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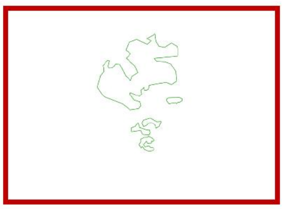
CLEAN ENERGY TRANSITION AGENDA

KÖKAR

Version October 2020



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Summary

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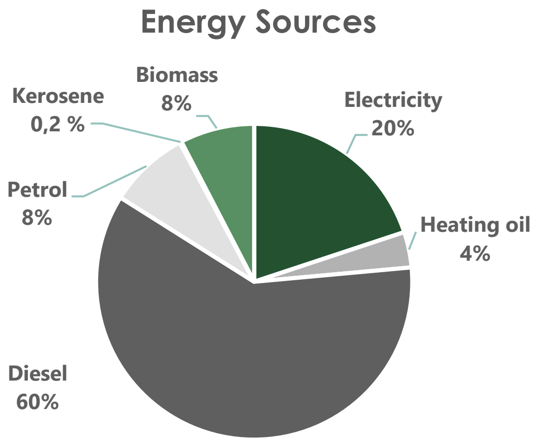
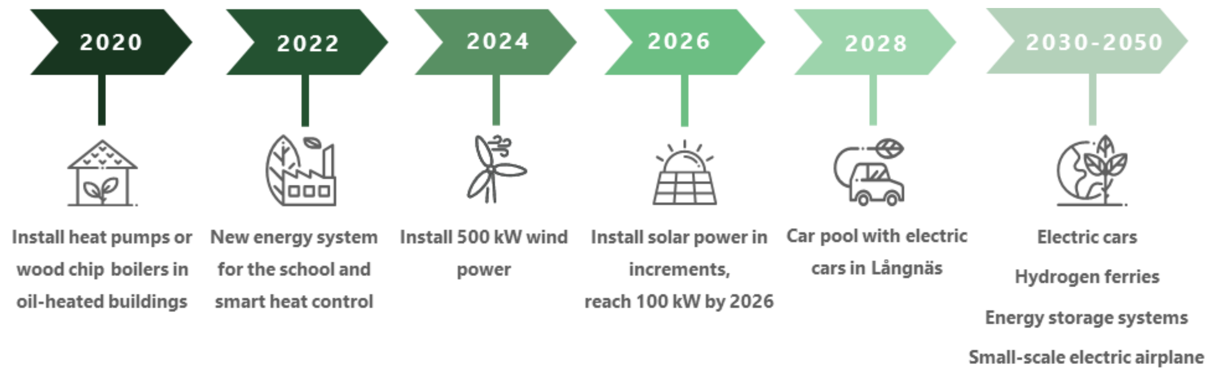
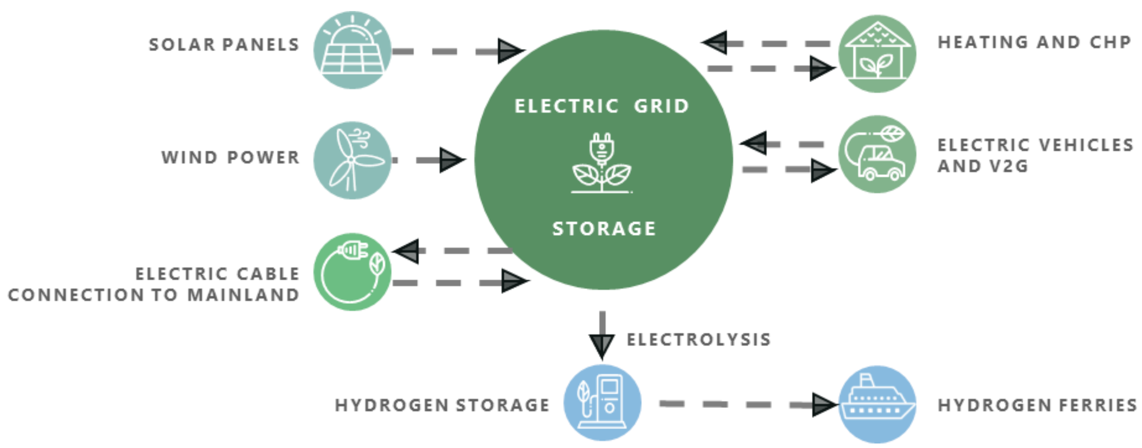
Kökar is a small island in the Åland archipelago with an ambitious energy transition agenda to become more sustainable within the Coast4Us framework. The work is funded by EU through the Central Baltic-program and supported by the Clean Energy for EU Islands Secretariat.

In the first part of the report the current energy system on Kökar is described, and the second part suggests technologies that could be implemented to reduce carbon emissions and increase renewable electricity production to become self-sustainable on a yearly basis.



In the figure above is a summary of the current energy use on Kökar. A roadmap with suggested technical solutions as well as a flow chart of the new energy system are presented in the figures below.





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The role of the EU Islands Secretariat was to advise the islands transition team and to facilitate the written agenda.

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List of Abbreviations

A2A	Air to air
A2W	Air to water
BSS	Battery storage system
CHP	Combined heat and power
CO_2	Carbon dioxide
EV	Electric vehicle
CETA	Clean Energy Transition Agenda
GWh	Gigawatt hours
IoT	Internet of things
kW	Kilowatt
kWh	Kilowatt hours
kWp	Kilowatt peak
LCOE	Levelized cost of energy
MW	Megawatt
MWh	Megawatt hours
N/A	Not applicable
O&M	Operation and maintenance
PV	Solar photovoltaic
RE	Renewable energy
V2G	Vehicle to grid
ÅEA	Ålands Elandelslag
ÅVA	Ålands Vindenergi Andelslag

Background

Kökar municipality has a comprehensive and ambitious sustainability plan within the framework Coast4Us, which is funded by EU through the Central Baltic-program. Furthermore, Kökar is a pioneering island of the Clean Energy for EU Islands Secretariat. In the framework of its transition agenda, Kökar's municipality has invited Flexens Oy Ab (hereafter referred to as Flexens) to conduct a survey of the energy system at Kökar, and to propose a development plan that increases renewable energy production and decreases carbon emissions.

PART I – Island Dynamics

Table 1. Island characteristics

Kökar island - summary	
Country	Finland
Location	Baltic Sea
Coordinates	38°58'42.5"N 1°24'37.6"E
Land area	64 km^2
Electricity interconnection with mainland	Yes
Highest governmental body	Municipal Council
Type of organization leading the transition	Community initiative, local business & local authority

Geography and Population

Kökar is one of six self-governed small archipelago municipalities in the Åland Islands with a total land area of 64 km^2 (total area 2,165 km^2). The population of Kökar island is officially 234 persons (2018), but from a political perspective, the island is a full-scale municipality. In reality, 160-170 persons live on Kökar in the winter, almost 1,000 in the summer, and the island is visited by some 18,000 tourists per year, which makes a technical population of 467 persons [(170×365 days) + (1,000×90 days) + (18,000×1 day)]. This results in high volatility and puts extra demand on the flexibility of the infrastructure. A winter's day, some 170 people use the island systems, while there can be a couple of thousands of users in July.

