saliba, Business Development Manager at ABB AG.

6 Proposal for a New Market Model for Åland

After defining the given situation and exploring all technical and economic opportunities, challenges and modernisation requirements, an approach for a new energy market model for Åland shall be developed. Different concepts and market aspects will be analysed and discussed in the following.

6.1 Considerations of Åland Becoming an Active Trading Platform

Åland is in a very odd situation being part of a Swedish bidding zone SE3 while belonging to the Finnish nation. While TSO Kraftnät Åland is no member in ENTSO-E as described in chapter 4.1.2, the Åland energy companies can even account themselves lucky when Åland has a proxy in an international organisation like the ones presented in chapter 4.1 at all. To join the Finnish bidding zone is no option since the today import intense Åland purchases electricity much cheaper in the current price area. KNÅ already asked Nord Pool to receive an own bidding zone in order to become a trading platform between Finland and Sweden focussing on future plans to install much renewable power. But Nord Pool declined the request due to Åland's irrelevant size today.[288] And when looking at the trade volume of Åland 2015 (without the HVDC tests) compared to all bidding areas at the spot market illustrated in figure 6.1, it appears that Nord Pool might be right.

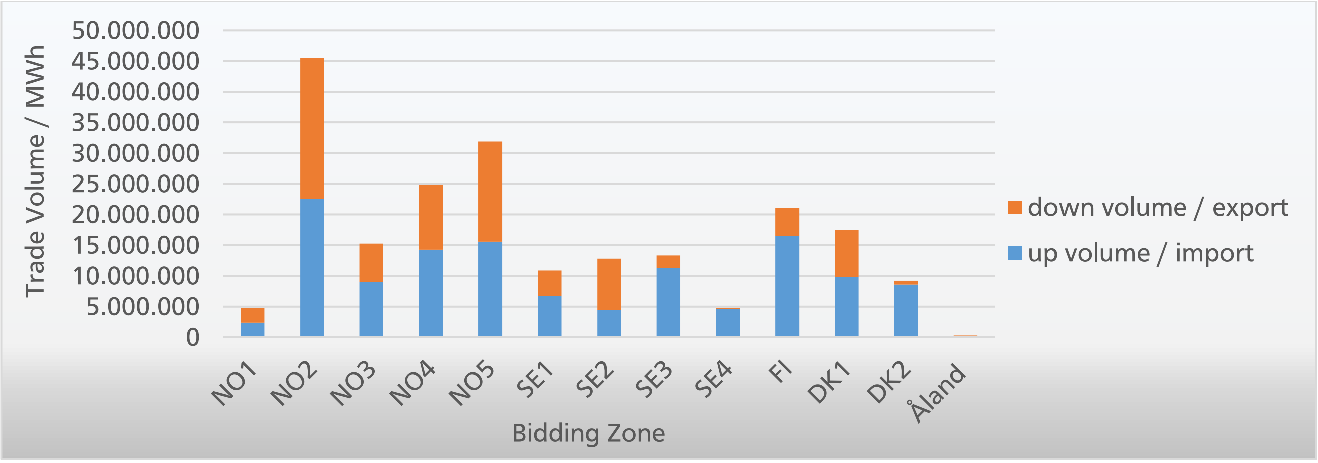

Figure 6.1: Volume of Regulating Bids at Nord Pool in 2015 in Comparison to Åland's Im- and Export Volume 2015.[289]

Having an own bidding zone as an export strong region sounds definitively profitable and Åland should, indeed, keep on aspiring this goal. But Nord Pool needs a good reason in form of trade volume to take Åland seriously. So it might be reasonable to first integrate more wind and solar power into the local grid to help reach that goal.

[288] Karlroth (2016): Expert interview with Jan Karlroth, CEO of Kraftnät Åland AB.
[289] Nord Pool (2016): Volume of regulating bids in MW 2015 hourly.

