FINAL JOINT REPORT OF THE PROJECTS

# FLEXe DEMO and CEMBioFlex

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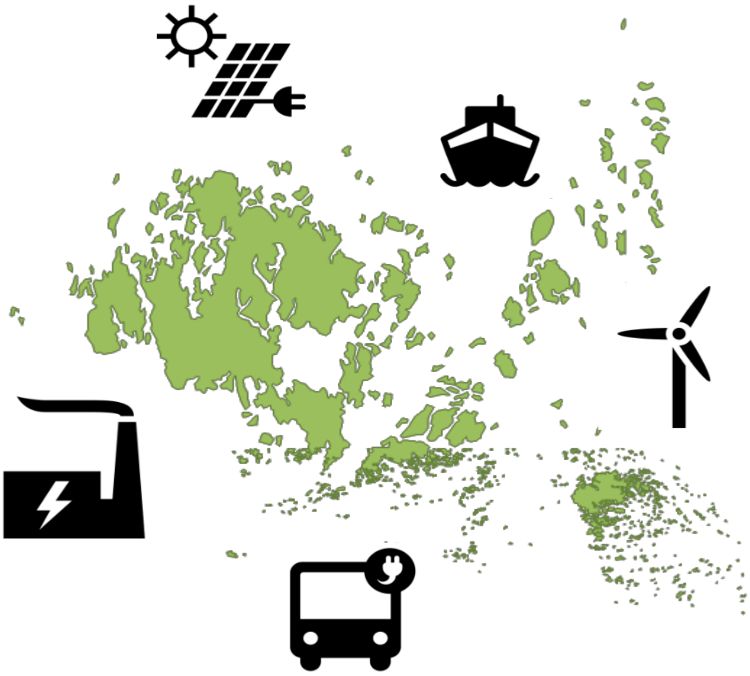

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**Editor** Pia Saari, CLIC Innovation

# Executive summary

By Pia Saari, CLIC Innovation

Globally, a major increase in the use of variable renewable energy, solar and wind, in electricity production is envisioned to limit $CO_2$ emissions, along with energy efficiency and electrification of heating, cooling, and transportation. This requires increased flexibility of the power system compared to current energy systems.

Smart Energy Åland or Åland FLEXe Demo project is about demonstrating a solution of a future flexible energy system based on 100% variable renewable energy production. Similar solutions need to be implemented elsewhere in the world on a larger scale to combat climate change. Being a predecessor in the area, the demonstration would have a reference value for the Finnish technology export industry and boost new technologies.

The envisioned 100% renewable energy system of the Åland Islands is to rely heavily on wind energy. The annual consumption of electricity was estimated to be app. 400 GWh in the future (now 300 GWh/a), peak capacity being 85 MW. The annual electricity generation mix would contain 70-80% wind, the rest originating from biomass and solar, 10-15% each. There are already clear plans how to enlarge the wind fleet in Åland Islands to reach the targeted capacity.

Roofs of existing real estates could accommodate the targeted amount of solar power. However, a solar park would be much more efficient in terms of CAPEX, OPEX and energy yield providing the lowest solar energy costs. Still, like with wind power parks, also solar parks would need a long term PPA to be feasible as investment.

Bioenergy can be seen as a rather cost-efficient flexibility and storage option in the energy system. Therefore, CHP maximization with large heat storage is suggested to the system to bring more flexibility and integrate the heat and power sectors. There is enough biomass available to fulfil these needs sustainably. On the other hand, heat pumps and solar heating were not considered feasible options as the former does not support flexibility, and in the latter case heat demand and availability do not match.

Electrical heating of small houses is a good and cost-efficient source for demand response in Åland Islands. Based on monthly averages, some percentages (1-4.5 MW) can be used in load shifting without compromising customer satisfaction.

In Mariehamn, local buses could easily be changed into e-buses. Based on studies, both types of electric buses, opportunity charged or depot charged, could be used in Mariehamn without causing trouble to the grid. Autonomous buses were seen too immature technology at this stage. There are also plans to convert some ferry routes into e-ferries. Ferries are more demanding for the power system due to high charging load.

According to recent simulation studies, the network can withstand large additions of renewables, but it requires investments to the network. Some network costs can be reduced by investing in battery energy storage systems.

To enable better flexibility in the energy system, some changes in the market model are suggested. To enable active local trading of the power, and to provide incentives for flexibility, there needs to be local market place for that which is interoperable with existing Nordic markets. This model would activate local resource owners to use their flexibility potential, and provide also benefits for Nordic markets. In addition to enabling the local trading of flexibility, incentives for end-users have to be provided by appropriate pricing structures. A tariff, which has a combination of a power-based fee (€/kW), a fixed fee (€/month), and an energy-based fee (cents/kWh), seems to be most viable tariff option for both small-scale and larger energy users. Also, enabling market actions of energy communities, e.g. sharing of local generation, or costs and benefits of the EV charging, would improve the possibilities of end-users to actively participate in energy markets, and increase the profitability of micro-generation within the energy community.

The suggested storage technologies are Li-ion batteries, flywheels and PtG. With PtG the product would be hydrogen because there is lack of local industrial carbon dioxide sources in Åland Islands to convert $H_2$ into methane. With a large share of wind/solar, the storage costs are remarkably higher than if biomass is used as base load. Also, relying on transmission cables to Finland and Sweden as a virtual long-term storage is a cost-efficient solution, but may compromise the reference value of the demonstration. However, the demonstration has valuable reference value even it does not reach the full 100% renewable energy.

The cost estimate of the demonstration is estimated to be at least M€ 300 – 500, depending on the chosen technologies. Since the required investments are currently not economically viable - as it is often the case with new demonstrations - the Finnish state and the European Union may be possible investors. Also, it is essential to find models to involve large companies in the realization of the demonstration. After all, it is their export potential which would bring the full benefit of the market reference to Finland. The Climate Leadership Council could also have some interest in financing for climate mitigation.

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# Abbreviations

| | |
|---|---|
| AC | Alternating Current |
| AEL | Alkaline Electrolysis |
| CAES | Compressed Air Energy Storage |
| CAPEX | Capital Expenses |
| DC | Direct Current |
| DSO | Distribution System Operator |
| GWh | Gigawatt hours |
| kWh | Kilowatt hours |
| KNÅ | Kraftnät Åland |
| LCOE | Levelized Cost of Electricity |
| HV | High Voltage |
| MW | Megawatt |
| OPEX | Operational Expenses |
| PEM | Polymer Electrolyte Membrane |
| PHS | Pumped Hydro Storage |
| P2G, PtG | Power-to-Gas |
| P2G2P | Power-to-Gas-to-Power |
| PPA | Power purchase agreement |
| PV | Photovoltaics |
| RE | Renewable Energy |
| RES | Renewable Energy Sources |
| SE3 | Swedish bidding area #3 in Nord Pool day-ahead market |
| SOFC | Solid Oxide Fuel Cell |
| TCO | Total Cost of Ownership |
| TSO | Transmission System Operator |
| V-RE | Variable Renewable Energy |
| V-RES | Variable Renewable Energy Sources |

# 1. Introduction

By Kimmo Siira, CLIC Innovation

This report has not been drafted or designed to be a comprehensive explanation of background, events or actions that has been taken with the FLEXe Demo project in Åland, since the start of the project 2015. There are many different analysis and reports from CLIC, ÅF etc. as well as master thesis works from Ms. Julia Leichthammer and Mr. Dario Nikzad that has documented the background and current situation. This document is designed to give understanding and possibility analysis of each eight subsystems of the whole ecosystem (Figure 1).

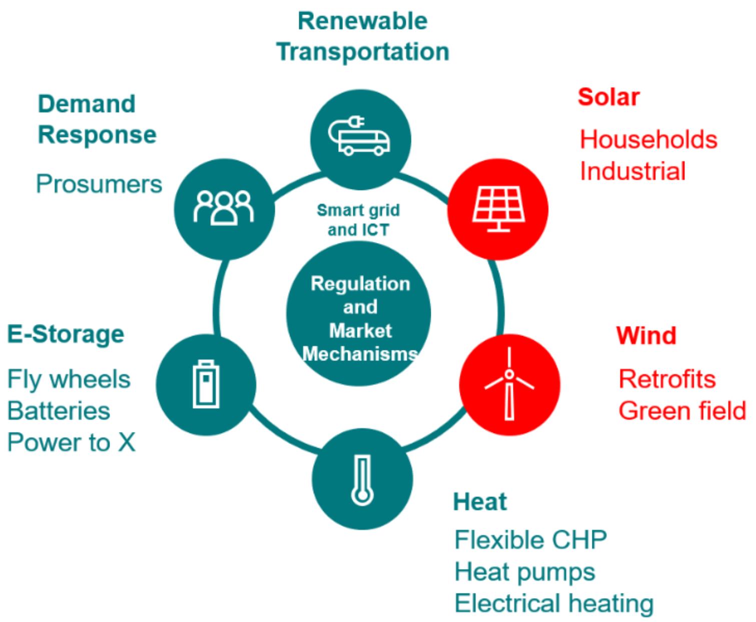



*Figure 1. The structure of the ecosystem.*

These eight streams - solar, wind, Heat/CHP, storage, demand response, renewable transportation, smart grid/ ICT as well as regulation and market mechanisms - are the core of the FLEXe Demo project. Each sub stream has done in-debt analysis on community level possibilities and to some extent of potential costs related of designing to be implementing a smart grid environment in this case to Åland archipelago.

FLEXe Demo project (2017-2018) was not and is not designed to be a comprehensive analysis of Åland's energy system, but Åland has been used as a testbed for how modern smart grid can be implemented in a modern society scale in comprehensive way; what does it need to be operated, what kind of challenges it will face and how those challenges can be mitigated. This report also analysis potential new market operators and aggregators role that might be needed when implementing modern smart grids.

This report is also designed to be a guidance and/or a reference book to new established platform company Flexens Oy Ab, that has been established in October 2018 between eight Åland located companies; Ålands landskapsregering, LeoVind Ab, Ömsen Försekringar Ab, Ålands Elandeslag, Mariehamns Elnät, Ålands Vindenergi Andelslag, Ålands Vindkraft and Viking Line Buss as well as and CLIC Innovation Ltd. Flexens will be managing the implementation of the projects and potential timetables, therefore this report does not take those issues into consideration.

Simultaneously with FLEXe Demo project and other similar, but with smaller scope project called CEMBioFlex was conducted. Some of the CEMBioFlex findings has also been used in this report. CEMBioFlex was contracting more to district heating and CHP side of production with also analysing electric transportation issues.

Once the smart energy demonstration platform was decided to be experiment in Åland archipelago, additional analyses were need. Therefore, CLIC put together 8 individual project sub-groups to evaluate opportunities from different perspectives. Two were production related, four were viewed as potential system flexibility providers, one stream analyzed purely the technical requirements of the current grid and what type of ICT solutions needs to be provided so, that the system can operate in the future as a smart grid. These team were led by companies joined by universities and research agencies. Each sub-group was responsible for their own time tables and work packages.

# 2. Background

By Kimmo Siira, CLIC Innovation

Global warming is one of the main threats currently facing our environment. In Paris Accord in 2015, governments agreed to limit global warming to 2 degrees Celsius. Latest IPCCC report released in October 2018 stated that we need to further limit the warming to max 1.5 degrees Celsius or we will face severe consequences in the near future. Limiting global warming to 1.5°C requires slashing global greenhouse gas emissions by 45 percent below 2010 levels by 2030 and reaching net zero by 2050.

Regardless we talk about 1.5 - or 2 °C, immediate and swift actions need to be taken. When evaluating emission generating sectors, by far the largest single sector is energy and power, followed by agriculture, manufacturing industries and transportation, which generates approximately 14% of annual emissions. By comparison energy and power sector accounts twice as much as transportation, around 1/3 of annual emissions generated, of which power and heat sectors are responsible of ¾ of emissions. Therefore, energy and especially power and heat sectors are crucial for climate change mitigation and offers huge potential for energy efficiency and renewable energy-based solutions.

It is world-widely recognized that Finnish companies are on leading edge, when it comes to cleantech solutions and product development. At the same time Finnish universities and research institutes have been doing leading innovation research clean solutions, circular economy and bioproducts. Since 2008 CLIC innovation Ltd (CLIC); which is owned by 30 companies and 16 universities and research organizations, and its predecessors CLEEN Ltd and Finnish Bioeconomy Cluster FIBIC Ltd have been the Finnish forerunner bridging these innovative companies, universities and research organizations with public funding potential to further develop these sectors. According to its current strategy, CLIC is building up ecosystems capable to design and demonstrate global systemic challenges in its focus areas.

CLIC's joint R&D&I programs in the field of cleantech and bio economy and its public-private partnership efforts and open innovation strategy have generated a remarkable project portfolio. These activities included initiating, developing and executing several large (up to 60 M€) clean and smart energy related research programs including smart grids (SGEM), flexible energy systems ($FLEX^e$), sustainable bioenergy solutions (BEST), efficient energy use (EFEU) and carbon capture and storage (CCSP).

## Platform demo idea

In 2015 CLIC started to evaluate further an idea of establishing a platform for Finnish companies to demonstrate their innovations and develop R&D in the fields of smart grid. It has been evident that energy markets are about to go through significant changes due the increase of solar and wind energy in the near future.

There is a wide consensus that high and significantly increasing share of variable renewable energy is inevitable to mitigate climate change but will jeopardize the stability and security of the present energy systems.

It is estimated that commonplace actions like flexible forms of electricity generation and enhanced grid capacity could integrate up to 25% share of variable renewable generation without significant curtailment or shortage of power. However, beyond this more novel flexibility enablers like demand response and energy storage must be applied.

The existing solution to meet the increased flexibility demand in energy systems is integrating various flexibility measures in the energy system. These comprise of interactions with various energy forms e.g. heat pumps and power to gas, energy storage especially for electricity, dispatch power, demand response, electrical vehicles etc. The platform enabling the integration is the smart grid, which relies on modern sensor and information technologies as well as new market mechanisms, incentives and policies driving for flexibility enhancing operation of energy system.

The Finnish export of the energy system related industrial sectors were in 2015 in the range of 10 billion € representing 19% of the total commodity exports (54 billion EUR). Due to the long presence of these high technology industries in Finland the level of research, technology and competence are state of the art. Besides, especially during the last ten years significant public and private funding has been allocated to the applied research in flexible energy systems in Finland. Considering the global market size, the significance of the related industries to the national welfare, R&D&I investments and competences it is vital that Finland would realize its excellent fundamentals to enhance the exports and invests in Finland in the field of flexible energy systems.

Finland has an internationally recognized track record in creating new knowledge, technologies and innovations by the means of publicly funded thematic R&D projects and programs. The recent flagship programs in the field of energy systems have been Smart Grids and Energy Markets (SGEM) 2009 - 2014 and Flexible Energy Systems (FLEX$^{e}$) 2014 - 2016 with an annual volume exceeding 10 M€/a. These programs integrated more than 30 companies and 50 research organizations to an open innovation-based ecosystem with a shared vision of future flexible energy system.

However, compared to our neighbours, Finland's innovation capabilities have been underperforming in implementing its innovations. Therefore, providing a fast track platform for companies to collaborate in domestic reference significantly increases the competitiveness of Finnish based companies and provide global impact of Finnish research.

Based on the above, CLIC started to work on a demonstration platform for flexible energy system, which would be scalable to global markets and creating a competitive edge for Finnish based companies, increase the global impact and relevance of Finnish research and attract invest into Finland.

## Location analysis

Analysis of a possible location for the demonstration was started by identifying criteria that would describe the suitability of the location to fulfil the targets of the demonstration i.e. societal scale with 100% RES production. The criteria were divided into five segments:

- Environmental circumstances and nature
- Societal and political aspects
- Technical feasibility
- Economical aspects
- Attractiveness.