Economy

Kökar is a small, lively archipelago with all the basic services of a municipality: a library and a school by the sea, a kindergarten, health services and a nursing home. The development of the municipality of Kökar is dependent on a vibrant local business. The main economic activities are shipping, agriculture, coast guard, bakery, tourism and public service. Entrepreneurship and entrepreneurial spirit have improved on Kökar in recent years: there were 33 registered entrepreneurs in 2013, compared with 18 in 2007. Kökar has an association of entrepreneurs that aims to promote entrepreneurship and cooperation between entrepreneurs. Most of the private entrepreneurs are in tourism, shipping, and agriculture, but a new bakery has also recently opened on Kökar.

The municipality is Kökar's largest employer, which employs about 30 people, most of whom work in daycare, nursing homes, and schools. In the table below all identified businesses on the island are listed. None of them are exceptionally energy-intensive businesses.

Tourism is an important industry that brings in € 1.9 million a year from 9,000 boat nights, 18,000 overnight stays and 4,500 day-visitors, who spend € 42 per day on average (boat tourists € 62 per day). There are 227 wage earners on Kökar who together in one year earn a total of € 6.3 million, of which € 1.1 million is paid in taxes. The many sectors, the broad knowledge and the many professionals make Kökar less vulnerable in case of a crisis. Kökar have raised half a million euros in EU grants for the development of guest harbors, a hiking route through the archipelago and to the development of bird watching.

Table 2. List of identified businesses on the island

Type of business	Number in total	Names of the companies
Restaurant/accommodation	6	Antons Gästhem, Brudhäll, Havspaviljongen, Klobbare Gästhem, Sandvik Gästhem, Skinnars
Small scale food production	3	Skärgårdsbröd, Peders Aplagård, Trångsund biodling
Food store	1	Kökar skärgårdsbutik
Construction services	1	Kökar Service
Post	1	Posten Åland
Taxi	1	Kökar taxi
Kayak rental	1	Seaside kajakuthyrning
Real estate	1	Fab Horsklint
Sea transportation	1	Ålands Sjötrafik AB

In total, Kökar have received approximately € 2,000 per inhabitant per year from the EU, and € 2,849 came in 2018 through Åland Government's system, including archipelago supplements. The municipal tax on Kökar is 19.75% (second highest on Åland). The municipality has a high loan stock per person (€ 8,788 per person) that arose when retirement homes and rental housing were built as well as when the school was renovated. Currently, the municipal economy is healthy, with a budget surplus in 2020.

Energy System Description

In this section, the energy system of Kökar is described and the energy consumption is presented by the different energy sources used in the island. In section 4, a more detailed description of the energy consumption in different sectors is presented.

Connection to the Mainland

Kökar is connected to the mainland by ferries and an electric and telephone underwater cable. The capacity of the electric cable is 1.5 MW (Kökar-Sottunga-Gustavs). There is a weak grid connection with occasional outages (3-4 interruptions per year) in the distribution grid that causes local energy problems on Kökar. Reserve generators need to be taken to the island when there are outages (e.g. for the nursing home). The distance to Kökar from the mainland is about 50 km travelling by ferry. Kökar is perceived as a remote place because it takes 2.5 hours to travel there by ferry.

Energy Consumption Descriptions by Energy Sources

Energy sources consumed on the island are electricity, oil-based fuels, and wood-based fuels. Oil-based fuels are divided into diesel, heating oil, and gasoline. Wood-based fuels refer to firewood and pellets used for heating purposes.

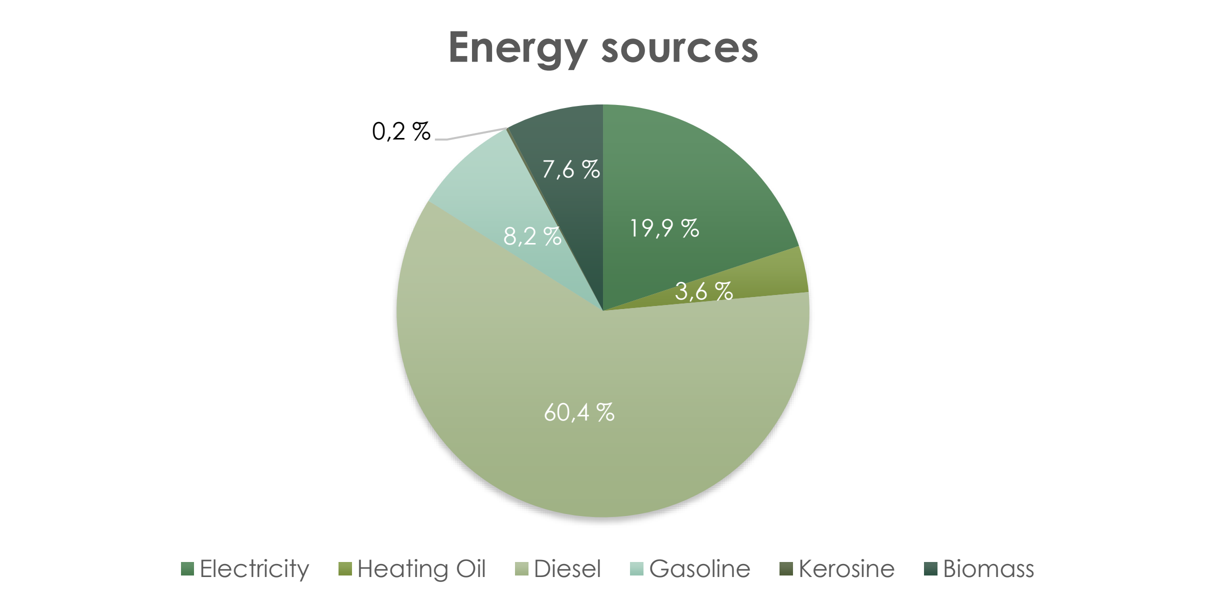

Figure 1. Energy sources on Kökar

Diesel

Diesel is consumed by ferries and land transportation such as trucks, vans, passenger cars and tractors. Ferry consumption data is provided by Ålands Landskapsregering and the on-land diesel consumption is estimated from the total land traffic consumption on Åland (ÅSUB)[1].

[1] Ålands statistik- och utredningsbyrå (ÅSUB) https://www.asub.ax/sv

The total diesel consumption is 8,969 MWh/year. The diesel is mostly consumed by the ferries, and they account for over 75 % of all diesel consumption.

Gasoline

Gasoline is consumed by boats and land transportation such as quad bikes, passenger cars, motorcycles and mopeds. The total gasoline consumption is 1,222 MWh/year which has been calculated from the total gasoline consumption from traffic on Åland (ÅSUB).

Kerosene

A rescue helicopter flies to Kökar approximately 20 times per year. The helicopter uses jet A1-fuel and consumes 30 MWh/year which corresponds to 0.2% of the total yearly energy consumption.

Heating Oil

Light heating oil is used for heating buildings. Based on local interviews, 12 households, two tourist service buildings, and the school building use oil as their main heat source. The estimated heating oil consumption is 550 MWh/year based on local interviews.