6.2 Monopoly vs. Competition

It is locally discussed whether or not Ålands Elandelslag should buy Mariehamns Elnät so that Åland has only one DSO in the legal form of a cooperative.[290] Both companies do not aim to achieve any profits as shown by their annual reports in chapter 2.1. ÅEA is owned by its customers in equal shares. The customers do not long for profit participation or good returns but aspire prices as cheap as possible.[291] And Mariehamns Elnät is owned by the city of Mariehamn where about one third of all Åland inhabitants live. Belonging to the city the company is also not designed to gain profit.[292]

Imaging only one DSO in Åland the average costs for the end-customers would be decrease due to economies of scale and redundant stuff reduction. Today's DG of ÅEA is longer, more scattered and more maintenance intense, in short: it is more expensive than Mariehamns Elnät's DG. And two third of the inhabitants pay this spread network. So would it be fair for one third of the inhabitants living in the capital to pay higher costs caused by a grid that connects the rest of Åland to the network? Not really. With today's constellation of two DSOs it is not real, though. However, real is that most of these two third pay the maintenance costs of only few living in the vast archipelago who pay only once the connection costs. Is it fair that most ÅEA customers causing the smallest portion of the ÅEA grid costs pay for the biggest portion caused by only few? No, but this is how this company works. There might be a demand to discuss other options.

According to the Freiburg School's concept of ordoliberalism, perfect competition does not necessarily come with innovation because many small companies do not have the resources for research like one big company.[293] That is, in fact, an argument considering how young and small Mariehamns Elnät is in comparison to ÅEA.

Pursuant to Kantzenbach's concept of the broad oligopoly, competition works best when there is a broad oligopoly with optimum interdependence supporting moderate product heterogeneity and limited transparency so that profit chances, entrepreneurial risk and financing options can be combined the best.[294] Transferring this concept to the Åland situation, ÅEA and Mariehamns Elnät might even maintain a close oligopoly with characterised by an over-optimum interdependence because of their close product portfolio as seen in chapter 4.5 and should consequently be further unbundled.

According to the neo-classical concept of free competition, the liberty of competition is not necessary but sufficient for a functioning market. Competition works best when the companies practise a spirit of competition being orientated by clearly defined legal prohibitions.[295] In the Åland case, the legal restraints

[290] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.
[291] Karlsson (2016): Expert interview with David Karlsson, CEO of Ålands Elandelslag.
[292] Eriksson (2016): Expert interview with Per Eriksson, CEO of Mariehamns Elnät AB.
[293] Gabler Wirtschaftslexikon (2016): wettbewerbspolitische Leitbilder.
[294] Gabler Wirtschaftslexikon (2016): wettbewerbspolitische Leitbilder.
[295] Gabler Wirtschaftslexikon (2016): wettbewerbspolitische Leitbilder.

are handled by the Finnish Competition and Consumer Agency and the Finnish Act on Restrictions of Competition. Consequently, everything should stay the way it is except for maybe intensifying the spirit of competition.

6.3 Heat Pumps vs. District Heating

Local discussions also raised the question whether to terminate district heating and to intensify heat pump installations possibly with micro-CHP.[296] A solution to decrease the costs of ÅEA's DG could be to only install and maintain micro-CHP at very remote customer locations. Decentral heat production with heat pumps is already common in rural Åland outside of Mariehamn. So also decentral electricity production could grow in remote parts of the island group. The case of ÅEA's expensive DG make, however clear, that is no option to extend the district heat network in the rural areas.

Focusing on Mariehamns Energi, it is clear that the company is both heat and electricity producer and provides important local secondary reserve power as presented in chapter 5.2. As long as it is more profitable to run local fossil and bio power plants compared to importing the respective amount of electricity and buying ancillary services externally, Mariehamns Energi is an important local resource in the frame of self-sufficiency. When the diesel turbines have reached their end of life until 2020[297] and if Mariehamns Bioenergi could not operate profitably in the future to due high operation costs as shown in chapter 5.2 then there should be a changeover towards heat pumps also in the capital.