For each of the criterion a proper variable was chosen to describe it. Each criterion was given a weight coefficient according to the perceived significance of the criterion in fulfilling the targets of the demonstration.

To select the locations for this analysis, various stakeholders were interviewed to get information on locations which have development projects including Cleantech targets or other initiatives towards materializing Cleantech showcasing. This led to a selection of the eight locations for this analysis from different parts of Finland with different demonstration profiles.

The most comprehensive and complex location in society and system point of view is the autonomous region of Åland islands, which consists of a group of islands between Sweden and Finland. Its population, GDP, electricity demand and land area are about 0.5% of Finland. Electricity demand is fulfilled mainly (70%) by import from Sweden and by local wind power (20%), the rest being local thermal power generation and also import from Finland. Because of self-governed island(s), the political, energy, traffic etc. systems share more or less the same physical boundaries. In addition, it's a small-scale but comprehensive society with the most favourable conditions for wind and solar power in Finland. Therefore, it is not a surprise that it was proposed as a possible location for a society scale demonstration for a flexible energy system that could be scaled up also for bigger societies.

Åland is an autonomous, demilitarized, Swedish-speaking region of Finland. Around 29 000 people live in Åland. The distance on the main island from north to south is 50 km and from east to west 45 km. Despite its relatively small size, there are 912 km of public roads in Åland. Åland's autonomy gives it the right to pass laws in areas relating to the internal affairs of the region and to exercise its own budgetary power. Islands' location midway between two expanding economic centres, southern Finland and the Stockholm region, is a major advantage, but also makes Åland sensitive to economic fluctuations in its two neighbouring markets. There are currently about 2,100 businesses, of which about 600 are agricultural enterprises. About 20 companies, mainly shipping firms, banks and insurance companies, have more than 50 employees.

Åland islands feasibility was studied already in 2015 but not compared against other locations nor a technical concept had been proposed by that time. A most recent and comprehensive study was carried out by Leichthammer in 2016 discussing on Åland islands' current energy system together with some societal aspects as well as the feasibility for fully renewable system. In addition, Child et al. have made in 2015 a comprehensive scenario work by simulating analysing six alternative systems to reach fully renewable energy system against three reference ones. They all conclude that fully renewable and sustainable energy (power and heat) system is achievable in Åland islands but most probably it is not now commercially feasible from the energy system point of view, hence, in order to reason the demonstration, there must be other benefits to boarder group of stakeholders than local customers, companies and society. As described earlier the hypothesis is that the main beneficiaries would be the Finnish technology industries and society having boost for their global sales due to the far beyond the state of art home market reference as well as its employment and invest in Finland externalities.

## Åland carbon footprint

The carbon footprint of Åland has been investigated in 2001, 2005, 2008, 2014 and 2015. The overall emission trend is a decreasing, see Figure 2. The emissions per sector are presented in Figure 3.

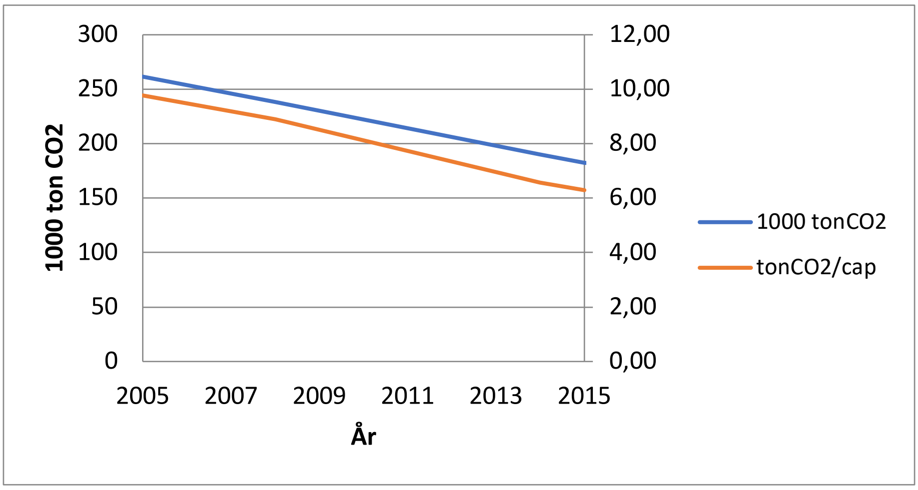



*Figure 2. Fossil $CO_2$ emission in Åland Islands 2005-2015.*

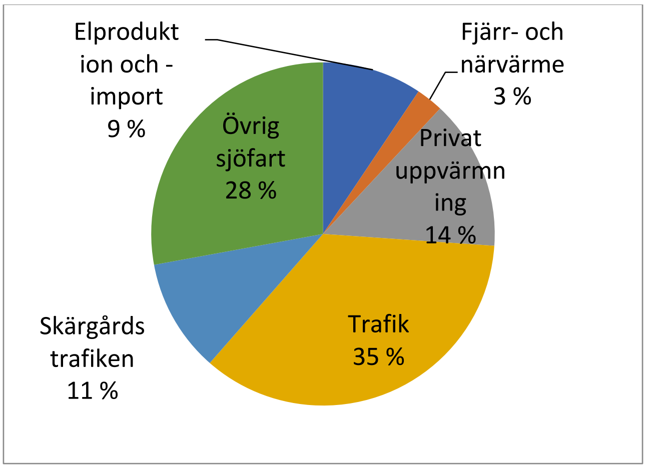



*Figure 3. Emissions per sector 2015. Dark blue = electricity, orange = district heating, grey = individual heating, yellow = road traffic, light blue = Landskapsregering's ferries, green = other shipping.*

## Åland 2030 strategy

The Development and Sustainability Agenda for Åland with the vision *Everyone can flourish in a viable society on the islands of peace* mark the framework for the sustainability work on Åland. To reach the vision seven strategic development goals have been defined (Figure 4).


*Figure 4. The seven strategic development goals in Åland Islands.*

The sixth development goal Significantly higher proportion of energy from renewable sources, plus increased energy efficiency is further expanded in Åland energy and climate strategy for 2030. The set targets of the strategy for Åland are that carbon dioxide emissions are to be reduced by 60% and that the share of renewable energy of total consumption is 60%. Of electricity consumption 60% is to be based on renewable local production. The targets are to be met by strategic measures that support:

- Increased local renewable energy production
- Increased utilization of local renewable resources for heating
- Increased distribution of other than fossil fuels for the transport sector
- Increased energy efficiency in buildings
- Increased sustainable procurement
- Increased unbiased information and advisory on climate and energy issues to the general public and enterprises
- Facilitating innovation and establishment of innovative companies
- Sustainable forestry, where forest resources are increasingly utilized
- Increased circular economy

## Åland 2051 vision

With the understanding that nature constitutes the foundation of human existence, the elected members of parliament and government, in 2014, chose to adopt a collective goal of total sustainable development in Åland no later than 2051. This is in accordance with an internationally used definition of the term sustainable development, which consists of four so-called Sustainability Principles:

In a sustainable society, nature is not subject to systematically increasing…

1 … concentrations of substances extracted from the Earth's crust (fossil fuels, metals and minerals)

2 … concentrations of substances produced by society (synthetic substances, chemicals that contain persistent substances; or natural substances that are in use in larger quantities than nature can handle)

3 … degradation by physical means (over-exploitation of natural resources, including water, forests, fish stocks or farmland; the usage of important natural environments for, for example, building, the introduction of alien and invasive species, production that results in refuse rather than being a closed substance cycle)

4 And, in that society, people are not subject to structures that systematically undermine their capacity to meet their needs, including health, influence, skills development, impartiality and creation of meaning.

# 3. Description of the current energy system in Åland Islands

By Kimmo Siira, CLIC Innovation and Berndt Schalin, Flexens Oy

## Current electricity generation assets and support schemes

Today wind power generates the most significant part of the landscape's electricity production. At present there are 19 wind turbines, which together are estimated to produce about 18% of the annual electricity consumption in the landscape of Åland. In order to maintain the core of the existing wind power production, the government of Åland has a support scheme for existing wind turbines, which applies from 1.7.2016 to 31.12.2022. The aid is a form of operating aid and is paid per produced megawatt hour in excess of the current market price and that to a maximum level that depends on the production capacity of the wind power plant. When the market price reaches a certain level, the aid is gradually reduced.

The Government of Åland intends to introduce a new production support scheme whose basic purpose is a more climate-friendly electricity production and modernizing the Åland wind power industry. The support scheme is expected to increase the share of renewable electricity to around 65-70% of the annual electricity consumption on Åland. Like the current support scheme, the government's intention is to introduce a support scheme that’s pays per produced megawatt hour in excess of the market price to a certain top level over a 12-year period. When the market price reaches a certain level, the aid will gradually be reduced. The aid is intended exclusively for new wind turbines at a minimum of 3 MW within the Åland territory. The Government pays the highest level of compensation at a low market price and if the conditions are so for the entire 12-year period, the maximum cost of the support system for the Government is estimated to approximately 17,200,000 (17.2 million euros).

Solar power is a minor part of the local electricity production but is expanding through government subsidies. Solar PV and heat in private housing get 40% subsidy on their investments and companies get 15% on PV investments.

## Krafnät Åland – The Transmission System Operator

Kraftnät Åland (KNÅ) founded in 1997, is the only transmission grid operator (TSO) of the Åland Island and owned by the local government, Ålands landskapsregering. KNÅ is certified TSO according to European law and another TSO in Finland. The other is Fingrid Oyj on the Finnish mainland.

The company maintains one 25 MW gas turbine and one 10 MW gas turbine for back-up power.

The transmission grid includes 23 power stations and 512 km of electrical lines in total. KNÅ´s transmission grid is connected to Vattenfall Eldistribution Ab's (DSO) 70 kV regional network in Senneby, Sweden. KNÅ owns the Senneby 110/70 kV power station (2x63 MVA transformers) and the 63 km long 110 kV 80 MW AC cable between Tellholm in Åland and Senneby. From the Tellholm station 110 kV overhead lines goes to Tingsbacka 110/45 kV power station. From Tingsbacka a 110-kV overhead line goes through the access point in Ingby to the converter station in Ytterby. From Ingby there is also a 110-kV overhead line to Norrböle power station.

The converter station in Ytterby is a part of the 100 MW HVDC-connection Ål-link, owned by KNÅ. The DC connection consists of two converter stations and a HVDC 162 km long cable between them. The other converter station is in Naantali on the Finnish mainland and is connected to the Finnish TSO Fingrid´s 110 kV transmission grid in the power station Naantalinsalmi. Ål-link was ready for operation in late 2015 and is owned by KNÅ. The HVDC connection works in both directions with the same capacity. The main purpose of Ål-link is to provide with back-up power in case of disturbances in the AC-connection to Sweden. Ål-link together with the AC-link to Sweden also give opportunities for transmission of power from Sweden to Finland or v/v.

The 45-kV grid starting in Tingsbacka supplies the 45/10 kV power stations connected to the two DSO's distribution network in Åland. There is also a 45 kV AC connection installed in 1991 between Åland Brändö and Kustavi on the Finnish mainland linking KNÅ´s grid to Caruna's distribution grid. The cable is 16,6 km long and can usually carry about 9 MW load. There is also local production connected to KNÅ´s grid. 13,8 MW wind power in Båtskär and 2,4 MW in Knutsboda. In Mariehamn there is some diesel power connected.

The highest power peak ever was noted on the 28th of February 2018 is 76,5 MW.

KNÅ is normally connecting Åland with the Swedish synchronised grid. In emergency towards mainland Finland. 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 Sweden´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 and Mariehamns Energi Ab are concluded as follows: These three act within certain balance power windows. The balance responsible companies must 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

## Connections to Finland and Sweden

Figure 5 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. The AC connection from Åland's shore in Tellholm to Senneby in Sweden (including the substation). Installed in 2000 the 110 kV AC cable is thermally designed for 80 MW but it is contractually agreed upon to use only 58 MW for 2018.

The HVDC connection Ål-link designed for 100 MW (125 MW possible for about 30 min). Normally for back up. Trading towards Finland possible when AC cable to Sweden is not available. Forms together with the AC-connection a link between Sweden and Finland. Transmission technically possible but some obstacles remains to overcome before the capacity it can offer will be used.

Between Åland Brändö and Finnish Kustavi there is a 45 kV AC already described. It has a special arrangement for the use of it. Since KNÅ is the owner of the network including the substations on the mainland, the company has to pay for the losses.

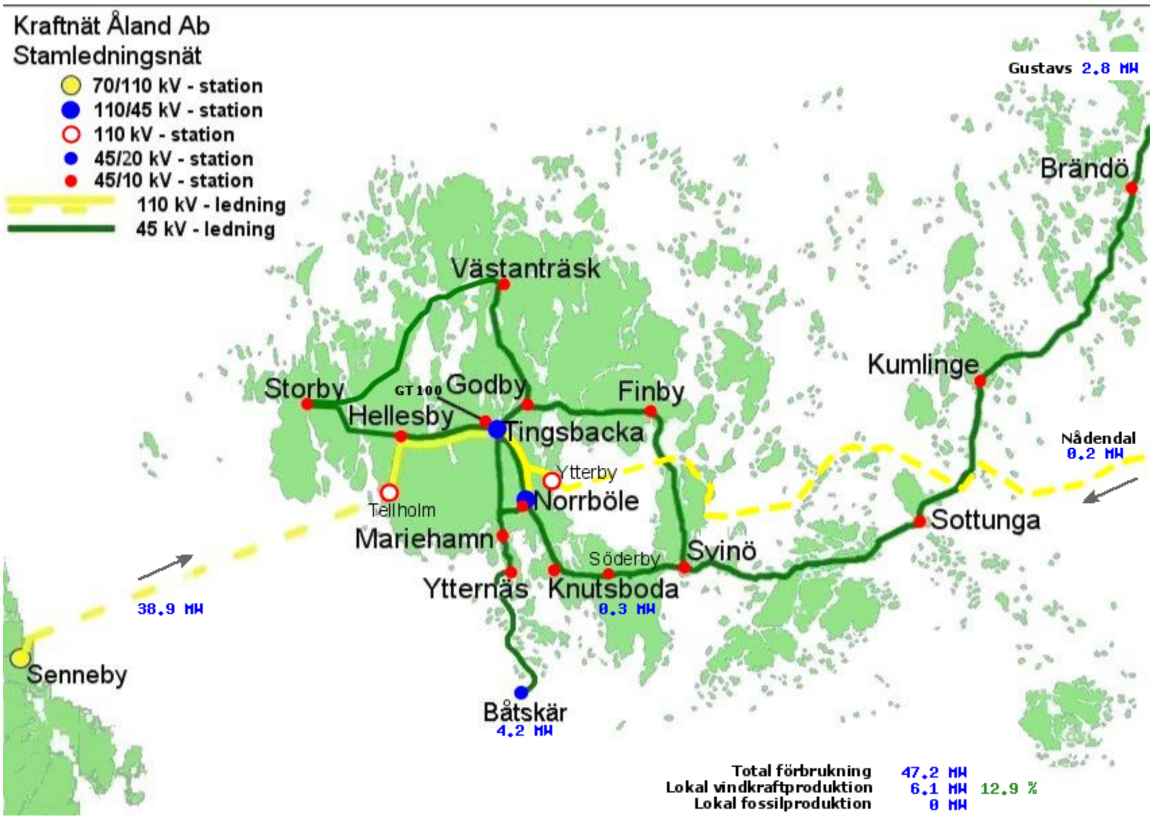



*Figure 5. Voltage Levels of Åland's Electricity Transmission Grid.*

It becomes clear when looking at Figure 5 and Table 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 1. Kraftnät Åland's grid is all in all 512 km long spreading all over the most important dwelling areas as Figure 5 illustrates.