Biomass Consumption

Biomass is used on Kökar to heat buildings in the form of pellets and firewood. Firewood is used mainly as an additional source to heat up homes and summer cottages. Based on local interviews, 50 – 70 households use wood boilers and/or wood stoves. The local bakery uses a pellet boiler as their main heat source and one of the tourist services uses one as an additional heat source. The estimated biomass consumption is 1,130 MWh/year.

Electricity Consumption

The annual electricity consumption is 2.9 GWh (2017), with a peak load of 750 kW and a minimum of 110 kW. There is no electricity-intense industry on Kökar and therefore most of the electricity is consumed in buildings. Out of 401 electricity subscribers, 170 has electric heating in some form, and their share of the electricity consumption is 55 %. The summer cottages account for 15 % of the electricity consumption, and the rest is consumed elsewhere, such as in buildings with another main heating systems (e.g. wood). Electricity consumption is divided into different sectors with more detail in section 4.

Table 3. Electricity consumption based on the type of subscription (Source: ÅEA)

Type of demand	Energy/year (kWh)	Share (%)
Customers with electric heating	1,625,540	55 %
Summer cottages	436,927	15 %
Other	893,631	30 %
Total	**2,956,098**	**100 %**

Local Energy Production

Wind Production

There is a wind power plant called Mika on Kökar island. The annual production accounts for roughly 50 % of the annual electricity consumption on the island. The 500-kW windmill, which is owned by Ålands Vindenergi Andelslag (ÅVA), and operated by Allwinds, is connected to Ålands Elandelslag's (ÅEA) distribution network. The wind turbine produces approximately 1,436 MWh/a (2019).

In addition to the Mika wind power plant, 30 kW of micro-wind turbines are installed on the island. The production from these turbines is roughly 60 MWh-70/year, which accounts for approximately 2 % of the total electricity consumption on the island.

Solar Production

There are 49 kW of roof-mounted solar photovoltaics (PV), more commonly known as solar cells. The solar electricity production is 44.1 MWh which accounts for roughly 1 % of the annual electricity consumption on the island.

Table 4. Installed roof-mounted PV-systems

Energy asset	Power [kW]	Owner
PV (residential)	18.1 (1.5 + 11.4 + 5.2)	Private houses
PV (tertiary)	31.0 (5.2 + 3.6 + 3.2 + 9 + 10)	Boutique, bakery, Kökar Service, accommodation service "Skinnars", Havspaviljongen
Micro-wind (residential)	30 (10 + 20)	Private houses (old farm)

Heat Pump Production

Different heat pumps are used on Kökar to transfer heat from air or ground to heat up domestic, municipal and commercial buildings. There is no data available regarding the number of installed systems on Kökar island, but based on local interviews, there are six ground heat pump systems on Kökar: the vicarage and three private buildings have a horizontal ground heat pump system, while the nursing home and one private building have vertical ground heat pumps.

There are a few residential air-to-water (A2W) heat pump systems and several air-to-air (A2A) heat pump systems installed, but the exact number of systems is unknown. At least two service buildings have A2W heat pumps.

Energy Consumption by Different Sectors

The energy consumption is divided into the following sectors:

1. Residential buildings
2. Summer cottages
3. Touristic services
4. Other businesses
5. Municipal facilities
6. Land transportation
7. Marine transportation
    7.1 Ferries
    7.2 Private boats
    7.3 Touristic boats
    7.4 Tourist services boats
    7.5 Coast guard station
    7.6 Rescue Boats
8. Aviation

The energy consumption is summarized in the table below.

Table 5. Energy consumption and CO2-emissions by different sectors [2]

MWh/a	Electricity for heating	Other Electricity	Electricity total	Oil based	Wood based	CO2 emissions (tCO2 equivalent)	Share of total energy	Share of CO2
Buildings								
Households	567[2]	222[2]	789[2]	240[3]	4753	115	10.0 %	3.8 %
Summer cottages	n/a	n/a	437[4]	0	591[4]	29	6.9 %	1.0 %
Tourist services	n/a	n/a	409.5[2]	20 [3]	32 [3]	33	3.1 %	1.1 %
Other business and services	n/a	n/a	199.5[2]	0	32 [3]	13	1.5 %	0.4 %
Municipal buildings	n/a	n/a	375[2]	280 [3]	0	98	4.4 %	3.2 %
Coast guard station			151[5]	0	0	10	1.0 %	0.3 %
Land transportation			2[7]	938 [1, 6]	0	244	6.3 %	8.0 %
Sea transportation								
Private boats				1,820 [7, 3]	0	473	12.2 %	15.6 %
Public boats (Ferries)				7,250 [8]	0	1,885	48.4 %	62.2 %
Tourists private boats				84 [3]	0	22	0.6 %	0.7 %
Tourist service boats				56 [3]	0	15	0.4 %	0.5 %
Rescue boats				69 [5]	0	18	0.5 %	0.6 %
Border guard station boats				106 [5]	0	28	0.7 %	0.9 %
Helicopter				30 [9]	0	8	0.2 %	0.3 %
Other (unidentified electricity consumption)			593			40	4.0 %	1.3 %
Total			**2,956**	**10,893**	**1,130**	**3,030**	100 %	100 %

*For oil CO2 emissions of 0.26 tons/MWh are being used. For electricity 0.068 tons/MWh is used.

The total energy consumption on Kökar, which includes electricity purchased from the grid as well as wood based and oil-based fuels, is 14,980 MWh per year.

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2 Source. Email. Ålands Elandelslag (ÅEA),

3 Source. Local interviews.

4 Source. Estimate based on national statistic. https://www.maaseuduntulevaisuus.fi/metsa/artikkeli-1.257680

5 Source. Email. Coast guardian stations.

6 Source. Fordonsmyndigheten. Statistics about registered vehicles on Åland and Kökar.

7 Source. Statistics about average fuel consumption of private boats.

8 Source. Landskapsregering. Ferry consumption data.

9 Source. Email. Finnish rescue service.

1. Residential Buildings

There are 113 steadily inhabited houses (9,754 m^2) on Kökar, of which 93 (8,234 m^2) are single-family houses and 25 buildings are terraced houses (1254 m^2). The total primary energy consumption of residential buildings is 1,503 MWh/a and the share of the total consumption is 10 %.

In Figure 2 the distribution of heating types in the residential buildings is presented. The different heating methods were acquired through local interviews. Several households have air-to-air heat pumps as an additional heat source, but the number is not specified.