6.4 Energy Efficiency vs. Reduction of Electricity Consumption

When speaking about future solutions for environmentally sustainable smart grids, there are discussions about whether to reduce the electricity consumption or to make energy consumption simply more efficient.[298] The beginning of chapter 3 demonstrated how the Åland electricity consumption was, indeed, increased comparing 2015 with 2008. But it also showed that the consumption was rather steady in the past few years. However, a changeover from fossil sources towards renewables is accompanied by an increase if electricity usage. For instance, if all vehicles in Åland were replaced by EVs, the fossil fuel consumption would be reduced whereas the electricity consumption would be increased. Another good example are modern houses moving towards smart homes: Improved wall insulations reduce the heat consumption while intensified digitalisation and automation heighten the electricity consumption. It becomes clear that the trend of creating more comfort for humanity and the trend to preserve the environment by using and harming it as little as possible are competing. Since European legislation moves

[296] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.
[297] Lindström (2016): Email dated 29.10.2016 16:45: "SV: Urgent: Gas Turbines".
[298] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.

towards nature preserving strategies as presented in the chapters 4.1 and 4.2 and simultaneously all nations strive for innovations and technological advantages (like Åland by becoming a green smart grid as a demonstration platform) the only solution seems to be a compromise between energy efficiency and energy reduction (not electricity reduction). In that frame, the impact of all energy forms together is decisive. Heating, cooling, mobility and electricity create the whole picture and it is not enough to just consider the electricity consumption.

Åland intends to establish a green smart grid connecting heat, mobility and electricity in the most efficient way for a sustainable future and to become more self-sufficient. So when planning a future smart grid solution for the island group all pieces of the puzzle should be taken into account carefully so that the all in all best outcome for the inhabitants, the environment and the economy can be achieved.

6.5 Import vs. Storage vs. Demand Response

A market defining discussion is whether to invest in energy storage systems or to buy electricity and ancillary services elsewhere.[299] This is not only a business decision to make but also a technical one. When storing electricity in batteries, for example, there will always be a certain amount that gets lost over time. When importing electricity there are fix transportation losses defined by cable designs, by the used current technology (AC or HVDC), by the design of the substations and by the transmission length itself. And when buying ancillary services from external providers it has to be paid attention to the respective costs. Alternatively, when considering to invest in a new battery park for Åland it should be calculated carefully how long the life span of these batteries is, how big the losses get by time (and their opportunity costs) and, of course, the maintenance and personnel costs of such a facility.

However, there might be a third alternative: demand response. If Åland establishes a full-developed smart grid with smart homes, smart factories, EVs and with solar and wind power based infeed, another option to balance the power is by controlling all network units remotely (with a VPP, for example, as explained in chapter 5.7). This way, there could be taken positive and negative power as need from all participating prosumption (production and consumption) or storage (EVs and private batteries) units.

But if ÅEA really takes the step to disconnect uneconomic consumption units in the vast archipelago and replaces those connections with the service for a smart home with micro-production and micro-CHP installation, the local frame of demand response possibilities will be limited around Mariehamn and other parts of the main island. Assuming the realisation of the 100 MW wind park and other huge renewable sourced power plants in the future, it must be calculated carefully if the amount of balance power provided by demand response is realistically enough to balance a system with much more load

[299] Häggblom (2016): Expert interview with Ralf Häggblom, ÅTEC Project Manager.

than today. Moreover, demand response based on spot price development as a service provided by companies in other sectors than the energy sector increase the risk of imbalance. Åland's legislation should rather be prepared for developments in both demand response to balance power (organised by the grid operators) and demand response to spot prices (organised by others).

Summing up, to have no trouble and costs with the installation and maintenance of battery parks is an argument for buying balance power from Sweden and the Finnish mainland. But it is, in fact, not only a question of comfort but also of cost efficiency. And maybe a combination of battery parks and demand response is not only more self-sufficient and smart but also more cost-efficient only using external balance power via Nord Pool in case of need. There are, indeed, many different realisation options imaginable. First Åland needs to increase their installed power and form a basis for grid modernisations as well as for the development of new smart solutions in the local system. When the market size in MW is developed, scenario calculations of import-storage-demand-response-variations have to follow.