*Table 1. Transmission Grid in Åland 2018*

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

## District heating system

### *Combined Heat and Power (CHP)*

Mariehamns Bioenergi has the only CHP unit in Åland today. It is a 9 MW heat and 1.8 MW electricity wood chip plant in Mariehamn. Due to high LCOE and low market prices it is not used commonly. In times of higher market prices (usually winter) it is economically feasible to use. Mariehamns Energi and Kraftnät Åland have generators and gas turbines for emergency situations. There are no current plans of new CHP plants on Åland.

### *District heating*

District heating is available in Mariehamn and in Godby.

### *Mariehamn*

In Mariehamn Mariehamns Energi distribute about 110 GWh to around 1,000 customers that are connected to the district heating network. 85% are wood based heat from Mariehamns Bioenergi and 15% is oil based from Mariehamns Energi's own oil burners and generators. Wood chips are used in first hand and oil only during cold days.

### *Godby*

In Godby Finströms kommun and Ålands Skogsindustrier distribute district heating from a 3 MW wood chip plant.

## Future demand and generation

All sub-groups analysed together as well as separately the current energy needs and estimated future demand and energy mix based on already existing investment plans as well as potential increases in dement and came into following conclusion. Based on the conclusions, two different scenarios were created (Table 2) where Future 1 is likely to happen by 2030 whereas Future 2 takes into consideration all potential variable renewable energy island can generate, regardless of the need nor usage. The idea is then either sell it to the open markets, store it or make another product type by using potential power-to -x processes.

*Table 2. The two scenarios or "Futures" with production mix and consumption.*

**Parameters:**

**Current:**
- Wind capacity 21 MW
- Heat (pumps) 20 $MW_t$
- Peak 67 MW
- Total consumption 300 GWh
- Cos (phi) = 0,95 ind/kap
- Min load 16 MW
- Capasity mix
  - Import 80 %
  - Wind 20 %

**Future 1:**
- Wind capacity 85 MW
- Heat CHP 20 $MW_e$
- Solar 15 MW
- Peak 85 MW
- Total consumption 400 GWh
- Cos (phi)= 0,95 ind/kap
- Min load 16 MW
- Capasity mix
  - Wind 70 %
  - Solar 15 %
  - CHP 15 %

**Future 2:**
- Wind capacity 170 MW
- Heat CHP 0 $MW_e$
- Solar 20 MW
- Peak 85 MW
- Total consumption 400 GWh
- Cos (phi)= 0,95 ind/kap
- Min load 16 MW
- Capasity mix
  - Wind 90 %
  - Solar 10 %
  - CHP 0 %

# 4. Wind

By Henrik Lindqvist, Allwinds

The wind conditions at Åland Islands are one of the best in the country, maybe some places in Lapland or along the western coastline have similar conditions. This means that on Åland is there no need for higher towers to gain good production. And building "semi offshore" or "offshore on the rocks" will give the projects offshore production with onshore installation costs. This is of course a big advantage for building at the Åland Islands.

Today is Allwinds the only company at Åland that operate and maintain wind turbines, takes care of project management and trade electrical energy produced by local wind power.

Allwinds is owned by three company that also are the owners of the fleet of turbines on Åland. This companies are Ålands Vindenergi Andelslag, Ålands Vindkraft AB and Leovind Ab. There is also one other company that owns one turbine, Ålands Skogsindustrier, and this turbine is also operated and maintained by Allwinds and the energy from this turbine is used by its owner.

## Investment suggestions, timelines and investors

*Table 3. Investment suggestions and timelines*

| Project name | Location | Installed MW | Timeline (year) | Price estimation |
|---|---|---|---|---|
| Långnabba (I&II) | South end of Eckerö | ~40 MW | 2020 | 45 M€ |
| Stenarna | In the archipelago between Eckerö and Hammarland | ~ 15 MW | 2020 or 2021 | 18-20 M€ |
| Rödskär | Directly west of Föglö | ~ 15 MW | 2025? | 18-20 M€ |
| Östra skärgården | In the archipelago south of Kumlinge | ~ 100 MW | 2030-2033 | 180 – 220 M€ |
| Södra skärgården (a fictive project at this stage) | In the archipelago north of Kökar | ~ 50 MW | 2035-2038? | 90 – 110 M€ |

Project Långnabba (Långnabba I & II) might be financed by local investors and banks if the local support system will be feasible. Project Stenarna and Project Rödskär might be financed by local investors and banks if there will be one local additional support system or if some PPA´s can be signed for them. The bigger projects (Östra and Södra skärgården) needs some other financial solutions and investors from mainland or from abroad.

Main bottle necks are the lack of some support systems or some other solutions that will attract investors and banks. On the technical side is there also some bottle necks regarding grid connections and logistical issues.

# 5. Solar

By Kaarle Mäkinen, Fortum

Åland has one of the best solar irradiation and energy yield conditions in Nordics and comparable to Northern-Germany (Figure 6).

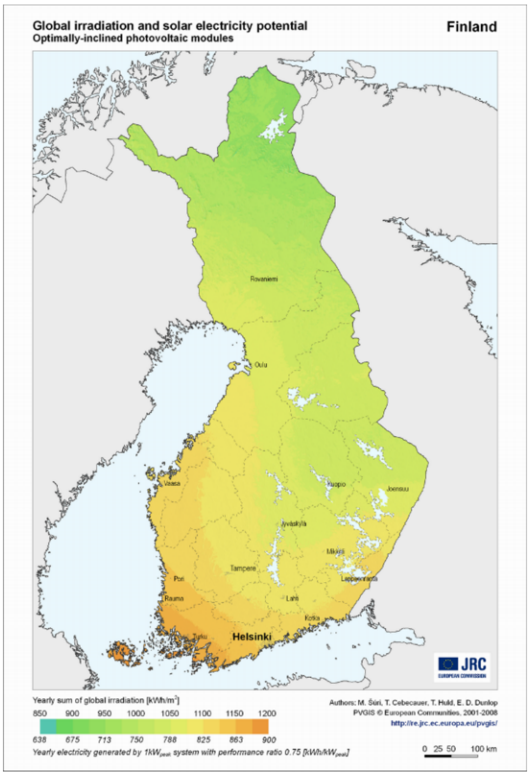



*Figure 6. Global irradiation and solar potential in Finland with optimally-inclined photovoltaic modules. Ref: PV-GIS European Commission.*

Considering solar energy production Åland island is the best location in Finland to place solar systems. Based on meteonorm satellite data and simulations we have got PV plant energy yield results as follows:

- 835 to 900 kWh/kWp/a for large roof-top solar power plants with module tilt angles ca 15 degrees
- 900 – 1025 kWh/kWp/a for large-scale ground mounted solar power plants with module tilt angles 20 to 30 degrees.

Solar market in Åland is rather immature and only few systems have been deployed (<1 MW cumulatively). Market is driven by few of local SME companies, mostly background in electrical works and building maintenance. Few more specialized solar companies such as. Solel Åland AB has emerged in recent years. Some of the key players are: Solel Åland, Allwinds and JFS El.

## Investment suggestions and timelines

Åland has a system consumption of 16 to 40 MW during seasons when solar energy is best available (March to October). 50 MW (dc) solar capacity would generate 49 GWh/a and account for ca. 17% of energy needs in Åland. 5% of solar energy would be surplus during summer time and needs to be curtailed, exported or stored.

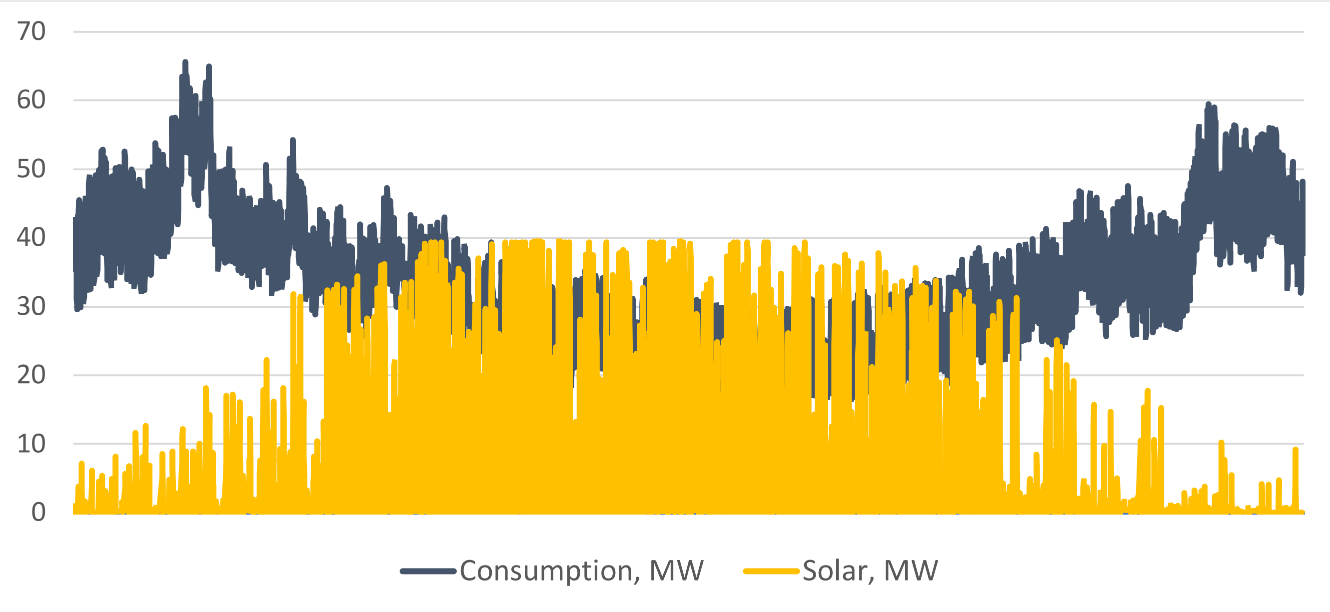



*Figure 7. March to October consumption of electricity [MW] in Åland Islands and solar production [MW] with 50 MW (dc)solar capacity.*

Three solar business segments were identified to develop projects and investments:

- Residential roof-top (1 to 10 kWp solar systems)
- B2B roof-tops (50 to 1000 kWp solar systems)
- Large scale solar power parks (ground mounted fields in + 5000 kWp)

*Table 4. The three identified solar business segments with CAPEX, OPEX and LCOE estimates.*

| | Residential | B2B | Solar parks, 10 MW |
|---|---|---|---|
| CAPEX, €/kWp | 1000 - 1400 | 700 - 900 | 550 - 700 |
| OPEX, €/kWp | +35 | 7 - 15 | 6 - 10 |
| Energy, kWh/kWp | 700 - 850 | 800 -900 | +900 |
| LCOE, €/MWh* | 95 - 130 | 65 – 80 | 55 – 70 |

*25-year lifetime, 1,5% inflation, 5% discount rate, 0,5% module annual power degradation

Solar module prices have come down due to technological developments (will continue gradually), as well as due volatile market changes e.g. China dropping down solar subsidies and EU releasing from Minimum Import Price regulation. It is expected that solar energy system costs and prices will go down also in the future but with relatively smooth and slow incremental way, as key components such as modules and inverters start to be less than half of the total investment and the rest is materials (aluminum in mounting systems), as well as labor costs of electrical installation.

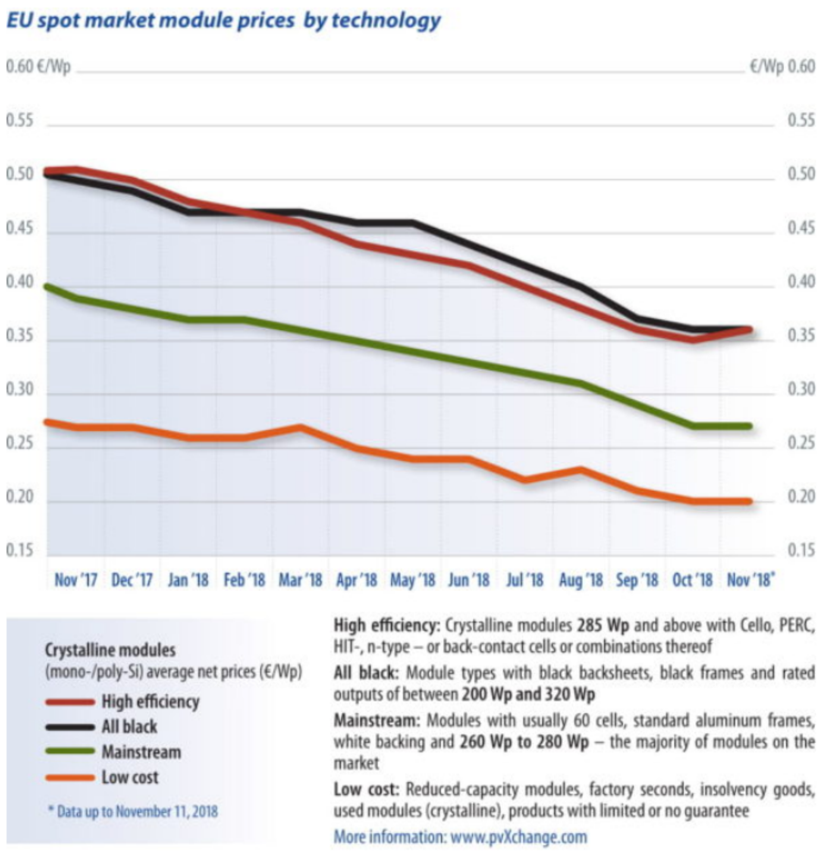



*Figure 8. EU spot market module prices [eur per Wp] by technology in 2017 and 2018.*

Solar systems in residential scale can be installed within few days or weeks depending on the grid approvals and permitting process, whereas B2B solar installations typically take few months up to half a year to deploy due to more demanding design, structural investigations, permitting and installation. In case of constructing a solar park, the longest lead time is typically in permitting and grid connection that can take few months up to many years, and the actual plant construction takes two to six months.

Considering current system prices, their development outlook and timelines of project development following roadmap could be proposed:

- Start promoting installation of residential solar systems where it makes sense for the end-clients
- Start promoting B2B solar installations, as they would provide more capacity, more energy with a lower cost versus residential systems. B2B systems could also be deployed fasted than large parks.
- Start development of multiple +10 MW solar park sites close to consumption, or few 25 to 50 MW plants in beneficial locations with feasible land and grid connection nearby.

Roofs of existing real estates could accommodate up to 50 MW of solar installations. Portfolio of 50 MW roofs would generate around 40 GWh of solar energy i.e. 13% of Åland's annual energy needs (ca. 300 GWh/a in 2012). In comparison a 20 MW solar park would be much more efficient in terms of CAPEX, OPEX and energy yield providing the lowest solar energy costs.