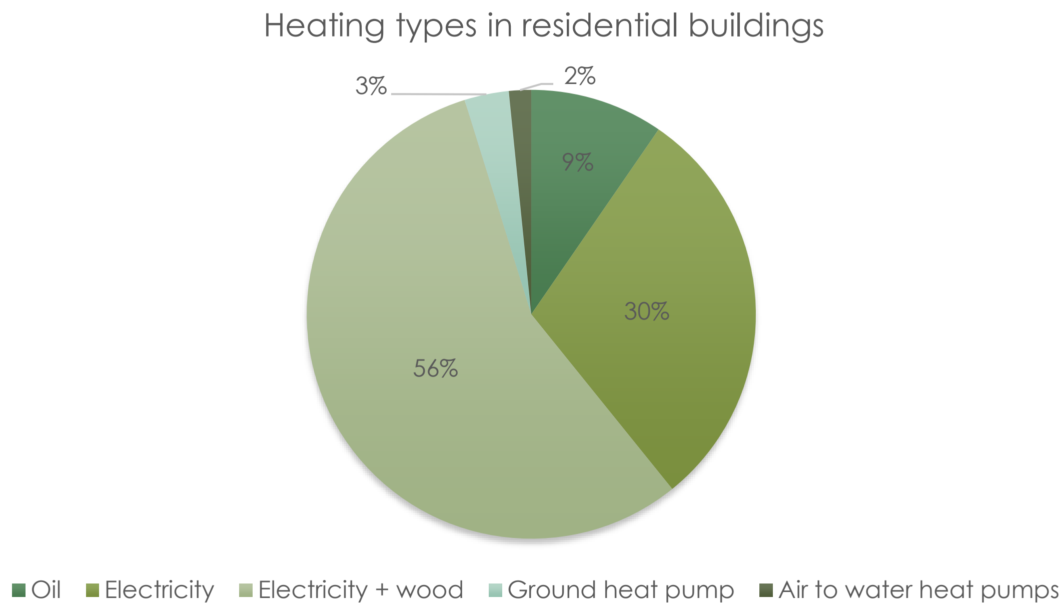

Figure 2. Heating types in residential buildings

In Figure 3 below the energy consumption is presented by different energy sources and electricity is additionally split into electricity for heating and other electricity.

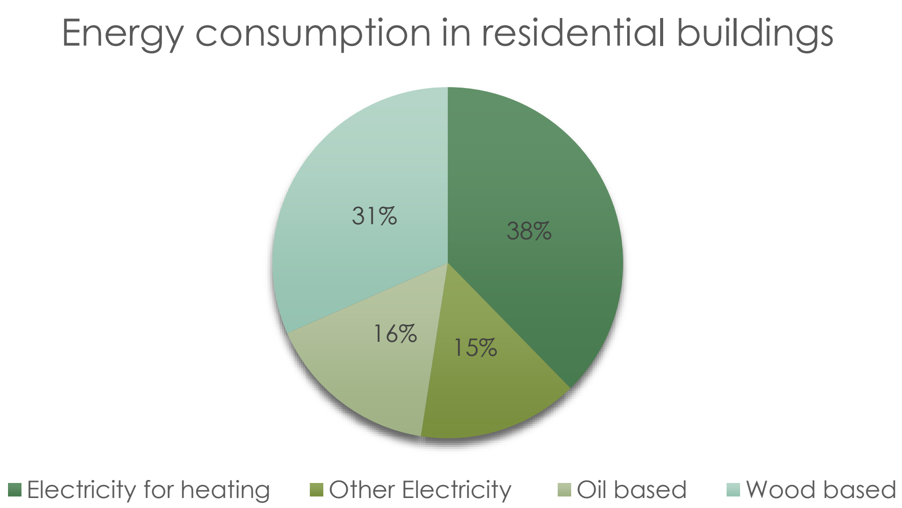

Figure 3. Heating types by sources in residential buildings

2. Summer Cottages

There are 197 summer cottages on Kökar, and their annual electricity consumption is 437 MWh/year. Based on the average consumption of firewood in Finnish summer cottages, the annual consumption of wood is 591 MWh/year. The energy from electricity and firewood combined in the summer cottages accounts for 7 % of the total energy consumption on Kökar.

3. Touristic Services

There are nine touristic businesses on the island (accommodation, food, and marina). Their total energy consumption is approximately 460 MWh/year, and their share of the total energy consumption on Kökar is 3 %. The heating types are specified in the table below.

Table 6. Heating types in touristic services buildings

Site	Heating type	Description
Brudhäll	Hotel, restaurant, and marina	A2W heat pump + oil as a backup
Sandvik Gästhamn & Camping	Guest harbor, camping, cabins	Electric heating
Anton's Gästhem	Rooms and apartments all year	Electric heating + A2A - heat pumps
Havspaviljongen	Guest harbor, restaurant, and cabins	Electric heating
Klobbars gästhem & stugor	Guest house, restaurant and cottages	Oil and wood
Peders aplagård	Café and apple farm sales	No heating
Skinnars	Various forms of accommodation, boat rental, and fishing	Electric heating
Ålands Sjötrafik AB	Sea transportation	A2A heat pumps x 2, oil

4. Other Businesses

The other businesses on the island are the building tech and maintenance company, the grocery store, the bank and the postal services. The heating types for these buildings can be seen in table 7 below. The total energy consumption is approximately 232 MWh/year and their share of the total energy consumption on Kökar is 1.5 %.

Table 7. Heating types in other business buildings

Site	Heating type	Description
Kökar service	Building- and service company	A2W - heat pump
Kökar skärgårdsbutik	Grocery shop	Recovery of the cooling machines' waste heat to the underfloor heating sufficiently
Åland Post and Ålandsbanken	Bank- and postal service	Electric heating
Skärgårdsbröd	Bakery & café	Pellets

5. Municipal Facilities

The municipal facilities on the island are the school and the town office, the nursing home, the kindergarten, the water treatment and the wastewater treatment plant. All the municipal buildings use electricity as their main heating source, except the school which uses oil. The heating types and energy consumption are presented in Table 8. The total energy consumption by municipal facilities is approximately 642 MWh/year, which accounts for 4.4 % of the total energy consumption on Kökar.

Table 8. Annual energy consumption and heating type of municipal buildings

Municipal buildings	Heating type	Electricity/year (MWh)	Oil/year (MWh/a)
Nursing home	Ground heat pump	185	0
School and municipal office	Oil	97	280
Water plant	Electricity + air-to-air heat pump	6	0
Wastewater treatment plant	No heating, enough waste heat from pumps and air compressor	16	0
Kindergarten	Electricity + air-to-air heat pump	59	0
Total		**362**	**280**

Transportation

Transportation is divided into land marine and aviation as well as their subcategories. The transportation accounts for 73% of the total energy consumption, and 78% of the CO_2 emissions on Kökar.

6. Land Transportation

There is no data on the fuel consumption of the land transportation on Kökar, but the number of registered vehicles is known. This number was compared to the registered vehicles in total on Åland and the fuel consumption was calculated based on the ratio between Kökar and Åland since the consumption for Åland in total is known. The number of registered vehicles is presented in table 9. In table 10 below, the annual energy consumption by fuel types is presented and the total consumption of 1,334 MWh/year accounts for 6 % of the total energy consumption on Kökar.

Table 9. Number of registered vehicles and fuel types on Kökar

Type	No of reg. vehicles	Fuel type
Quad bikes (larger)	3	Gasoline
Trucks	10	Diesel
Light quad bikes (including moped cars)	9	Gasoline
Mopeds	45	Gasoline
Motorcycles	10	Gasoline
Package cars	55	Diesel
Passenger cars	144	Gasoline
Passenger cars	16	Diesel
Tractors	88	Diesel
EV	1	Electricity
Total	381	

Table 10. Annual consumption of different fuel types

Fuel type	Annual consumption (MWh/a)
Diesel total	380
Gasoline total	952
E-car total	2
Total	**1,334**

i *The energy consumption for land transportation was also calculated in an alternative way, by estimating the average annual energy consumption for each vehicle type and multiplied by the number of vehicles. The results were in the same range.*

7. Marine Transportation

Marine transportation is divided into six subcategories: ferries, private boats, tourist private boats, tourist service boats, rescue boats and coast guard boats.