6.6 Incentive Systems and Politics

This thesis has shown that there are many options to install a green, self-sufficient smart grid in Åland. However, the biggest obstacle in the way is the financing. How to finance new big wind and solar power plants, new smart villages and battery parks? How to motivate private persons to install solar panels and micro-CHPs in their home, to upgrade their home towards smart homes and to buy EVs? How to finance new cables and recharge stations for EVs? In regard to accounting, Financing requires investments. Investments are enhanced by incentives. In order to make a whole island group invest in a smart grid as described in this thesis, the Åland government has to change politics creating such incentives. The politics could even raise the awareness of EVs by replacing all vehicles of the public transport by e-busses.

For instance, EVs do not enjoy tax benefits in Finland. One approach on the mainland, however, is to halve the parking prices for EVs.[300] Accordingly, Åland could introduce parking fees but make it free for EVs. Or Åland could offer a scrappage premium for old vehicles if the owner replaced it with an EV instead following the German model[301]. However, before Åland supports the private investments in EVs the governmental budget needs to form the basis for an adequate infrastructure (cables, substations, recharge stations).

Concerning off-grid smart homes with micro-CHP, Ålands Elandelslag should present an incentive for new connection points in order to avoid high grid costs for the rest of the customers (the owners) as

[300] Vuola; Lindgren (2015): Is an Electric Vehicle Boom About to Take Off in Finland?
[301] Gabler Wirtschaftslexikon (2016): Abwrackprämie.

discussed in chapters 5.4 and 6.2. ÅEA could prepare a smart home cost model to show the price advantages for customers in the long run when choosing an off-grid option and provide the service entering a new market segment.

Solar panels for private households with or without batteries and grid connection should also receive a taxation incentive given by the Åland government. Instead of reducing the device prices actively by expending the governmental budget the government could decrease certain taxes for inhabitants who install micro-production units and batteries.

What works with private people can also work for bigger companies. Åland government could allow tax exemption for local companies when installing new renewable power plants. Åland receives 0,45% of the estimated annual revenues of the Finnish government, as stated in chapter 2.4.1. In order to achieve the local green smart grid goals, this sum should be divided differently between all the sectors than before. If the government looked for other areas where they could save some money they would probably find some additional subsidies for the local smart grid plans.

7 Conclusion and Outlook

At this point the central results of this thesis shall be summed up in a final conclusion presenting an outlook for the energy market development. In accordance to the VTT SWOT analysis presented in chapter 2.3 and as a result of this thesis an updated SWOT analyses can be found in figure 7.1 summarising the most important facts identified.