*Table 5. Analysis of existing real estates in Åland and solar potential.*

| Existing real estates in Åland | pcs | Footprint, m2 | Solar feasiblity, % | Solar roofs, m2 | Area eff. m2/kWp | Solar potential, kWp | Production, kWh/kWp | Production, MWh/a |
|---|---|---|---|---|---|---|---|---|
| **Residential buildings, private** | 8 215 | 1 347 310 | 10 % | 134 731 | 7 | 19 247 | 750 | 14 435 |
| **Residential building, block house** | 143 | 75 936 | 20 % | 15 187 | 21 | 723 | 800 | 579 |
| **Vacation building** | 4 414 | 337 073 | 10 % | 33 707 | 7 | 4 815 | 700 | 3 371 |
| **Industrial** | 197 | 193 385 | 40 % | 77 354 | 21 | 3 684 | 850 | 3 131 |
| **Business, office and other** | 19 495 | 1 912 036 | 25 % | 478 009 | 21 | 22 762 | 825 | 18 779 |
| **Other non-relevant for solar** | 140 | 260 459 | 0 % | - | | | | |
| | **32 604** | **4 126 199** | | **738 989** | | **51 232** | | **40 295** |
| | | | | | | | | |
| **Large solar farm 20 MWp** | | 300 000 | | | 15 | 20 000 | 900 | **18 000** |

## Potential financing, investors and challenges

Potential investors to solar system are largely dependent on size of the solar power project:

- Residential (1000 – 10 000 €): Customer themselves. Leasing models available in some markets and residential projects can be aggregated into larger portfolios to investors.
- B2B (10 000 to 1 000 000 €): companies, or 3rd party investors in form of Leasing contracts or Power Purchase Agreements ("PPA"). Typical PPA providers are energy companies or heavy investor backed solar companies, whereas some banks are offering leasing financing to solar systems.
- Large scale solar power plants: (+ 5 M€): energy companies from their balance sheet or financial investors. Typically, project financing and dedicated SPV firms are used. Some markets like California have adopted Solar Community models, where solar energy users co-invest in a specific solar energy project.

Solar energy makes fundamentally sense in Åland, however few factors can slowdown or hinder projects to materialize:

- Small market size; lack of competence, may limit interest of companies outside Åland to enter the market.
- Closed and locally driven market; may limit interest of companies outside Åland to enter the market.
- Current heavy investments in connection cables to grids in Sweden and Finland; ocean cables must be paid back, thus TSO/DSO need their revenues from end-customers and may dislike solar installations reducing grid energy consumption on the consumption side.
- Solar park would need a long term PPA (+15 years) to be feasible as investment, such off-takers buying solar energy via grid transmission might be challenging to find.

# 6. Demand response

By Gunnar Westling, Ålands Landskapsregering

Today both Mariehamns Elnät (MEL) and Ålands Elandelslag (ÅEA) offer day and night tariffs for their consumers. Tariffs based on time of day is a simple way of demand response according to normal variations of load from day to night. Mostly customers with electrical heating uses day and night tariffs. The day and night tariffs are linked to a certain time, 11 pm and 7 am, and not to the real load. There are no other types subsidies for demand response or customers savings today.

Electrical heating is a good and cheap source for demand response, it is a large electricity consumer and with some sort of heat storage it is possible to control without decrease customer happiness. Other forms of electricity consumption offer more power to control.

## Potential flexibility sources

The demand response for customers focus on electrical heating in the first phase. Over 4,000 customers have day and night tariffs and probably electrical heating in Åland.

## Electrical heating power (MW) in small houses

The total amount of power used for electrical heating is unknown but with comparison of consumption from normal customers and day and night tariff customers an approximation is possible. The approximation includes all day and night tariff customers on Åland.

The heating is larger during winter and lower in the summer. During winter demand response via electrical heating is more useful and the overall consumption is also higher and more volatile then, so demand response will have a greater impact on balance in winter time. The same amount of power is also available for increasing the consumption in the summer but cutting the consumption is not possibly in the same extent as in the winter.

Based on monthly averages 1-4.5 MW can be used in demand response. In occasions with maximum differences up to 10 MW can be used according to the approximation, see Figure 9. 10 MW is thus the maximum power demand response can use via electrical heating. 10 MW is a noticeable power source for both the retailers, grid operators and electricity production companies.

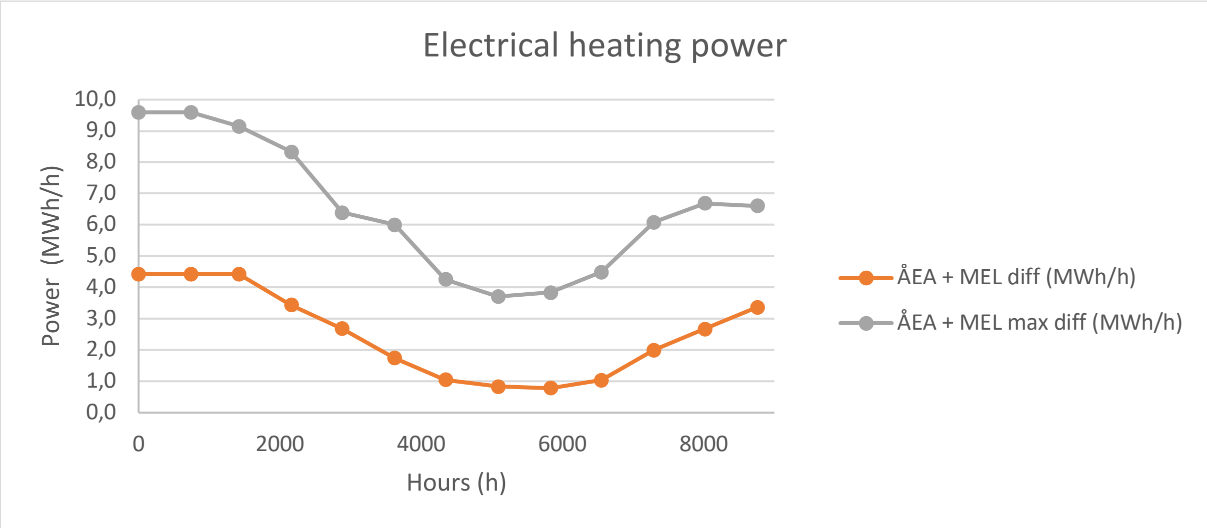



*Figure 9. Electrical heating power over a year in hours.*

During a winter day the upper and lower peaks does not differ largely from the daily average, less than 10 MW (Figure 10). Heating is a necessary part of society so heating power cut from consumption must return so that the transferred amount of energy (heat) is the same. In extreme cold temperatures it is harder to cut heating power because it effects the customers more and faster.

If demand response is used in 1-2 hours consumption the peaks in consumption can be lowered to some extent. Loner time, more heat storage, gives better balance in consumption and more energy to transfer.

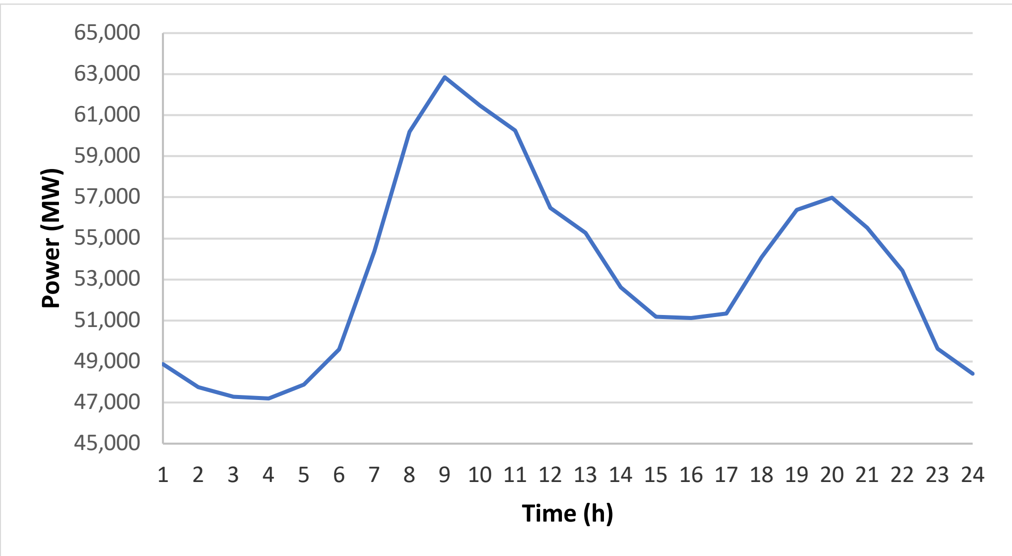



*Figure 10. Total power curve [MW] during 9th of February 2017.*

In this case electrical heating in small houses have been investigated. Small houses are located throughout Åland and there are of course a lot more in densely populated areas. Electrical heating is used in most types of houses and on most locations but an exception is areas with district heating, Mariehamn and Godby. Oil and wood boilers are still common in Åland but many of them have some sort of axillary electrical heating (Table 6).

*Table 6. Heating sources in Åland*

ÅSUB Boende och byggande

**3.10. Antal byggnader efter bränsle 31.12.2017**
*Buildings by heating fuel 31.12.2017*

| Hustyp/*Type of building* | Totalt | Fjärr-, värme/ *District-, localheat* | Olja, gas/ *Oil, gas* | Ved, torv, koks/ *Wood, peat coke* | El/ *Electricity* | Jordvärme/ *Geothermal* | Övrigt el. okänt/ *Other or unknown* |
|---|---|---|---|---|---|---|---|
| **Totalt** | **13 716** | **968** | **4 072** | **1 614** | **4 574** | **923** | **1 565** |
| Bostadsbyggnader/ *Residential buildings* | 10 516 | 733 | 3 697 | 1 485 | 3 315 | 873 | 413 |
| Affärsbyggnader/ *Shop buildings* | 1 091 | 45 | 80 | 76 | 695 | 14 | 181 |
| Kontorsbyggnader/ *Office buildings* | 119 | 49 | 33 | - | 28 | 1 | 8 |
| Trafikbyggnader/ *Traffic buildings* | 1 108 | 43 | 57 | 18 | 295 | 12 | 683 |
| Vårdbyggnader/ *Institutional buildings* | 65 | 22 | 20 | - | 12 | 7 | 4 |
| Samlingslokaler/ *Buildings for assembly* | 141 | 22 | 27 | 6 | 46 | 3 | 37 |
| Undervisningsbyggn./ *Educational buildings* | 64 | 27 | 26 | - | 8 | 1 | 2 |
| Industribyggnader/ *Industrial buildings* | 338 | 17 | 99 | 20 | 112 | 5 | 85 |
| Lagerbyggnader/ *Warehouses* | 199 | 5 | 18 | 3 | 39 | 5 | 129 |
| Övriga byggnader/ *Other buildings* | 75 | 5 | 15 | 6 | 24 | 2 | 23 |

Källa/*Source*: Statistikcentralen, Boende/*Statistics Finland, Housing*

To make demand response possibly in an organized way you need equipment at every customer, some sort of communication and a central unit managing the whole system. The cheapest way is to use the electrical meter and its existing communication channel trough a common standardized API.

The price is estimated to ca 500,000 euros which include 4,000 customers á 50 euros and a central unit and communication for 250,000 euros. With more customers more power will be available and the cost per customer will be lower. Good marketing and profitable deals for customers is necessary to get a widespread citizen engagement in the project.

The local industry is small and have low power demand. To adjust their consumption to load and prices will probably not be in their interest because of not enough economic incentives.

## Prosumers and citizen engagement

Solar PVs are becoming more popular and the prosumers are becoming more numerous. During 2018 ca 50 persons have applied for government subsidies for solar PVs to a total investment cost of 400,000 euros. This is only solar PVs on houses and company buildings, summer cottages are not included. 2019 is probably going to be more intensive.

A framework for citizen engagement was created by Solved. The importance of having close dialogue with citizens was underlined, and early co-operation is also needed. Citizen-oriented and tailor-made communication strategy was established and Flexens will implement this. It also is important to educate, provide information, have direct dialogue, demonstrate the value of participation, be transparent, visualize and utilize multiple outreach techniques, for example. Citizen engagement will be jointly done by with Flexens and Åland Landslagsregering. Potential customer financing plans will be done jointly with Citizen Engagement process and they are closely linked to each other's. The financing plan will also include possible blockchain financing where local citizen can also participate

## Current issues hindering the potential investments

Who should have to primary right and be the active part in demand response? And who can earn something from it? These questions must be answered.

The order of priority is TSO, DSO, Retailer and Customer. The TSO and DSO need to have their grid balanced and, in some cases, not usually, cutting customer consumption is the only way. The retailer is economically interested to match consumption to their forecasts. The customer wants the "product" they have ordered. The order of active control is the opposite, the customer make active choices in accordance with their demand on the "product".

With the current market prices in SE3 area there is little economical opportunity to make demand response popular for customers. In a market with bigger price variations in accordance with available power the incentives will be more interesting for the customers. In an isolated system demand response have a direct impact on the price. The Finnish market is more volatile, see Table 7.

*Table 7. Prices in SE3 and FI area 28th of February 2018 when the highest peak power ever occurred in Åland, 76.5 MWh/h.*

EUR/MWh

| 28-02-2018 | SE3 | FI |
|---|---|---|
| 00 - 01 | 37,98 | 37,98 |
| 01 - 02 | 37,70 | 37,70 |
| 02 - 03 | 37,70 | 37,70 |
| 03 - 04 | 37,82 | 37,82 |
| 04 - 05 | 38,06 | 38,06 |
| 05 - 06 | 39,02 | 199,94 |
| 06 - 07 | 44,98 | 202,06 |
| 07 - 08 | 57,38 | 249,97 |
| 08 - 09 | 70,67 | 205,09 |
| 09 - 10 | 68,83 | 202,08 |
| 10 - 11 | 68,04 | 202,02 |
| 11 - 12 | 50,09 | 63,36 |
| 12 - 13 | 44,97 | 55,01 |
| 13 - 14 | 43,47 | 55,08 |
| 14 - 15 | 42,89 | 59,27 |
| 15 - 16 | 42,82 | 55,09 |
| 16 - 17 | 44,96 | 55,09 |
| 17 - 18 | 67,94 | 76,94 |
| 18 - 19 | 72,91 | 72,91 |
| 19 - 20 | 50,87 | 59,25 |
| 20 - 21 | 44,91 | 44,91 |
| 21 - 22 | 41,54 | 41,54 |
| 22 - 23 | 38,72 | 38,72 |
| 23 - 00 | 37,76 | 37,76 |

# 7. Heat

By Tomi Thomasson, VTT, Anna Pääkkönen, TAU, and Tero Joronen, Valmet Technologies

How to achieve a fully renewable energy system that domestically produces its power and heat while simultaneously maintaining the system functional during continuous production valleys in wind generation? In other words, what is the best way to support the wind production? The production valleys were statistically assessed and noted significant in both energy content (max. 3.73 GWh) and peak power (max. 63 MW), requiring consideration of the available domestic fuel resources and suitable technology options for their conversion.

Mariehamn has district heating system, and is practically only place to consider larger CHP-production. In Figure 11 (below) is presented the district heating demand of

Mariehamn has district heating system, and is practically only place to consider larger CHP-production. In Figure 11 (below) is presented the district heating demand of Mariehamn. Maximum heating demand in 2017 was 36 MW, average 13,6 MW, and in the summertime minimum heat demand is approximately 4 MW.