7.1 Ferries

The island is connected to the mainland and the main island via ferries. Three different ferries are operating to Kökar: Gudingen, Skiftet, and Knipan. The diesel consumption of the ferries is in total 7,250 MWh/year and accounts for approximately half of the total energy consumption.

How the ferry consumption has been allocated for Kökar

1.	*Gudingen*	*9,102 MWh/year*
2.	*Skiftet*	*8,818 MWh/year*
3.	*Total consumption Gudingen + Skiftet*	*17,920 MWh/year*
4.	*Långnäs - Sottunga - Kökar*	*2,250 trips/year*
5.	*Långnäs - Sottunga - Kökar*	*51,7 km*
6.	*Långnäs - Sottunga - Kökar*	*116,325 km/year*
7.	*Kökar - Galtby*	*652 trips/year*
8.	*Kökar - Galtby*	*53,8 km/trip*
9.	*Kökar - Galtby*	*35,078 km/year*
10.	*Lankans - Sottunga - Kökar - share of total kms per year:*	*77 %*
11.	*Kökar - Galtby - share of total kms per year:*	*23 %*
12.	*Långnäs - Sottunga - Kökar in MWhs per year:*	*13,768 MWh*
13.	*Kökar - Galtby in MWhs per year:*	*4,152 MWh*
14.	*Kökar's share of MWhs is 1/3 of Långnäs – Sottunga - Kökar connection:*	*4,589 MWh*
15.	*Kökar's share of MWhs is 1/2 of Kökar - Galtby connection:*	*2,076 MWh*
16.	*Knipan (15.6–19.8) Långnäs - Kökar in MWhs*	*1,170 MWh*
17.	*Kökar's share of MWhs is 50 % of Knipan's consumption*	*584 MWh*

Total ***= 4,589 MWh + 2076 MWh + 585 MWh = 7,250 MWh***

7.2 Private Boats

Based on the number of cottages and citizens, it is estimated that there is a total of 300 boats on Kökar. It is assumed that 50 % of the boats use diesel and 50 % use gasoline. Therefore, the energy consumption of private boats is 1,820 MWh/year which accounts for 12 % of the total energy consumption on Kökar.

How private boat consumption has been estimated for Kökar

The boats have different consumption based on the sizes and age, and the following consumptions are used to estimate the consumption of private boats. It is estimated that the annual use is 35 hours per boat.

Avg. Consumption (l/h)	Share of the boats	Number on Kökar	Annual consumption (l/a)
< 5 l/h (sail and electric boats, excluded)	12 %	36	0
5 l/h	38 %	114	19,950
10 l/h	9 %	27	9,450
25 l/h	39 %	117	102,375
50 l/h	2 %	6	10,500
Total		300	142,275

7.3 Tourist Boats

The tourist boats spend on average 2 hours in Kökar waters when arriving and leaving the Kökar guest harbor. The average consumption is 30 l/h and the estimated number of guest boats per year are presented in table 11 below.

Table 11. Estimated number of guest boats per year on Kökar

Guest Harbor	Motorboats	Other boats	Total boats
Karlby Gästhamn	450	683	1,133
Sandvik Gästhamn	500	1,000	1,500
Havspaviljongen	200	600	800
Total	**1,150**	**2,283**	**3,433**

According to this the annual fuel consumption is 84 MWh per year which accounts for 0.6 % of the total energy consumption.

7.4 Tourist Service Boats

There are two companies offering tourist cruises on Kökar. Their annual energy consumption is in total 56.3 MWh, which is less than 0.5 % of the total energy consumption.

7.5 Coast Guard Boats

Border guard stations consume approximately 106 MWh of diesel per year in Kökar waters, which is roughly 0.6 % of the total energy consumption.

7.6 Rescue Boats

Rescue boats are used when the rescue helicopter cannot be used due to rough weather conditions. This happens approximately 10 times per year. The total consumption of the rescue boats are 69.2 MWh/year and account for 0.5 % of the total consumption.

8. Aviation

Currently, there is one safety helicopter operating to Kökar approximately 20 times per year. It consumes kerosene and the annual energy consumption for Kökar routes is 30 MWh/year, which accounts for 0.2 % of the total energy consumption.

Stakeholders

This section is based on extracts from Leichthammer J. (2016), "Different Optimisation Perspectives in the Åland Energy Market due to the Increase of Renewable Energies" p. 11-15. It includes input from Flexens and the Clean Energy for EU Islands Secretariat.

Åland Government

"After Sweden had lost Åland and Finland to Russia in 1809, Åland was part of the Finnish grand duchy. After Finland had gained independence in 1917, Åland attempted to be officially reunited with Sweden which was denied by Finland. Consulted by the League of Nations, Åland accomplished the right of self-government within the Finnish nation in 1921. Consequently, Åland was demilitarised and neutralized so that Sweden would not have to fear Finnish attacks from the island group in between. Since 1922 the parliament (Åland's landskapsregering) with its 30 members decides about matters such as the local energy market. Finland's primary responsibilities consider the fields of foreign affairs, judiciary, most of civil and criminal law, customs duties and taxes. Åland's government receives an annual compensation sum for the taxes and charges paid to Finland which equals to 0,45% of the estimated annual revenues of the Finnish government, state borrowings excluded. Åland's government can split this sum self-assessed for its local matters. Most of the money is usually spent on health and environment, then finance and after that education."[3] Of Åland's thousands of islands, 60 are inhabited. Åland has 16 municipalities, of which Kökar is one.

Kökar Municipality – Kökar Kommun

The municipality of Kökar has, despite its small size, a fully developed municipal service that covers all areas that also exist in larger municipalities. Kökar has well-equipped primary school with a good teaching staff. Kökar's library is located in the same building. Day care is well organized with day care for all children. There is also health care, a doctor's surgery and a newly built care home.

Kraftnät Åland (KNÅ)

"Kraftnät Åland (KNÅ) founded in 1997 is the only transmission grid operator (TSO) of the island group and owned by the local government. The company maintains one 25 MW gas turbine for back-up power. The transmission grid (TG) includes 22 power stations and 512 km of electrical lines in total. As the local TSO connecting Åland with the Swedish synchronised grid KNÅ has the obligation to both ensure power supply for the inhabitants of the islands and the stability in the whole system from the in- and outside. As the Åland grid is part of Nord Pool's bidding zone SE3 KNÅ has balancing responsibility. An old system is still maintained in which contracts between the TSO and each of the two local DSOs as well as the electricity producer Allwinds are concluded as follows: These three act within certain balance power windows. The balance responsible companies have to predict their energy infeed into the grid and the estimated consumption day-ahead. If their prediction is wrong, Kraftnät will balance the power

[3] Julia Leichthammer, 2016. Different Optimisation Perspectives in the Åland Energy Market due to the Increase of Renewable Energies.

by buying energy from (if the prediction was too low) or by selling it to (if the prediction was too high) the Swedish TSO Svenska Kraftnät. The price of these interactions is regulated for a contractually settled price which equals to the current up-/down-price at Nord Pool. Beyond this window Kraftnät is allowed to sell (export) power for higher prices or buy (import) it for lower prices than the balance prices at Nord Pool. This approach shall lead to a more exact prediction and more supply security."[4]