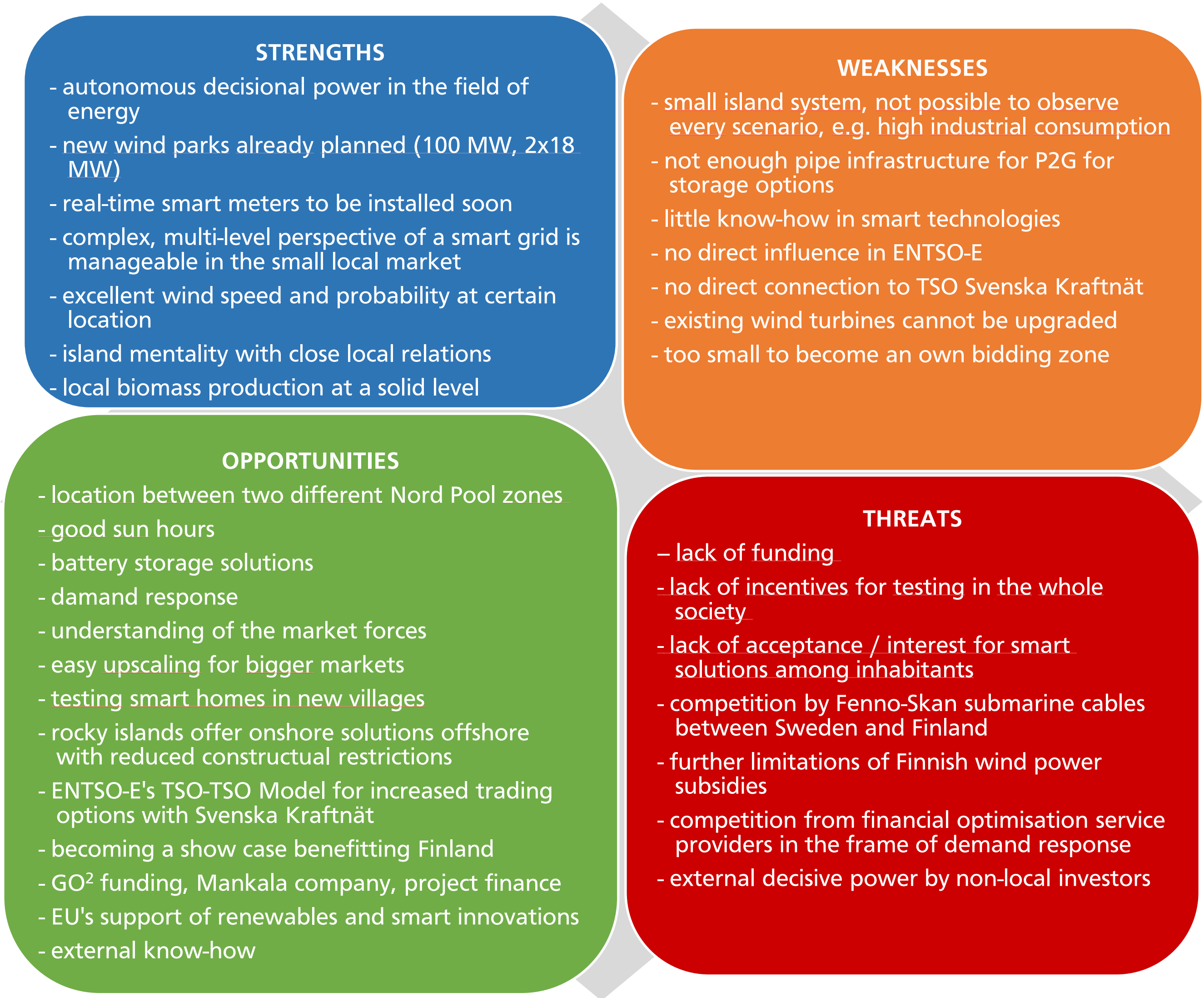

Figure 7.1: SWOT Analysis as a Result of this Thesis.

Beside all the local motivation and the rich ideas, Åland lacks of funding possibilities at the moment which is the biggest threat to the smart energy platform. Due to the politically tense situation in Finland and because of decrease subsidies for wind power from the mainland, Åland cannot reckon with monetary support from Finland right now. It can, however, advertise the possibility to invest in Åland to become a show case smart grid giving Finland not only a higher reputation in the matter of future energy solutions but also concentrated know-how that could be sold to improve the national economy.

Åland should nevertheless closely follow up on the European legislation as well as upcoming programmes to support smart technologies and renewable energies. Every chance to receive funding should be taken. With an increased public awareness, the small island grid might achieve the local goals much faster. GO², Horizon 2020 and other international funding systems should be applied for. Besides, the energy companies could consider to found a joint Mankala company. Even though the local companies would probably need to give up control towards another external and bigger company, this could be a low-risk solution in order to reach the goals.