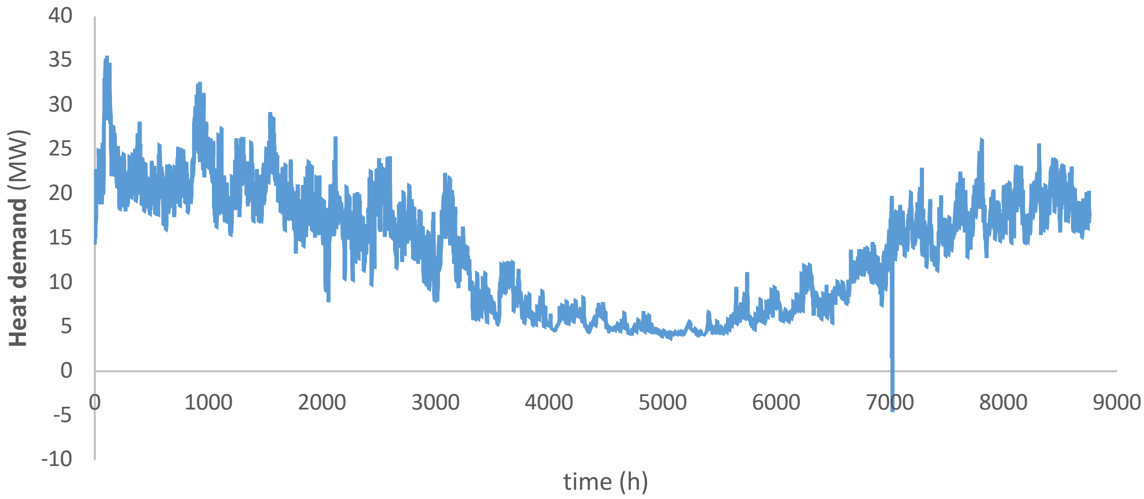



*Figure 11. Heat demand in Mariehamn district heating network (source Mariehamns Energi)*

The resource availability was assessed for biomass, waste and carbon dioxide using data from literature and project partners. The biomass availability (395 GWh/a) was found sufficient to enable capacity additions. Biogas, due to its limited production capacity (16.5 GWh/a) on the island, was considered to require excessively large storage capacity to be able to provide peak electricity. Consequently, as the volume of the existing sources of carbon dioxide are dependent on biogas production, the potential for methane production was also found limited (1.88 GWh/a).

In order to analyze the system design in more detail, an optimization model comprising the existing production units and potential new units in both power and heat sector was created using gathered techno-economic information of the system. Two distinctly different future scenarios of the power system configuration were defined by the project group and selected for evaluation along with a combination of the both as follows:

- 187 MW wind
- 87 MW wind and 15 MW biomass
- 187 MW wind and 15 MW biomass

Techno-economic feasibility of the scenarios was compared using two key performance indicators, the share of imported electricity (%) and the annual system net profit (€/a). The former could be analyzed from the optimized annual power and heat generation shares. For the first two scenarios, the system differed notably in the heating sectors: in the first scenario, the optimal approach was to utilize the existing biomass heating boilers in addition to investing to new capacity, whereas in the second scenario new heating boiler capacity was not required due to inclusion of CHP. Despite of this, the first two scenarios led to rather similar level of self-sufficiency in power sector; approximately 24.5% (86 GWh) of the electricity was imported. In the third scenario, the value was decreased to 11.1% (39.1 GWh). This highlights two opposing conclusions: CHP can be an important element in maximizing the self-sufficiency of the system, but the added capacity does not linearly improve the self-sufficiency. This was shown in the third scenario by 46% of the CHP production being excess, only shifting the wind production to export, as the only available conversion from power was electric heating.

From a purely economic perspective, the second scenario appeared the most feasible, reaching an annual system net profit 21% and 19% higher than in the first and third scenarios, respectively. The system configuration of the second scenario was at the same time the most challenging to convert into fully self-sufficient due to high reliance on imported electricity. If self-sufficiency is emphasized, maintaining some reliance on imported electricity is considered reasonable regardless of the approach. The problem lies in providing the peak electricity; while solutions such as biogas turbines or distributed fuel cells could be scaled up to the required peak power, the approach would lead to very low peak utilization time and hence an economically infeasible investment.

If included in the scenario, majority of the heat was produced with CHP, which significantly increased the total biomass consumption due to lower heat efficiency compared to heating boilers. As concerns of the biomass availability were presented, the scenarios were simulated while limiting the maximum allowable biomass consumption in steps of 10% from 395 GWh. At around 215 GWh/a, the share of heating boilers began to increase, and with biomass availability at 119 GWh/a, the optimal heating sector configurations mainly comprised heating boilers and electric heating. Again, two conclusions can be drawn: the realistic biomass availability should be confirmed having great impact on the system design, and technical feasibility of electric heating should be studied further.

Batteries can only be a partial solution in reaching full self-sufficiency, as the possibility for the required continuous dispatch does not exist. This is considered to apply for both vehicle-to-grid approach, in which discharge for multiple consecutive days cannot be assumed despite of the potentially higher total capacity, and for utility batteries, which simply lack the capacity even if scaled excessively large. Examples of such would be the recent projects at Hornsdale Power Reserve (129/100 MWh/MW) or Southern California Edison (80/20 MWh/MW). Concerns can also be raised on the overall feasibility. Cumulative upkeep cost of batteries over decades is often entirely ignored, as complete replacement is eventually required. While aggregated electric vehicles and residential batteries would partially solve the problem of investment cost, hidden burden would be created on both economic and practical level for the consumers. Heavy use would be detrimental to the batteries, and if unscheduled deep discharge would take place, the vehicle range would be significantly limited.

The scalable production of domestic energy carriers was considered limited to hydrogen and ammonia, unless additional carbon is captured. Building the hydrogen infrastructure solely for power production would be questionable; for example, the hydrogen strategy of Japan (METI, 2017) also emphasizes mobility. As the storage of hydrogen is both expensive and inconvenient, and the proposed workarounds such as liquid organic hydrogen carriers (Aakko-Saksa 2017) are not considered mature enough, ammonia would offer an alternative path. Ikäheimo et al. (2018) discuss that the viability of ammonia as a long-term storage method is evident. In Åland Islands, the energy carrier would allow "stranded" wind farms with no power grid connection, from which the liquid product would periodically be transported.

When considering other options, heat pumps and solar heating, for district heating at Mariehamn, simple study of feasibility was conducted. With current large heat pump investment costs 454 €/kWth (Based on Helen heat pumps under Esplanadi-park in Helsinki) the investment to new heat pumps is not feasible as the capital cost are high. Feasibility of heat pumps is also highly dependent on the price of electricity. Solar heating in large scale would require a large space in order to produce a reasonable amount of heat, and with current collector prices, this will not be economically feasible even in the long run. For the solar heating, the worst fact is that the demand on winter months and production on summer months do not match, and relatively high investment cost does not pay out. However, household scale solar collectors might be beneficial for the energy system. The most economical solution for the district heating network is biomass fired heat only capacity to replace the current oil boilers. The benefit is that the heat production price is relatively low as it is directly related to biomass price. However, any additional heat only will weaken the overall economics of the current CHP plant by cutting the operation hours as can be seen from figure 12, where the effect of heat only boilers to CHP operation is presented. Also, large heat pumps will have the same effect on the CHP operation.

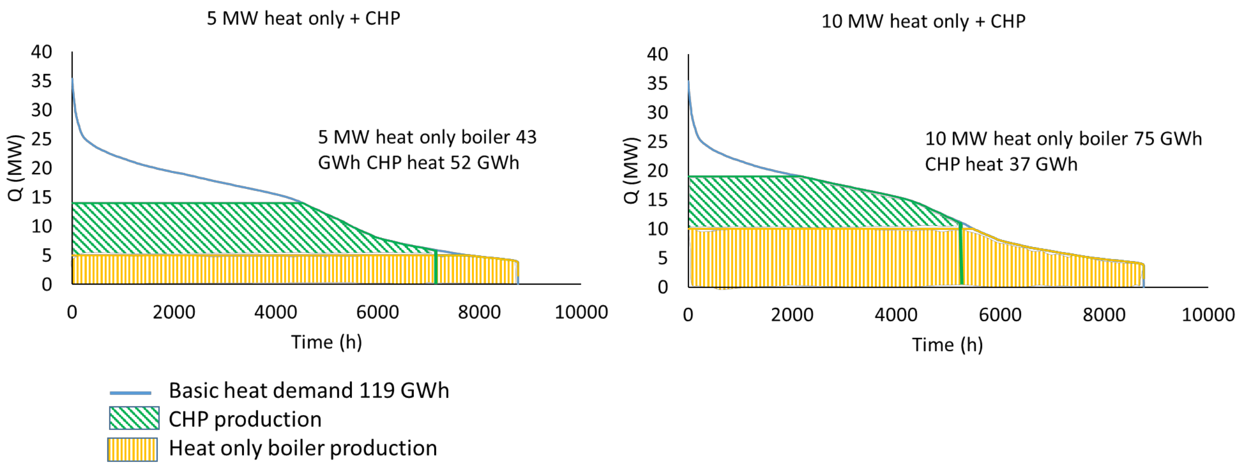



*Figure 12. Effect of heat only boilers to CHP production*

Another option for the heat only boilers is to invest in a larger CHP facility. The study showed that a CHP plant with 20 $MW_{th}$ and 10 $MW_{el}$ would be feasible and could also provide flexibility to the variable power production with increasing amount of wind capacity. Optimizing the minimum load and start time of the plant will make it more flexible for both heat and power demand response. Additional investments in turbine bypass and low-pressure turbine will increase the flexibility even more, however this will weaken the feasibility of the plant since the total capital cost will increase significantly with additional features. Overall economics of CHP is highly dependent on fuel cost and heat sales which limits the feasibility of additional power flexibility features in Mariehamn since there is no significant industrial heat demand at present.

# 8. Electric transportation

By Jim Häggblom, Viking Line Bus and Riku Pasonen et al., VTT

## Buses

### *Mariehamn city transports*

Power demand for fast charging of electric bus in very manageable for urban area grid like in Mariehamn. Smart control of the charger with reactive power injection however offers benefits also for urban power grids. Basically, this means to utilize charger apparent power capacity for reactive power feeding (capacitive or reactive) to compensate grid needs. In practical terms this means that charger to be able to do this needs to have active three phase bridge and output capacitor to enable current flow via DC side when vehicle is not connected. Simulation in the study was done with Matlab Matpower tool which has optimum power flow algorithm to minimize grid losses. In addition to losses, voltage level in grid can be levelized when reactive power is fed close to locations with high power loads. Those two benefits are more impactful in weaker rural grid but basic ability to feed reactive power is beneficial in urban grids also. Three simulated locations displayed estimated reduction in ball park or 60% of reactive power need from upstream grid.

Although simulation used optimum power flow, reactive power injection can be practically utilized by much simpler method. Reactive power levels in supplied data were quite stable, therefore constant value can be added in charger control for compensation. Only priority type of control will have to be in place where active power demand of charging overrides the reactive power setting during high charging demand. In any case it is recommended to have charger with this reactive power injection capability to utilize the power electronic device for benefit of the grid during the time vehicle is not charging.

Based on the simulations and the TCO analysis, both types of electric buses could be used in Mariehamn. Both bus types have pros and cons. The opportunity charged bus has a somewhat lower energy consumption, and the environmental impact regarding energy use would be smaller than in the depot charged case. This type of bus, however, suffers from the high dependency on the charging infrastructure, and this dependency is aggravated as only one fast charger would be available. The requirements on service of the charger in case of some kind of malfunction is quite high. The utilization rate of the charger is very low, as only two buses are in operation. In case electrification of other vehicles, such as delivery trucks, is under consideration, the costs of the bus operation could be reduced if the charger would be shared with other vehicles. The depot charged bus could be a good option for Mariehamn. The main concerns regarding this bus are related to uncertainties in the battery lifetime and the energy consumption in extreme weather conditions. In case the energy consumption is higher than expected (for instance during cold winter days), the bus might require extra charging sessions. It is expected though, that the total cost of operation will somewhat increase whatever type of electric bus is chosen as compared to diesel buses.

General battery capacity for a depot charging bus is 320 – 350 kWh and for an opportunity charging bus 50 – 60 kWh. A higher battery capacity adds on more weight to the bus and is less energy efficient due to added weight. The investment price for a depot charging bus is higher due to the increased battery capacity needed. However, the dependability is higher for a depot charging bus, since fast battery charging stations are more complex and therefore more sustainable to technical issues. According to VTT in the Mariehamn city case, there is not any substantial difference in which charging alternative is used.

Investment cost of e-busses are for opportunity charging 430 000 € per bus and depot charging 520 000 € per bus. Fast charger (opportunity) cost estimate is 360 000 € + installation costs depending on location and for depot charger 60 000 €. It is to be noted that it is still uncertain if the city of Mariehamn wants e-buses at all.

### *Åland regional transports*

There are approximately 28 buses on the island handling regional transports and charter services on and away from the Island. Several of these could be replaced with low or high floor buses with a battery capacity of 80 - 350 kWh, depending on charging solution. It is still unclear if depot charging or opportunity charging is the best solution for regional transports. Investment cost estimates are the same as for city transport busses.

### *Autonomous buses*

Autonomous buses have been developed during the last years, and they could eventually provide an addition to conventional bus operation. However, it should be kept in mind that the technology is far from fully developed. Autonomous buses have been tested on different locations in Finland (as well as in other countries), and the development and testing of these buses is an ongoing process. The buses tested are very small and can take around 10 passengers each. In fact, they are mainly developed for feeder traffic to provide public transport for shorter distances (the last mile). The maximum speed of the buses has been limited to 18 km/h. One major reason for this is the safety, as harsh brakings could be harmful for the passengers at higher speeds. The low speed of the buses limits their usability in normal traffic, as other vehicles travel at much higher speeds. Furthermore, the travelling time becomes long, and most people would probably choose another mean of transport. The buses still need an operator on board, as remote control of the vehicles has not been developed yet, and even though the buses run autonomously most of the time, they still need help from the operator in certain situations. For instance, crossings are still difficult to handle autonomously, and the operator has to intervene rather often. The buses simply do not understand traffic rules very well, and their performance is not still acceptable when operated in normal traffic. The buses have so far only been used on predefined routes that have been programmed into the vehicle, and special arrangements, such as extra signs and priority at crossings, have been made. The buses currently available still face a lot of challenges related to variations in weather conditions and other unforeseeable events, such as parking violations. Hence, it is clear that the technology is not yet ready for commercially competitive operation.

One of the main benefits of autonomous buses would be to reduce the personnel costs. This, however, would require remote control, which is currently not available.

Developing such a system to a level with an acceptable reliability would take several years. Another benefit would be to increase the number of passengers using public transport instead of their own car, which could be achieved if the service is flexible and cheap enough. In order for this to happen, the buses need a lot of development. Ideally, the small buses would be used on demand and more like autonomous taxis. The technology available today is, however, very far from this. One should also keep in mind, that people have to get used to new technology. According to experiences from tests of autonomous buses, most people are not afraid of the technology as such, but they are afraid of each other. Having an operator on board makes people feel safe, but when the technology is developed enough to allow remote control, the situation might be different, and it is not self-evident that all passengers would appreciate this new technology.

## Private cars

Approximately 30 000 people live on the Aland Islands and the number of private cars is just as many. However, the number of e-vehicles is still quite low. In 2017 35 EVs were registered on Åland and in 2018 the number was 73, and this is normal cars and vans. Approximately 90% of charging of electric cars is done at home. For the current number of e-vehicles on and visiting the island the existing infrastructure can be considered to be sufficient. There is a need to encourage apartment owners to offer charging possibilities for tenants.

Charging station investors may be Mariehamns elnät, Ålands Elandelslag, stores, Ålands Landskapsregering, Mariehamns stad.

## Ferries

There are plans to convert some ferry routes into e-ferries.

- E-ferry from Töftö – Prästö by the year 2020.
  - Ferry running time from a to b is 4 minutes. Cable solution. Current ferry to be converted.
- Ongoing tender for an e-ferry to run from main Aland Island to the Island of Föglö. Ferry to enter service by the year 2022.
  - Battery capacity of 1000 kWh. Hybrid ferry -> onboard diesel engines. 20 min runtime, 10 min charging. (Type FinFerries Elektra)
- E-ferry to run between the Island of Föglö and the Island of Kökar by the year 2022.

- Battery capacity unknown. Hybrid ferry -> onboard diesel engines. Running time approximately 50 minutes, charging time unknown.

- E-ferry to run between the Island of Föglö and the Island of Sottunga by the year 2022.
  - Battery capacity unknown. Hybrid ferry -> onboard diesel engines. Running time approximately 35 minutes, charging time unknown.