Ålands Elandelslag (ÅEA)

Ålands Elandelslag (ÅEA) is the DSO in Kökar. "Ålands Elandelslag, owns the grid in the countryside and archipelago outside of Mariehamn, where about two third of the inhabitants live permanently or in cottages only during summer. The legal form is a cooperative so that every customer holds an equal share in the company. ÅEA owns 1,045 grid stations, 2,084 km LV and 1,186 km MV grid as well as around 14,886 metering points."[4]

Electricity Producer Allwinds AB

Allwinds operates the only wind turbine in Kökar. "Allwinds, founded in 2011, is the local wind park operator owning 21.16 MW wind power and maintaining 21.76 MW which represents the total amount of installed wind power in Åland. The company is equally owned by three firms: Ålands Vindenergi Elandelslag (founded in 1994), Åland Vindkraft AB (1997) and Leovind AB (2003). Due to its share in the daily load curve and because Allwinds is an electricity supplier to end-consumers using the Åland grid, the company is also held balance responsible by TSO KNÅ."[4]

Kökar Business Association

Gathers business owners on the island in common issues such as sea transports and joint marketing. The attractiveness of Kökar is of major importance to them, both for getting customers and for hiring employees.

Företagsam Skärgård

An association formed by the six archipelago municipalities in Åland: Brändö, Föglö, Kumlinge, Kökar, Sottunga and Vårdö. Its aim is to promote immigration, business establishment, advice and support to the business community, as well as education.

Ålands Natur och Miljö

A non-profit, non-governmental organization promoting sustainable development on the Åland islands. The organization shares a following vision that: "We want to see Åland as a sustainable society, at the latest in 2051. In order to reach this goal, we all have to work together

[4] Julia Leichthammer, 2016. Different Optimisation Perspectives in the Åland Energy Market due to the Increase of Renewable Energies.

continuously. We are at the moment 1,160 members in our organization, which gives us a strong mandate to influence policy-makers and the society overall."[5]

The Nordic Archipelago Cooperation

A cross-border governmental cooperation encompassing the archipelago regions of Stockholm, Uppsala, Sörmland and Östergötland, the provinces of Southern Finland, Nyland and Kymmenedalen, and Åland. The organization mainly deals with co-operation issues and maintenance of contacts between archipelago areas. Its activities have been partly financed by the Nordic Council of Ministers since 1978.

Flexens Oy Ab

Flexens supports Kökar Municipality with the clean energy transition. Flexens is a project development company for sustainable, flexible and integrated energy systems based on renewable energy sources. The company works as a cooperation platform for the leading technology providers in the sector. Flexens has identified the opportunity to develop and build a full society scale energy system based on renewables on Åland – an island with ideal wind and solar conditions, an ambitious climate- and energy strategy as well as a population dedicated to sustainability. The overall goal of Flexens is to pilot and demonstrate a fully renewable energy system which that is feasible both technically and economically. Flexens is owned 50% by CLIC Innovation and 50% by the following Åland Parties (local demo partners including the Government of Åland, testbed operators and energy companies). CLIC Innovation is a consortium of Finnish research institutes and companies specialized in energy systems, bioeconomy and circular economy.[6]

[5] https://www.natur.ax/english
[6] https://flexens.com/the-demo/

Policy and Regulatory Overview

The Åland Policy and Regulatory Overview is based on Leichthammer, J. (2016), "Different Optimisation Perspectives in the Åland Energy Market due to the Increase of Renewable Energies" p. 38-40.

The section on European Policy and Regulation was written by the Clean Energy for EU Islands Secretariat, as published on its website.

Åland Policy and Regulatory Overview

Åland Government has three main goals related to energy and CO_2-emissions by 2030.

- 100% of the electricity will be produced using local and renewable energy sources
- The share of renewable energy of total consumption is 60 %
- 60 % lower CO_2-emissions than 2005

Åland Electricity Laws

"Valid since May 2016, the law Landskapslag (2015:102) replaces the previous Electricity Act (1982:38). The law handles the production, transmission and distribution as well as export and import of electricity. It also applies to network operations, balance responsibility, balance power and network tariffs. Furthermore, it declares that the Åland parliament accepts most of the Finnish Electricity Market Act but changes it regarding the local requirements. It is common to adopt Finnish laws since it is easier and faster for the small island legislation to simply change fully developed laws, as on the mainland there are much more resources and qualified personnel. So, the Åland legislator adds paragraphs according to local conditions and erases other contents which do not apply to Åland, as in this case."[7]

Finnish Energy and Climate Roadmap 2050

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

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

[7] Julia Leichthammer, 2016. Different Optimisation Perspectives in the Åland Energy Market due to the Increase of Renewable Energies.

6. Base -80% Scenario – like Baseline Scenario with emissions reaching the target levels

According to this report, published by the Ministry of Employment and the Economy (MEE), about 80% of all greenhouse gas emissions are caused by energy production and consumption, including transportation energy. Until 2050 all emissions shall be reduced by 80-95% compared to 1990.[8]

Depending on the used methodology, in each scenario Finland is expected to reach 45-65% (nuclear power considered as imported energy) or 70-80% (nuclear power considered as domestic energy) energy self-sufficiency in 2050. Since Finland is connected to the Nordic and European grid trading electricity bidirectionally, economic understanding enforces that the variable production costs must be lower inside Finland than outside to achieve total self-sufficiency[9]. In that matter this roadmap differs significantly from the European roadmap in so far as the EU intends to create one united European energy market whereas Finland plans on increasing its energy autarky[10].

European Policy and Regulation

Energy and Climate Actions

Energy is one of several shared competences between the European Union (EU) and the Member States. EU policy is currently based on three pillars (known as the "energy trilemma"):

- Competition
- Sustainability
- Security of supply

Through policy and regulation, the EU promotes the interconnection of energy networks and energy efficiency. It deals with energy sources ranging from fossil fuels, through nuclear power, to renewables (solar, wind, biomass, geothermal, hydro-electric and tidal). Three legislative packages were adopted to harmonize and liberalize the internal European energy market between 1996 and 2009. These addressed issues of market access, transparency and regulation, consumer protection, supporting interconnection and adequate levels of supply.

For a while now, the EU is actively promoting Europe's transition to a low-carbon society and is regularly updating its rules to facilitate the necessary private and public investment in the clean energy transition.

A variety of measures aiming to achieve an integrated energy market, the security of energy supply and a sustainable energy sector are at the core of the EU's energy policy:

- Renewables Directive: mandatory targets, national plans grid rules…
- Emission Trading Scheme (ETS), reflecting a carbon price to achieve the cap.

[8] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. Chapter 1: Central premises, p.13 et seqq.

[9] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. Chapter 2: Energy production and energy system

[10] Ministry of Employment and the Economy (2014): Energy and Climate Roadmap 2050. The committee's comments, p.70

- Energy Union: secure, sustainable, competitive and affordable energy
- 3rd energy package: unbundling, harmonised grid operation rules, network codes etc.
- Energy Efficiency Measures
- Institutional measures: ENTSOs, ACER, CEER…
- Development of the longer-term framework: 2020, 2030, 2050

Latest EU Legislation on Energy, Environment and Climate

On 11 December 2019, the European Commission presented its Communication '**The European Green Deal'**[11], setting a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy, where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use.