The local legislation should, moreover, work on future laws considering demand response. Demand response can be the answer to balance the load in the future but it can also become a financial optimisation service from other market players. The system stability has priority and the laws should not leave any loopholes risking that. However, there could be achieved a compromise between both optimisation perspectives. Because if the demand side would really react immediately to spot price developments this might change the total way exchange functions today and price shocks could be avoided in the long term. Although Nord Pool is not Åland's responsibility, the consequences of changes at the spot market would also have an impact on Åland. If extreme price shocks would disappear due to demand response the local companies would, hence, carry less entrepreneurial risk.

The legislation also has to adapt consumer rights to future data hub solutions as presented by Consilia Solutions in order to make a competitive, transparent platform possible that contributes to the local energy efficiency. The Finnish preliminary work on that is supposed to pave the way for that in the frame of NordREG's working group on smart meter and data hub opportunities.

Furthermore, the Åland government has to develop incentives for private persons to invest in solar panels, storages, micro-CHP and EVs by either using either the annual Finnish payment or by decreasing certain taxes or other costs for those who help built the future. A start could be the changeover to e-busses in local transport.

Focussing on the technical results and developments identified in this thesis, it becomes clear that the trend of becoming an interconnected smart grid with more micro-production, micro-CHP and almost real-time metering data is accompanied by the trend of smart homes. Not only Åland intends to become greener and more self-sufficient but also households, facilities and factories. Consequently there are two major system developments where modernisation is required:

1. In the LV grid the cables must endure temporarily higher loads caused by solar infeed and the rising electricity demand for increasingly digitalised smart homes and EVs. Besides, many households located remotely need upgrades towards smart homes to become off-grid self-sufficient with storage and micro-CHP solutions.

2. In the MV and HV grid new wind and solar power parks must be connected to the system as well as battery storages (also the option to use Allwinds' old mine as gas storage must be taken into account).
3. There will be an increased digitalisation in the whole system collecting, transmitting and saving information. Many new responsibilities have to be sorted out, customer rights have to be adapted and software solutions will play a bigger role in the energy market so that the sector will open up and grow more complicated. VPPs will play a central role coordinating all the big and small production and consumption units to balance the system automatically.

The task fields of especially the rural DSO Ålands Elandelslag will be newly identified enlarging the portfolio with off-grid customer solutions in order to help reduce the company's costs, the grid's error-proneness and to help realise efficiency measures for a different future market model.

For balancing matters, the grid operators and local producers have to calculate carefully different scenarios where and how to install local reserve power and where to buy external ancillary services. Self-sufficiency in regard to energy consumption from renewables is a noble goal, indeed. But self-sufficiency in regard to reserve power even if the external option could be cheaper would be counterproductive. So the consequences of demand response options (they could be limited to industrial facilities) must be thought out considering possible competition from financial optimisation service providers who threaten the system balance. In comparison, also storage options must be calculated carefully (installation, maintenance, personnel, live span, losses). These findings have to be compared to external ancillary services and the costs for transmitting the energy in times of need (spot prices, losses).

By getting bigger regarding the installed power KNÅ will increase their political influence on an international level. Besides, the chances will grow for Åland to become its own bidding zone at Nord Pool. But as long as Åland belongs to SE3, they could export wind power to Finland where the net export is negative and, thus, profit from the price differences in the zones. However, the competition from the Fenno-Skan connections between Sweden and Finland has to be observed.

So there are many different fields in the multi-level perspective of a green smart grid in Åland. The Åland Smart Energy Platform is a good foundation for future developments but it has to strengthen its role and its presence in order to achieve more public awareness in and out of Åland and, hence, to reach more potential investors. Being aware of their weaknesses and using their strengths Åland can hopefully meet the external threats. Nevertheless, Åland does possess many opportunities and convincing arguments to develop a green smart grid. Beside funding the market needs a concrete plan. And external cooperation can always help provide competences and solutions. With external money and know-how on the one hand and a strong island mentality on the other hand, Åland can manage to develop a good strategy in order to become a self-sufficient, 100% renewables smart grid.

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