Based on the evaluation of different ferry types for the route between Degerby and Svinö it can be concluded that the most beneficial type is fully electric ferry. It provides the significant emission savings, which is two order of magnitude compared to others. In addition, the yearly costs of battery vessel are significantly lower, even taking into account the relatively short battery lifetime.

Hybrid diesel-electric solution did not provide any savings in $CO_2$ and energy usage, which is explained by the load profile with quite short acceleration/deceleration intervals and long cruising time.

For power grid options, new 45 kV line was the most cost-efficient option for ensuring power quality standard fulfilment. For alternative route Svinö and Mellanholm, existing grid can take the load but transformer load at Svinö should be observed and evaluated for long term loading.

# 9. Storage

By Amanda Grannas and Michael Grünenfelder, Pöyry

In order to reach 100% autonomy with renewable energy sources (RES), Åland will increase its wind power production significantly. The energy transition with an increase of the share of variable renewable energy (VRE) sources (wind and solar) in the energy generation mix leads to large variations in the energy production, which does not coincide with the consumption. To smooth these gaps and peaks in electricity production and consumption, neglecting the existing interconnection to Finland and Sweden, energy storage is a necessity.

The future large variability in energy supply on Åland by 2030 is caused by wind power. This excess energy can either be stored for electricity or in heat.

We see four levels of storage (Figure 12), Seasonal Storage, Load Shifting, Renewable Energy Integration and Ancillary Services, kicking in at different time steps to balance the production vs. consumption.

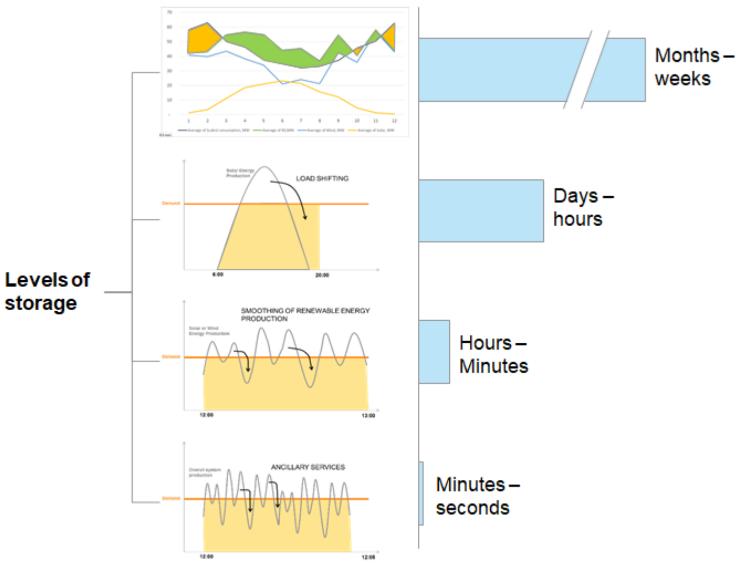



*Figure 12. Four levels of storage: Seasonal storage, Load shifting, Renewable Energy Integration and Ancillary Services*

Seasonal storage covers periods of a few weeks during periods when there is not enough wind or solar power resources. This long-term storage provides security in energy supply and is crucial for achieving autonomy with 100% RES without cable interconnections.

Load Shifting shifts renewable energy production to when it is needed (peak demand). This increases the renewable energy (RE) efficiency reducing the wasted energy, enables energy produced by RES to be sold when electricity prices are higher increasing the profitability of RES and contributes to the increase of RES on the market.

Renewable Energy Integration aims to smooth the VRE production, wind and solar. The main advantages are to lower the burden on the electrical grids reducing the investment needs to strengthen the grids and increasing RE penetration.

Ancillary Services stabilizes the grid in case of quick drop/increase in energy production/demand or a failure, works as a primary reserve, regulates frequency and supports voltage. This fast responding storage technology improves the grid flexibility, performance and efficiency favouring RE integration and needs to be capable of doing a black start.

Storage requirements of these four levels of storage are collected in Table 8.

*Table 8. Technical requirements of the four levels of storage.*

| **Levels of storage** | **Seasonal Storage** | **Load Shifting** | **Renewable Energy Integration** | **Ancillary Services** |
|---|---|---|---|---|
| **Requirements** | - Very high capacity<br>- High efficiency<br>- Slow response times (hours)<br>- Very low number of cycles | - High capacity<br>- High efficiency<br>- Slow response time (hours)<br>- Low number of cycles | - Low capacity<br>- Medium efficiency<br>- Medium response time (minutes)<br>- High number of cycles | - Low capacity<br>- Low efficiency<br>- Very fast response times (seconds to milliseconds)<br>- Very high number of cycles |
| **Time range** | 3 hours – weeks | 15 min – 3 hours | < 15 min | |
| **Levels of storage for this project** | Long Term | Mid Term | Short Term | |

Commercially, all these storage levels require investments and implementation of regulation to handle the electricity market of the new storage technologies, which is the case especially in ancillary services. Renewable Energy Integration and Ancillary Services could be merged and provided with the same technology for storage systems at the size of Åland providing they cover the required capacity and response time.

To cover the storage requirements of these four levels, different technologies are being looked into with regard on both technical and financial feasibility. We have divided them into Short, Mid and Long-Term storage. The Short-Term flexibility time range of 15 min has been defined according to Nord Pool's shortest intraday trading market[1]. Mid Term storage is the assumed operation time of 3 hours of the Battery. Long Term is defined as the time range when power-to-gas (P2G) steps in.

Short Term covers both Ancillary Services and Renewable Energy Integration, Mid Term Load shifting and Long-Term Seasonal Storage. Figure 13 presents the storage capacities as a function of time of discharge.

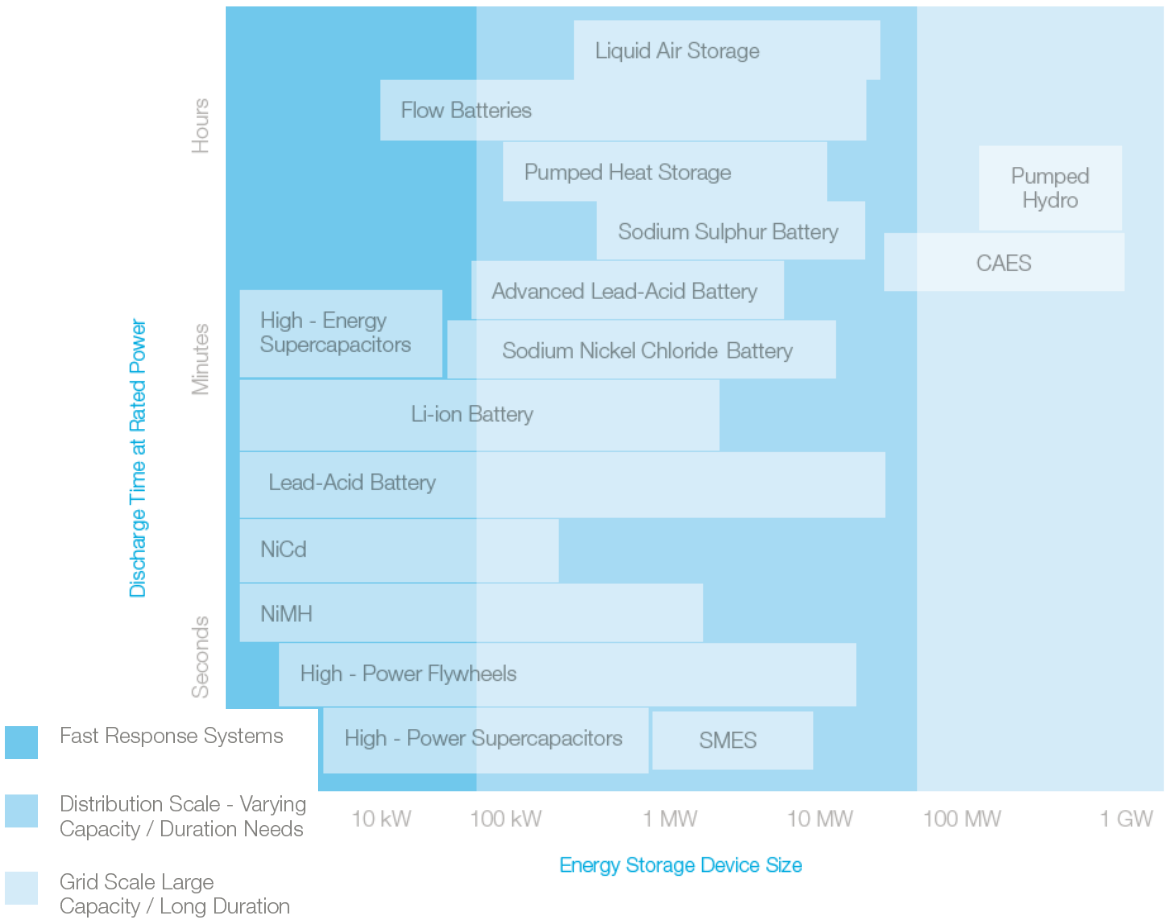



*Figure 13. Electricity Storage review with respect to storage time and capacity[2].*

## Exclusions and assumptions

There is an existing decommissioned iron cavern, which could be converted into a Pumped Hydro Storage (PHS) or Compressed Air Energy Storage (CAES) site.

[1] Nord Pool. *Intraday trading*. https://www.nordpoolspot.com/trading/intraday-trading/
[2] ARUP. Five Minute Guide Electricity Storage Technology, 2014.

Although at the moment further research is required to understand its full potential and profitability. Theoretical possibilities of both technologies underground or under the sea are also to be investigated more carefully.

## Short-Term Energy Storage

Short Term energy storage requires response times of milliseconds to minutes, high efficiencies and tolerability of a high number of cycles. Flywheels and supercapacitors are used for these applications due to their high-power capacities, whereas several battery technologies are also suitable for these requirements. For Åland we have been looking into Flywheel and Batteries due to their degree of commercialization and price range.

The fast-response storage system is in charge of managing voltage and frequency fluctuations. The main aim of this kind of storage is to enhance the grid stability, which is essential in a small grid such as in Åland. Storage systems utilized for these applications usually have very high-power capacity and lower energy potential.

VRE sources provide active power output based on the weather conditions, meaning that sudden variations in power supply are expected. As a result, the increasing injection of intermittent renewables increases the chances of disturbing the grid frequency equilibrium.

The Åland system can be considered as a micro-grid system. A high VRE integration, both from centralized and decentralized location, inevitably raises the chance of grid instability. As a result, a robust and reliable control system has to be implemented in parallel to the new renewable installations.

### Li-ion Batteries

Li-ion batteries is the most established technology for grid scale energy storage and prices are reducing constantly, with a price deduction of 50% until 2030[3].

[3] IRENA, *Electricity Storage and Renewables: Costs and Markets to 2030*. October 2017. ISBN 978-92-9260-038-9.

*Table 9. Technical requirements of the four levels of storage*

| Li-ion battery typical characteristics (NMC battery) | |
|---|---|
| C Rating | 1/4 |
| Round-trip efficiency | 84-90% |
| Depth of discharge | 100% |
| Lifetime | 20 years |
| Full charge discharge cycles | 7,000 cycles |
| Capital cost | 1,300 €/kW |

## Flywheel

The kinetic energy storage technology considered for the primary frequency control is a state-of-the-art flywheel solution. The fast discharge time and power capacity are the two main factors making the flywheel one of the most appropriate options for frequency containment and restoration[4].

*Table 10. Typical technical requirements for Flywheels[5]*

| Flywheel typical characteristics | |
|---|---|
| C Rating | ≥4 |
| Round-trip efficiency | 85-90% |
| Depth of discharge | 75-90% |
| Lifetime | 20-25 years |
| Full charge discharge cycles | 10,000 – 100,000 cycles |
| Capital cost | 1,225 €/kW |

Other energy storage technologies, such as lead acid, Ni-Cd batteries, vanadium-redox flow batteries, super capacitors or superconducting magnets, are possible options for frequency regulation, although flywheel is often considered the more appropriate now and in the next future to address primary frequency response (Greenwood, et al., 2017). Comparing it with a Li-ion battery, flywheel shows a faster response time, better efficiency, lower degradation ratio and longer lifetime (up to 100,000 cycles) (Morray, 2017) (Östergård, 2011).

[4] Amiryar & Pullen. 2017.
[5] Amiryar & Pullen. 2017.

## Flywheel piloting opportunity

The energy system of the future will provide fully renewable generation of electricity. Managing the natural variability of these energy sources, without keeping back-up gas and coal-fired generation, requires cost-effective energy storage. Teraloop is a grid-scale energy storage system that provides an alternative to Lithium-ion batteries, while addressing new markets.

We store energy in kinetic form by accelerating a rotating mass of Carbon Fibre Composite to high speed, using electrical motor technology. When this energy is needed, we convert the kinetic energy back into electricity by operating the system as a generator.

*Table 11. Characteristics for Teraloop flywheel [6]*

**Our unique configuration will evolve existing flywheel designs to provide up to 5 hours of energy supply from each unit, and which can be scaled to meet the needs of a rapidly growing market. Teraloop flywheel unit target characteristics**

| | |
|---|---|
| Unit energy | 50-250 kWh |
| Unit power rating | 0.1-1 MW |
| Duration | 0.1-5 hours |
| Round-trip efficiency | 90% |
| Depth of discharge | 100% |
| Lifetime | 30+ years |
| Full charge discharge cycles | ≥ 1,000,000 |

*Figure 14. Teraloop unit, stacked units, and array configuration (Teraloop, 2018)*

Teraloop's market entry will be for users from heavy industry, with a system that provides a high ratio of power to energy. These applications have highly variable

[6] Teraloop target flywheel characteristic (Teraloop, 2018)

energy demands, where existing technology cannot reduce costs and carbon emissions. We currently have two early-stage pilot projects in this sector.

At the local distribution end, utilities will use our devices to stabilize grids that supply fast-charging of electric vehicles, where uncertain demand and high rates of charge quickly reduce the life of Li-ion batteries.

Our longer-term goal is to provide daily storage for grid-services, for example with wind and solar asset operators, who need co-located storage to smooth output from their arrays.

## Mid-Term Energy Storage

Discharge times of minutes to hours are usually featured in Mid Term storage. On this Load Shifting level we have lots of different opportunities, including PHS, CAES, Power to Gas (P2G) and all types of battery storage systems.

The Mid Term storage will be covered partly by both technologies suited for some Short Term and Long-Term energy storage. Less factors in the electricity system reduce its complexity. For Åland, we have yet been looking into P2G and Li-ion batteries for Mid Term storage.

## Long-Term Energy Storage

Long-Term storage, Seasonal Storage level, needs to cover periods of weeks or months. With a cable connection, this type of storage would not be needed. Long term energy storage technologies require high capacities and efficiencies. Suitable widely commercialized technologies would be PHS and CAES on larger scale and P2G converters in combination with gas storage systems. Concrete block Energy Vault storage could be an alternative to PHS on Åland. Redox flow batteries and NaS batteries could with declining investment costs provide reasonable storage on a weekly scale[6]. Until now, P2G has been considered to provide the Long-Term Seasonal Storage.

### P2G

Power-to-gas (P2G) entails the conversion of surplus wind electricity via electrolysis into hydrogen ($H_2$) and/or methane ($CH_4$), which can be re-electrified in fuel cells or combined cycle gas turbines and can therefore be used for network balancing and energy storage in a timescale of milliseconds up to weeks. However, when comparing the Levelized Cost of Energy (LCOE), P2G is better suited for mid- and long-term storage applications.[7]

The core component of the P2G concept is the electrolysis cell, where separation of water molecules to hydrogen and oxygen occurs through by applying an electric current. 1 kg of $H_2$ requires 38 kg of water[8]. In this report we will not consider the further conversion of $H_2$ into $CH_4$ due to lack of carbon dioxide ($CO_2$) intensive industry on the Åland islands.