Figure 4 - Clean energy targets Green Deal[12]

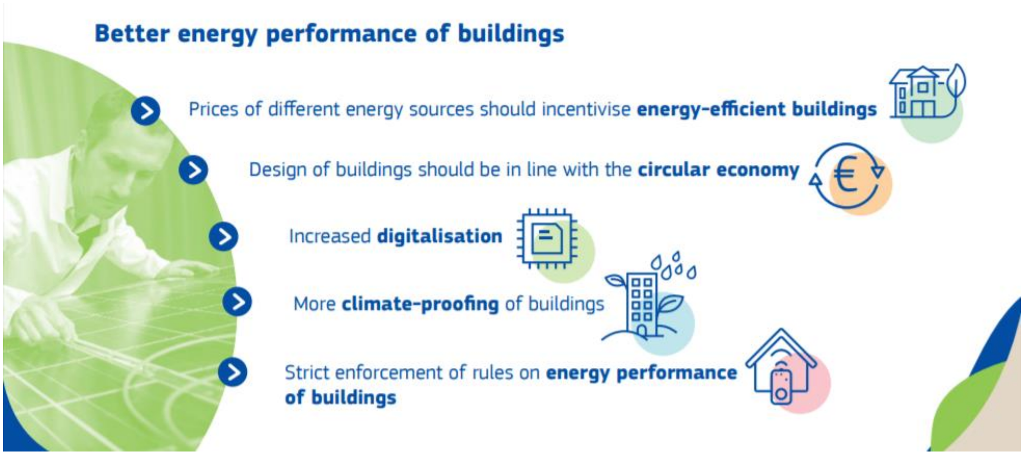

Figure 5 - Building and Renovation targets Green Deal[13]

[11] Communication on The European Green Deal. European Commission - European Commission. https://ec.europa.eu/info/publications/communication-european-green-deal_en. Accessed March 16, 2020

[12] Clean energy. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6723. Accessed March 16, 2020

[13] Building and renovating. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6725. Accessed March 16, 2020

Figure 6 - Sustainable mobility targets Green deal[14]

The Commission stated that the European Green Deal will reflect this growth strategy in its long-term vision for rural areas. It will pay particular attention to the role of outermost regions in the European Green Deal, considering their vulnerability to climate change and natural disasters and their unique assets: biodiversity and renewable energy sources. The Commission will take forward the work on the Clean Energy for EU Islands Initiative to develop a long-term framework to accelerate the clean energy transition on all EU islands.

On the 4th of March 2020 the European Commission unveiled the **European Climate Law[15]** proposal aiming at cutting greenhouse gas emissions to zero by 2050 and making it legally-binding for all member states. The European Commission is proposing a mechanism for regularly raising the EU's emissions reduction target over the next three decades. By September 2020, the Commission shall review the Union's 2030 target for climate in light of the climate-neutrality objective and explore options for a new 2030 target of 50 to 55% emission reductions compared to 1990. The European Commission stressed that she will engage with all parts of society to enable and empower them to take action towards a climate-neutral and climate-resilient society, including through launching a European Climate Pact.

On **30 November 2016**, the European Commission published its so-called "Winter Package" with eight proposals to facilitate the transition to a "clean energy economy" and to reform the design and functioning of the European Union's electricity market. This package of proposals can be divided into three categories:

- Proposals to amend the existing energy market legislation;
- proposals to amend the existing climate change legislation; and
- proposals for new measures.

In the autumn of 2018 and spring of 2019, several directives were adopted under the **Clean Energy for all Europeans Package**. The eight legislation measures can be placed in four groupings:

1. Energy Efficiency:
    - The Energy Efficiency Directive; and
    - The Energy Performance in Buildings Directive

[14] Sustainable mobility. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/fs_19_6726 . Accessed March 16, 2020

[15] The European Climate Law. European Commission - European Commission. https://ec.europa.eu/commission/presscorner/detail/en/FS_20_360 . Accessed March 16, 2020

2. Internal Energy Market Reform:
    - The Internal Electricity Market Design Regulation;
    - The Internal Electricity Market Design Directive;
    - The Agency for the Cooperation of Energy Regulators (ACER) Regulation; and
    - The Risk Preparedness in the Electricity Sector Regulation.
3. Renewable Energy:
    - The Renewable Energy Directive;
4. Governance:
    - The Governance of the Energy Union and Climate Action Regulation.

These new Electricity Market Design (EMD) rules make the energy market fit for the future and place the consumer at the centre of the clean energy transition. The new rules are designed to empower energy consumers to play an active role in driving the energy transition and to fully benefit from a less centralised, and more digitalised and sustainable energy system. The new rules enable the active participation of consumers whilst putting in place a strong framework for consumer protection.

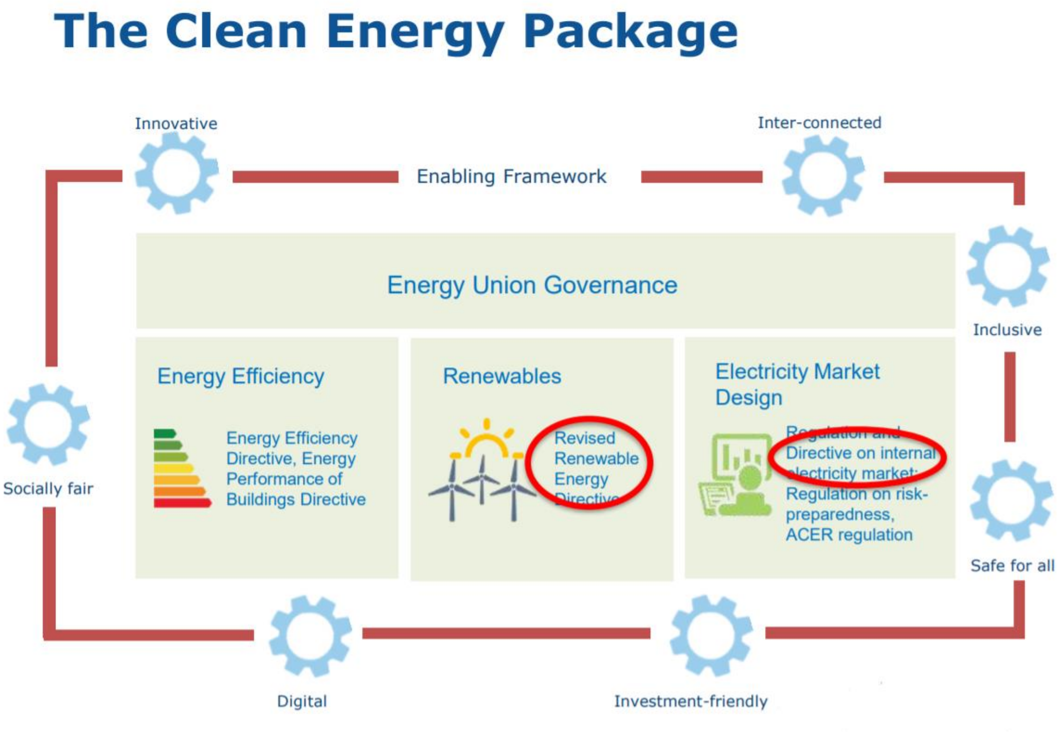

Figure 7 - Structure of the CEP[16]

Energy Communities

For EU Islands the most important new rules are those that empower citizens and small producers under the new concept of Renewable (REDII) or Citizens (EMD) Energy Communities. These are groups of citizens, social entrepreneurs, public authorities and community organisations participating directly in the energy transition by jointly investing in, producing, selling and distributing renewable energy.