For the electrolysis, there are several technologies for electrolysis, Alkaline Electrolysis (AEL), Polymer Electrolyte Membrane (PEM) and Solid Oxide Electrolysis (SOEC). SOEC is the most efficient one but not yet commercialized. AEL is the most established, cheapest (1,000-1,200 €/kW[9]) but needs 30-60 minutes to restart. PEM is newly commercialized, has better start-up characteristics than AEL but is more expensive (1,860-2,310 €/kW[10]) and has a shorter lifetime. Since batteries and flywheels take care of the network stabilization, AEL is suitable for the requirements of mid- and long-term storage. [11]

*Table 12. Characteristics of P2G with Alkaline electrolysis*

| P2G AEL characteristics[12] | |
|---|---|
| Duration | minutes-weeks |
| Round-trip efficiency | 34-44%[13] |
| Depth of discharge | 80-100% |
| Lifetime | 15-20 years |
| Capital cost | 1,000-1,200 €/kW |

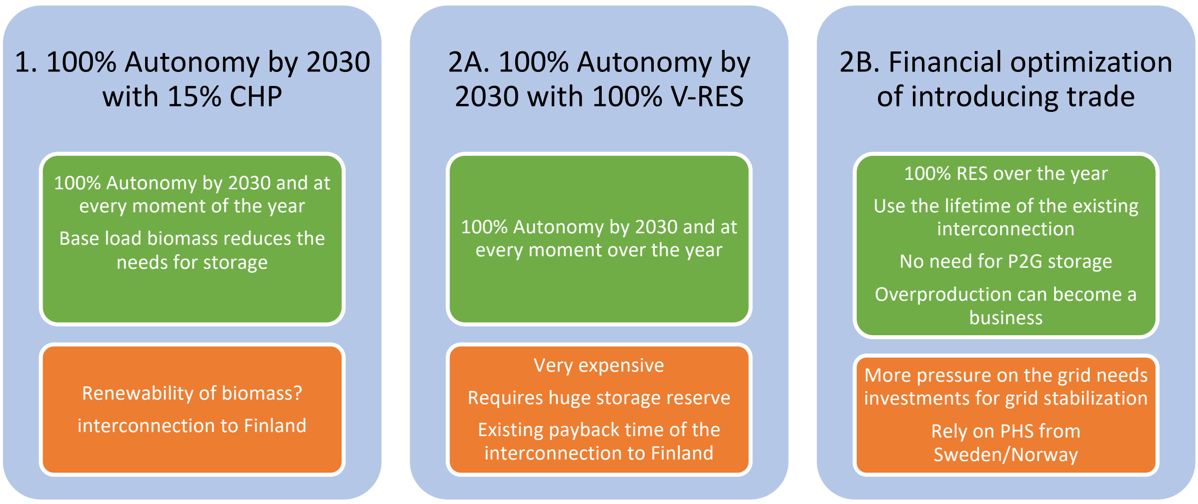
Assuming an average efficiency of ~30% for P2G2P, we would need to store 600 GWh of surplus VRE to get 200 GWh of energy later on. On contrast, with a storage mix reaching an efficiency of ~50% we would need 400 GWh of surplus VRE to get 200 GWh when needed.

[7] European Power to Gas White Paper. *Power-to-gas in a Decarbonized European Energy System Based on Renewable Energy Sources.* September 2017.
[8] Lambert M. The Oxford Institute for Energy Studies. *Power-to-Gas: Linking Electricity and Gas in a Decarbonising World?* October 2018.
[9] Schmidt O. et al. *Future cost and performance of water electrolysis: An expert elicitation study.* December 2017. https://doi.org/10.1016/j.ijhydene.2017.10.045
[10] Schmidt O. et al. December 2017.
[11] Lambert M. October 2018.
[12] Schmidt O. et al. December 2017. Deloitte Centre for Energy Solutions. *Electricity Storage – Technologies, Impacts and Prospects.* September 2015.
[13] Frauenhofer IWES. *Energiewirtschaftliche und ökologische Bewertung eines Windgas-Angebotes*. p. 18. February 2011 (in German).

Alternatively, P2G technology could be utilized for using $H_2$ directly in transport, e.g. for hydrogen ferries, or stored in containers using Solid Oxide Fuel Cells (SOFC), which can release both heat and power in times of no wind an no sun. In this case, electricity and heat should be tighter interlinked for investigation, which would also be necessary for a higher benefit for Åland.

## Investment suggestions and timelines

The plan to attain 100% autonomy with renewable energy sources can be accomplished through different investment focuses and schedules. We have concluded three storage scenarios, which all take into consideration 100% RE production on Åland over the time of a year and are based on the agreed energy generation capacities[14].




[14] Siira K. CLIC. *Findings, Figures and Future*. Slide 7. *2 alternative routes from 300 to 400 GWh*. Presentation. FLEXe Demo Final Seminar. 9 January 2019.

*Table 13. Capacity- and energy production in the described scenarios*

| | Scenario 1 | | | Scenario 2.A | | | Scenario 2.B | | |
|---|---|---|---|---|---|---|---|---|---|
| | **MWp** | **GWh** | | **MWp** | **GWh** | | **MWp** | **GWh** | |
| **Wind** | 85 | 276,3 | | 170 | 552,5 | | 170 | 552,5 | |
| **Solar** | 15 | 14,7 | | 20 | 19,6 | | 20 | 19,6 | |
| **Total V-RE production** | **100** | **291,0** | | **190** | **572,1** | | **190** | **572,1** | |
| Required base load/storage/import[15] | | 175 | | | 115 | | | 115 | |
| **Biomass** | 20 | **140** | | 0 | **0** | | 0 | **0** | |
| **Cable** | 0 | 0 | | 0 | 0 | | 80 | 70 | |
| **Storage** | | | **Input** | | | **Input** | | | **Input** |
| **Flywheels** (90% efficiency[16]) | 10 | 1 | 1,1 | 10 | 1 | 1,0 | 10 | 1 | 1,1 |
| **Batteries** (87% efficiency[17]) | 20 | 25 | 28,9 | 40 | 91 | 101,1 | 20 | 44 | 50,3 |
| **P2G** (34% efficiency[18]) | 40 | 9 | 26,5 | 60 | 23 | 77,0 | 0 | 0 | 0 |
| **Total storage losses** | | 21,3 | | | 64,1 | | | 6,7 | |
| Min production (400 GWh annual consumption) | | 421,3 | | | 464,1 | | | 406,7 | |
| Total RE production | | **431,0** | | | **572,1** | | | **572,1** | |
| **Total balance** | | **9,6** | | | **108,0** | | | **165,4** | |

The table shows that there is potential for export or further developed usage of the excess energy produced in scenarios 2A and 2B.

## Cost of the energy generation and storage set-up

The corresponding expenses (CAPEX, annual costs and LCOE) to the three scenarios above are summarized in Table 13.

[15] Fortum. *Platform for 100% smart and renewable energy in Åland. Solar and RE roadmap.* Slide 7. 20 November 2017.
[16] Teraloop target flywheel characteristics (Teraloop, 2018)
[17] NMC Li-on battery characteristics (LAZARD,2018)
[18] Frauenhofer IWES. *Energiewirtschaftliche und ökologische Bewertung eines Windgas-Angebotes*. p. 18, February 2011

*Table 14. Expenses of the whole set-up (energy generation + storage) in scenario 1, 2A and 2B. Operational costs are assumed to be fixed and the annually sold amount of electricity 400 GWh*

| | | Scenario 1 | | | | Scenario 2A | | | | Scenario 2B | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | €/kW | MWp | CAPEX (M€) | M€/yr | LCOE (€ct/kWh) | MWp | CAPEX (M€) | M€/yr | LCOE (€ct/kWh) | MWp | CAPEX (M€) | M€/yr | LCOE (€ct/kWh) |
| Wind (onshore)[19] | 1000[20] | 48,24 | 48,24 | 7,76 | 4,51 | 48,24 | 48,24 | 7,76 | 4,24 | 48,24 | 48,24 | 7,76 | 4,24 |
| Wind (offshore) | 2100[21] | 15 | 31,5 | 3,77 | 10,2 | 100 | 210 | 25,16 | 9,63 | 100 | 210 | 25,16 | 9,63 |
| Solar | 900[22] | 15 | 13,5 | 1,18 | 10,71 | 20 | 18 | 1,57 | 7,85 | 20 | 18 | 1,57 | 7,85 |
| Biomass | 2000[23] | 20 | 40 | 6,81 | 4,86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Total RE (M€)** | | 98,24 | **133,24** | **19,52** | | 168,24 | **276,24** | **34,49** | | 168,24 | **276,24** | **34,49** | |
| Flywheel | 1225 | 10 | 12,25 | 1,04 | 94,41 | 10 | 12,25 | 1,04 | 103,83 | 10 | 12,25 | 1,04 | 103,83 |
| Battery | 1300 | 20 | 26 | 2,42 | 8,36 | 40 | 52 | 4,81 | 4,6 | 20 | 26 | 2,42 | 4,48 |
| P2G | 2500[24] | 40 | 100 | 10,58 | 25,68 | 60 | 150 | 15,87 | 23,38 | 0 | 0 | 0 | 0 |
| Cable | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3,27 | 4,68 |
| **Total Storage (M€)** | | 70 | **138,25** | **14,04** | | 110 | **214,25** | **21,72** | | 30 | **38,25** | **6,73** | |
| **Total (M€)** | | 168,24 | **271,49** | **33,56** | **8,39** | 278,24 | **490,49** | **56,21** | **14,05** | 198,24 | **314,49** | **41,22** | **10,31** |

The capital cost is definitively lower in scenarios 1 and 2B. It is important to note that the potential of excess produced energy, as presented in Table 13, in scenario 2A and 2B for export or further refinement are not taken into consideration yet in these calculations. With a large share of V-RES, the storage costs are remarkably higher than if we introduce biomass as base load or rely on cables for long term storage. Operation and maintenance costs per year do not differ remarkably in these three scenarios. The LCOE is lowest in scenario 1, which is partly due to the not respected overproduction in scenarios 2A and 2B.

[19] Existing wind capacity of 21,76 MW (ÅF FLEXe Demo report. 2017. Part 2. p. 5)
[20] Child M. LUT. *Scenarios for a Sustainable Energy System in the Åland Islands 2030.* p. 14. 5 September 2016. ÅF FLEXe Demo report 2017. Part 2. p. 8.
[21] Child M. LUT. p. 14. 2016.
[22] Averaged price assumption of residential systems (1500 €/kW) and industrial installations (700 €/kW). Fortum. 2017. Siira K. Presentation. Slide 9. 9 January 2019.
[23] ÅF FLEXe Demo report. 2017. Part 2. p. 19.
[24] Pitsinki J. Wärtsilä. *Case Åland 100% Renewable Scenarios.* Presentation. FLEXe Demo Final Seminar. 9 January 2019.

## Potential Investment and timeline

Storage is a residue of more installed VRE capacity, especially wind. Table 15 summarizes the assumed storage capacities installed for energy storage based on the potential investment timeline of wind power. The table is indicative and uses the capital expenses presented in Table 15. Durations of permitting procedures has not been considered.

*Table 15. Potential investment timeline for scenario 1 (with scenario 2A in brackets) based on the investment timeline for wind power*

| | 2021 | 2022 | 2025 | 2026 | 2028 | 2034 |
|---|---|---|---|---|---|---|
| **Installed energy source** | | | | | | |
| Wind (MW)[25] | 60 | 75 | 75 | 90 | 90 | 90 (190) |
| Solar (MW) | - | - | 15 (20) | 15 (20) | 15 (20) | 15 (20) |
| Total V-RES | 60 | 75 | 90 | 105 (110) | 105 (110) | 105 (210) |
| Biomass (MW) | - | - | - | - | 20 | 20 |
| Total RE | 60 | 75 | 90 | 105 (110) | 125 (110) | 125 (210) |
| **Installed storage** | | | | | | |
| Flywheels (MW) | 10 | 10 | 10 | 10 | 10 | 10 |
| Batteries (MW) | - | 20 | 20 (40) | 20 (40) | 20 (40) | 20 (40) |
| P2G (MW) | - | - | - | 40 (60) | 40 (60) | 40 (60) |
| Total installed storage (MW) | 10 | 30 | 30 (50) | 70 (110) | 70 (110) | 70 (110) |
| **Additional storage investment (M€)** | **12,5** | **26** | - **(26)** | **100 (150)** | **-** | **-** |

## Assumptions and remarks on the calculations for the three scenarios

In isolated systems, we have to take consider the grid code for isolated systems, where double or extreme contingencies [N-2] may occur[26]. In practice, this means that there needs to be a reserve to cover the capacity, voltage and frequency in case the two largest energy sources fall out. Considering the scenario 2, with the two largest wind farms of 100 MW and 40 MW, we would need storage or any other back-up reserve of 140 MW. CAPEX for this whole system installation would be ~750 M€. We assume the largest wind farm to be divided into separate transformer stations. The total reserve capacity is assumed to be 100 MW in order to cover the peak of ~85 MW (~35 MW for base load and 50 MW for peaks) with some reserve.

[25] Existing wind capacity of 21,76 MW ~20 MW (ÅF FLEXe Demo report 2017. Part 2. p. 5)
[26] Luduvino S. Rede Eléctrica Nacional, S.A. *Grid Code for Isolated Systems*. October 2010.

Demand response, electric vehicles, electricity sales outside Åland, where to locate new generation capacity and costs of permitting has been excluded.

The calculations are made without simulations and simply based on some given data, existing reports, assumptions and experience. Storage should be built out partially in accordance with building out more wind capacity.

## Scenario 1

- Assumed that 7 days of no wind/no sun (critical periods) outside of winter months, i.e. we have 60MW for 7 days in fully autonomous mode w/o wind/sun
- 85 MW full load only during winter months
- Biomass
  - 20 MW running 7000 h/year
  - Covers ~37% of the critical periods
  - → 20 MW*7000h = 140 GWh
- Flywheel
  - lasts 15min @10MW
  - Ran 365 days/year
  - → 10 MW*0,25h*365 days = 1 GWh
- Batteries
  - Can't support the grid in long term storage
  - @20MW will last ~1,5h
  - Critical periods of 5 days*3=15 days/year batteries empty
  - Covers ~23% (5,5 GWh) out of critical periods
  - Assume 2 charge-discharges /day
  - → 20 MW*1,5h*2*350 days + 5,5 GWh = 25 GW
- P2G
  - @40MW will last 7 days (with full H2 tank)
  - Covers ~40% of the critical periods
  - 5 GWh additional usage over the year to cover the required storage
  - →23 GWh * 0,4 + 5 GWh = 14 GWh

## Scenario 2A

- Assumed that 7 days of no wind/no sun outside of winter months, i.e. we have 60MW for 7 days in fully autonomous mode w/o wind/sun
- 85 MW full load only during winter months
- Flywheel
  - lasts 15min @10MW
  - Ran 365 days/year
  - → 10 MW*0,25h*365 days = 1 GWh

- Batteries
  - Can’t support the grid in long term storage
  - @40MW will last ~3h
  - Critical periods of 5 days*3=15 days/year batteries empty
  - Covers ~33% (7 GWh) out of critical periods
  - Assume 2 charge-discharges /day
  - → 40 MW*3h*2*350 days + 7 GWh = 91 GW
- P2G
  - @60MW will last 7 days (with full H2 tank)
  - Covers ~67% (14 GWh) out of critical periods
  - 9 GWh additional usage over the year to cover the required storage

## Scenario 2B

- Cable connection kept
- Flywheel
  - lasts 15min @10MW
  - Ran 365 days/year
  - → 10 MW*0,25h*365 days = 1 GWh
  -
- Batteries
  - @20MW will last ~3h
  - Needed in combination with solar
  - Ran 365 days/year
  - Assume 2 charge-discharges /day → 20 MW*3h*2 = 43,8 GWh
  -
- Export instead of P2G
  - Cable covers 70 GWh of the required storage

## Potential financing plan and investors

FLEXe Åland Demo project is a demonstration presenting a solution to increase RE production combatting climate change. Similar solutions need to be implemented elsewhere in the world on a larger scale. Being a predecessor with this precise project, would be a reference value for the Finnish technology industry and boost new technologies. Since the required storage investments are immense, the Finnish state and the European Union would be probable investors. The Climate Leadership Council or the Nordic Energy Corporation could have interest in financing for climate mitigation.

The largest storage costs come from the Load Shifting and Seasonal Storage caused by the increase of VRE sources in the energy generation mix. The responsibility of these storage costs could be shifted to the producers of VRE. In this case the LCOE for wind and solar would increase significantly. With the current Finnish subsidy system, the increased LCOE could possibly be covered.

Batteries, especially Li-ion batteries, are already established technologies, whereas flywheels and $H_2$ in the energy mix are still more unfamiliar as components of the power system.

## Reasons to invest in Teraloop

Accelerate our renewable future: An investment in storage is a commitment to reduce carbon emissions. The long-life of our system results in very low gCO2/kWh of energy throughput.

Profit from new markets for storage: We solve energy storage for high-cycle, highly variable processes in Energy Intensive Industries. Companies in this sector are required by regulation to curb emissions and energy use, and existing storage technologies cannot meet their needs.

Growth company through lower cost of storage: The raw material we use for energy storage is carbon, which is abundant, and located all around the world. Learning-rate, automation, modularity and scale will reduce the manufacturing cost to competitive levels, while offering superior performance.

We simplify CAPEX decision making: By offering high availability, long life, and simple re-configuration for “power” or “energy”, Teraloop reduces the CAPEX risks due to uncertainty in energy market rules.

A value chain of our electric future: Capital is being divested from oil. We offer an opportunity for those who look for alternatives to the Lithium value chain.

Resource independence from Lithium: The availability of Lithium presents a significant cost-risk to its value chain and is a sensitive geo-political/sustainability risk.

## Reasons to invest in P2G

There is a developing market for $H_2$ industry, buildings and power, transport and energy storage. Especially in decarbonizing the energy sector, $H_2$ is regarded a beneficial component as electricity carrier to provide flexibility to the power system.[27]

The Fuel Cell and Hydrogen Joint Undertaking (FCHJU), by the European Union, invests in “clean, efficient and affordable solutions that fully demonstrate the potential of H2 as an energy carrier and fuel cell as energy convertor, as part of an energy system that integrates sustainable solutions and energy supplies with low carbon

[27] IRENA. *Hydrogen from Renewable Power*. Technology Outlook for the Energy Transition. September 2018. ISBN 978-92-9260-077-8

stationary and transport technologies". In case of inclusion of $H_2$ in the energy system or transportation of the Åland islands, the requirements for potential support from FCHJU are fulfilled.[28]

There are several ongoing projects and demonstrations within the usage of $H_2$ in supporting the energy sector and the prices of the electrolyzers are predicted to decrease. With increasing energy capacity demand, the price of hydrogen production could by 2030 drop by even 70%[29].

Including promising and a less mature P2G technology, i.e. SOFC electrolyzers, could increase the international interest towards this Åland FLEXe Demonstration.

## Current issues hindering the potential investments

For the time being, storage is very expensive, especially when taking into consideration that there is still an existing interconnection to Sweden and Finland. Using the interconnection does not require any new investments on storage. The cable to Sweden has an estimated lifetime of 20 years. In addition, the cable to Finland was taken into usage in 2015, had investment costs of 125 M€ and payback time of 25 years.[30]

The European Commission is encouraging the development of an integrated European electricity network[31]. There is regulation[32] in establishing *The connecting Europe Facility* with priorities on an interconnected grid and conditions for access to the network for cross-border exchanges in electricity.

Since storage is a residual of the generated VRE, building out storage strongly relies on the development of wind power capacity.

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[28] FCH Joint Undertaking. *Vision & Objectives*. https://www.fch.europa.eu/page/vision-objectives
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[32] REGULATION (EU) No 1316/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2013 establishing the Connecting Europe Facility, amending Regulation (EU) No 913/2010 and repealing Regulations (EC) No 680/2007 and (EC) No 67/2010.

# 10. Smart grid

By Mikko Västi, University of Applied Sciences and Jagdesh Kumar & Hannu Laaksonen, University of Vaasa

According to a separate simulation study "Åland Electrical Network Simulations" which was based on different scenarios, the network can withstand large additions of renewables, but it requires investments to the network. Some network costs can be reduced by investing in battery energy storage systems. This allows shaving off peak loads in the network, thus reducing the need to over dimension transformers and lines. It also results in smaller voltage drops across the network.

The preferred way of running the network was meshed network with 2 connection points to the 110-kV network (Tingsbacka and Norrböle). This will require a change in operation paradigm, which is currently running the system as radial network. This change will improve network reliability but will increase complexity in operation and relay protection.

Detailed simulations about what happens to the network, if there is no HVDC connection point at Sottunga were not carried out, but some preliminary results can be drawn. The 45-kV network cannot transmit all the power that will be produced by the renewable power in the archipelago area. To transmit that amount of power will need strengthening the network or most likely a connection point to HVDC or 110 kV network. But these results are preliminary, thus they might change with more detailed investigations.

It might be beneficial to make an own 45 kV line to supply shore-to-ship loads, since there will be 20 MW of those loads to reduce loading of lines towards Mariehamn.

Network stability studies were not performed. There is a large risk of network instabilities due to large generation units. This may warrant building ring connection to certain planned Wind Farms for example Östrä Skärgården. It can be beneficial to add battery energy storage systems to provide support to network frequency control.

# 11. Regulation and market mechanisms

By Samuli Honkapuro, Lappeenranta University of Technology

At the moment, Åland has its own TSO (Kraftnät Åland, KNÅ), two DSOs, and four retailers. Åland has connections to Sweden (AC-line) and to Finland (DC-line). Finnish cable is used only as a back-up, and energy is mainly imported from Sweden. Retailers are buying energy from Swedish counterparts by SE 3 area price with fixed deliveries. Kraftnät Åland is only Balance Responsible Party (BRP) in Åland, and it is responsible for maintaining power balance (technically and commercially) in Åland. Kraftnät Åland makes balance settlement towards Sweden (eSett), and retailers operating in Åland make balance settlement to KNÅ and procure imbalance power from KNÅ (in other words, KNÅ is an open supplier for local retailers).

Although connection from Sweden is connection between two countries (Sweden and Finland), it is not considered to be a cross-border interconnector, but a load serving line. In other words, Åland is a large industrial customer for Vattenfall, and costs of the power transfer are billed based on that. Because of this, the role and responsibilities of KNÅ differ somewhat from those of the other Nordic TSOs.

DSOs operating in Åland are vertically integrated companies, and unbundling is done only in accounting, as they are smaller than threshold for legal unbundling.

## Changes needed for future requirements

### Local energy market

To enable active local trading of the power, and to provide incentives for flexibility, there needs to be local market place for that. At the moment, local balance power trading is done only afterwards in balance settlement process, based on amount of imbalance power and imbalance power price.

Furthermore, to be able to benefit also from the possibilities to trade in surrounding Nordic markets, that is to export excess generation and trade flexibility, there needs to be transmission lines and interoperable market solutions to mainland (Sweden and Finland). Hence, the solution is to establish local energy market to Åland, which is interoperable with existing Nordic markets.

When taking into account limitations of such a small market area, and legal viewpoints, most straightforward solution is to establish the local balancing market, and continue the operation as a part of the Nordic markets as today. In such local market place, flexibility resource owners and aggregators could trade the flexibility in short-term market (intra-hour), and this flexibility could be used to balance local demand and supply in Åland, and flexibility offers could be aggregated to be offered to Nordic balancing and reserve power markets. This model would activate local resource owners to use their flexibility potential, and provide also benefits for Nordic markets. If the flexibility offers include the information about the location, DSOs could use the flexibility for congestion management, if needed. More detailed procedure for this local balancing market shall be agreed by the relevant stakeholders, especially Kraftnät Åland has relevant role here as local balance responsible party.

## Pricing structures

In addition to enabling the local trading of flexibility, incentives for end-users have to be provided by appropriate pricing structures. Here, we have to separate the pricing in the competitive markets (i.e. sales of energy) and monopoly pricing of network services.

In retail electricity pricing, incentives for flexibility can be improved by introducing a dynamic tariff, which is based on the market price of the energy in wholesale markets. In Åland case, it would be beneficial to incorporate also local energy price to retail price. In addition to energy pricing, customers can be incentivized for energy related actions by green and social values, for instance by making customers aware, when there is local generated renewable energy available. Moreover, customers can be provided also with the real-time information of the $CO_2$ emissions and source of the energy. There is even possibility to elaborate this to personal electricity related carbon credit system, by incorporating electricity consumption and $CO_2$ emissions of the power generation.

Network fee has to ensure the cost recovery for DSO, to be intelligible and fair (reflect the costs) for customers, and encourage customers towards resource efficient use of electricity. In addition to these criteria, regulation sets the point tariff requirement, which forbids the location-based pricing within the area of a DSO. A tariff, which has a combination of a power-based fee (€/kW), a fixed fee (€/month), and an energy-based fee (cents/kWh), seems to be most viable tariff option for both small-scale and larger energy users. Power based fee, which is an addition to small-scale users' present tariff structure, provides customers with incentives for peak-cutting, and hence, has a positive impact on the network load. Furthermore, it improves the cost-reflectivity of the tariff.

## Energy communities' market participation

Enabling market actions of energy communities, e.g. sharing of local generation, or costs and benefits of the EV charging, would improve the possibilities of end-users to actively participate in energy markets, and increase the profitability of micro-generation within the energy community. For instance, it has been piloted in mainland Finland, that sharing the local PV generation within housing co-operative, by using measurements from existing AMR-meters, is technically feasible and cost-efficient solution. There is no need for any network modifications or installation of any new measurement devices, but energy community can be formed by sharing the micro-generation with users of the community based on the hourly measurement of the generation and loads of each participant. Some legal barriers for such operation model have been discovered to occur in mainland Finland, at the moment there is work going on to find the solutions to overcome these barriers. However, enabling of such energy communities in Åland could be considered.

## Proposed new roles and responsibilities

There are some new roles and responsibilities for stakeholders, especially regarding to local energy market. However, most of the market actions will continue as today, so these changes provide new tools for market participation, but do not remove the present ones.

### TSO – Kraftnät Åland

As a local TSO, KNÅ is responsible for system operation and balance management. Furthermore, it is only balance responsible party in Åland, and provides balance settlement towards Sweden. All this will be valid in the case of the local market also. However, in the case of the local market, KNÅ should have responsibility for organizing the internal and external trading in local market place. As the KNÅ is balance responsible party, it has possibilities to participate in Swedish regulating and reserve power markets, and by that way, aggregate the flexibility bids from Åland to Nordic markets. In addition, there should be a bidding procedure in local market, that is a process how the participants can offer their flexibility to this local balancing market. KNÅ should organize also this process, but it can purchase that also from the service provider. KNÅ could define the commission for the market organization to be such that is covers the costs of the services in long-run.

### DSOs

DSOs are responsible for operation of distribution system and ensuring the continuity of supply in distribution network, as they are today. Proposed changes will provide them new opportunities for congestion management in network, also in the case of the disturbances, as they could purchase flexibility from the local market. Moreover, there is proposed novel pricing structures, which DSOs could adopt, to improve the cost reflectivity of the pricing.

In case there are flexible loads, that can be controlled via smart meter (e.g. water heaters), DSOs should ensure that market players, who operate in flexibility markets, have access to these controllable resources and they can aggregate these to markets. It should be noted, that DSOs are typically allowed for load control only during the abnormal situations. Because of this, it is also highly important that roles of the monopoly companies (DSOs) and market operators (retailers) are clearly separated, also in the case of the vertically integrated utility.

## Retailer / aggregator

For retailers, purchasing energy from Sweden, selling it to end-users, and balance settlement for KNÅ continues similarly as today. However, there will be new possibilities for benefitting from local flexibility by trading in local market. Retailers can operate as aggregators by collecting small flexible resources (such as controllable loads) and offer these to local market. Retailers can also purchase this as a (technical) service.

Retailers will benefit from the local markets and flexibility aggregation, as those will provide them tools for active balance management, and minimizing the costs of the imbalance power. However, realizing these benefits will call for active participation in the market, and recruiting the active customers with controllable loads and other flexibility resources. For this, price incentives and new kind of services can be used.

# 12. Further investigation needs and next steps

There are a number of aspects that need to be further evaluated in the process of heading towards Smart Energy Åland demonstration.

An existing decommissioned iron cavern (Nyhamn) might be converted into a Pumped Hydro Storage (PHS) or Compressed Air Energy Storage (CAES) site. At the moment further research is required to understand its full potential and profitability. Theoretical possibilities of both technologies underground or under the sea are also to be investigated more carefully. Other topics related to storage were identified as follows:

- The actual supply – demand simulation to identify actual storage demand
- Opportunities for $H_2$
  - P2G2P
  - $H_2$ for transportation in e.g. ferries
    - Would the 400 GWh/year of electricity consumption still be valid?
  - Storage using SOFC (~CHP)
  - Export benefit vs. electricity export
    - $H_2$ has a smaller and less saturated market
    - Increasing demand of $H_2$
- Potential of CAES or PHS in existing caverns or underwater balloons (or oil containers currently in use by the back-up generators)
- Cost of the whole set up in different storage scenarios

In the heat sector, research issues include calculating different scenarios for biomass fired CHP. Also, possible enlargement of the DH network with new heat storages may bring extra flexibility to the system. Role and potential of power-to-heat could also be examined.

As continuation to the transportation study, a roadmap for fully electric transportation could be done. This tackle issues like interlinking means of travel and answer questions where should various charging stations be placed. Also, gas ferries and buses were left out of the study and this could be done later. Problem with gas of course is that if target of Åland is to fully independent for external energy, it might be challenging to resource enough means to produce the needed gas.

The investment road map needs to be planned carefully. Based on these results, there are a number of activities that can be started without delay. These include, for example, increasing the amount of wind and solar power, and electrification of buses. Also, citizen engagement needs to be implemented as soon as possible. This has to be planned together with the communication strategy. Realization of the flexibility market should also be started immediately. As the cables can act as virtual storage in the beginning, storage investments need not be prioritized. However, storage can also be built partially in accordance with building out more wind capacity.

Having large companies to demonstrate their technology and solutions in Smart Energy Åland is essential. Therefore, models to involve them is important for the realization of the demonstration.

# 13. References and more material

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# 14. Project participants in projects FLEXe Demo and CEMBioFlex

(in alphabetical order)

ABB

Allwinds

Business Finland

CLIC Innovation

E2M

Eaton

Fortum

Fingrid

Kraftnät Åland

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Mariehamn Elnät Ab

NODES

Pöyry

Schneider-Electric

Tampere University of Technology (TUT)

Teraloop

UPM

Vaasa University

Vaasa University of Applied Science

Valmet

Viking Line Buss

VTT

Wärtsilä

Ålands Elandslag

Ålands Landskapsregering

Implementation of the demonstration – Smart Energy Åland – will be taken forward by Flexens Ltd. Flexens will work actively to promote further investments in renewable generation capacity and decarbonising the heating and transportation systems. The basis for successful renewables integration in an open and competitive market is a flexibility trading platform. **Visit https://flexens.com/**