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[16] Joint Research Centre (2018). Energy Communities in the Clean Energy Package. Local Communities and Social Innovation for the Energy Transition, Ispra. https://e3p.jrc.ec.europa.eu/file/1957/download?token=xYQCIENO

What?

- Generation of energy from renewable resources and technologies, which are partly or wholly owned by local communities

Who?

- Groups of citizens, social entrepreneurs, public authorities and community organisations participating directly in the energy transition by jointly investing in, producing, selling and distributing renewable energy

What can they do?

- Produce, consume, store and sell renewable energy, including through renewable power purchase agreements;
- Share, within the renewable energy community, renewable energy that is produced by the production units owned by that renewable energy community;
- Access all suitable energy markets both directly or through aggregation in a non-discriminatory manner

It is noticed throughout the EU that the participation of local citizens and local authorities in renewable energy projects through renewable energy communities has resulted in substantial added value in terms of local acceptance of renewable energy and access to additional private capital which results in local investment, more choice for consumers and greater participation by citizens in the energy transition. Therefore, the RED II and the EMD state that the Member States should ensure that renewable energy communities can participate in available support schemes on an equal footing with large participants. To that end, Member States should be allowed to take measures, such as providing information, providing technical and financial support, reducing administrative requirements, including community-focused bidding criteria, creating tailored bidding windows for renewable energy communities, or allowing renewable energy communities.

It is up to the Member States to set the fees and tariffs to be borne by the CEC. They can allow the CEC to be a distribution system operator (DSO) or a closed distribution system operator (CDS), and they must facilitate the roll-out of RECs by removing market barriers and taking account of RECs in support mechanisms.

The potential for energy community development in Kökar island was analyzed in 2020 in a Master thesis from Lund University[17].

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[17] Söderholm, J. (2020). *Powered by actors and business models - Analysing the potential for energy community development in new regions using the case of Kökar island* (Master dissertation). Lund University, Lund, Sweden.

PART II – Transition Agenda and Pathways

Vision

A transition to a renewable energy system requires a step-by-step development in which both new and well-proven renewable energy technologies are installed. These reduce both carbon dioxide emissions and make energy use more efficient.

The development plan for Kökar defines the following vision of the island's energy system.

Thanks to good wind and solar conditions, all electricity is produced by renewable sources. With the help of a smart electricity network and energy storage the heating sector and the transport sector are decarbonized. All sectors cooperate, provide flexibility and contribute to an innovative and sustainable energy system where Kökar becomes a small-scale role model from a global perspective.

By 2030: *The local renewable electricity production is equal to annual electricity consumption. All oil use in buildings is replaced with a renewable energy alternative.*

By 2050: *Both land and marine traffic is decarbonized. Energy storage systems, such as batteries and hydrogen, are implemented on a larger scale to reduce electricity import and increase flexibility.*

Proposed Technical Solutions That Reduce Energy Consumption and Emissions

In this part of the report, suggestions that could be implemented to reduce carbon emissions and increase renewable energy production are presented. The table below is a summary of all suggestions, stating the impact of the solution as well as estimated investment costs and yearly operation costs.

Table 12. Summary of suggested technologies and their impact

No.	Measure	Responsible partner	Total investment (k€)	Public funds (k€)	O&M - costs (k€/a)	Energy saving/RE production (MWh/a)	CO_2-savings (tCO_2/a)	Payback time (a)	Impact Energy (%)	Impact Electricity (%)	Impact tCO2 (%)
1a.	PV residential buildings	Consumers	735	282,5*	2,1	424	28	15-20	-2,8 %	-14,3 %	-0,9 %
1b.	PV commercial buildings	Private companies	80	20*	0,3	52	3	10-15	-0,3 %	-1,8 %	-0,1 %
1c.	PV summer cottages	Consumers	788	0	0,4	74	5	+25	-0,5 %	-2,5 %	-0,2 %
1d.	PV municipal	Municipality	120	30*	0,3	64	4	10-15	-0,4 %	-2,2 %	-0,1 %
2a.	Smart heating control in households	Consumers	90	Tax credit for household expenses possible	3,1	142	10	2-5 years	-0,9 %	-4,8 %	-0,3 %
2b.	Smart heating control in commercial buildings	Private companies	n/a	25%, up to 10 k€ per house	n/a	91	6	2-5 years	-0,6 %	-3,1 %	-0,2 %
3.	Heat pumps to oil-heated buildings	Consumers	180	18	1,8	160	42	10-15 years	-1,1 %	3,2 %	-1,4 %
4a.	New hybrid energy system for the school	Municipality	550	negotiable	5,5	360	79	n/a	-2,4 %	n/a	-2,6 %
4b.	Micro -CHP system for the school	Municipality	600	negotiable	15	377	101	n/a	-2,5 %	n/a	-3,3 %
5.	Electric vehicles as passenger cars	Consumers	4800	0	24,5	600	197	n/a	-4,0 %	7,2 %	-6,5 %
6.	Carpool	Municipality	400	n/a	n/a	120	42	n/a	-0,8 %	1,9 %	-1,4 %
7.	Hydrogen ferry	n/a	n/a	n/a	n/a	n/a	1885	n/a	n/a	n/a	-62,2 %
8.	Hydrogen Sjötrafik AB	Private companies	850	425	32,8	218	113	n/a	-1,5 %	12,5 %	-3,7 %
9.	Battery electric Kjellskärsbåten	Private companies	210	105	0,4	15	5	n/a	-0,1 %	0,3 %	-0,2 %
10.	Wind Turbine	Municipality	400	0	10	1440	412	8-10	-9,6 %	-48,7 %	-13,6 %

*Governmental support from Åland's Landskapsregering

The following sections describe each suggestion in more detail. In each section the corresponding part of table 12 is presented. All tables below show the same parameters for the different suggestions and will therefore not be labeled specifically. The parameters are total investment, operation and maintenance costs, public funds that could be obtained, energy savings or renewable energy production depending on the suggestion, carbon savings and payback time.

1. Roof-mounted PV

Solar panels are the most economical when they are installed near the consumption and are connected behind the main meter to avoid grid tariffs. They are typically mounted on roofs to save space and to be securely installed. The PV investments below are estimated for residential housing, summer cottages as well as commercial and municipal buildings. The O&M costs (0.005 €/kWh) include the inverter upgrade once during the lifecycle of the PV system and maintenance inspection costs.

1a. Residential Buildings

Only a few households on Kökar have solar panels installed. Landskapsregeringen supports solar panel investments with up to € 2,500 per new installation depending on the size. The renewable energy (RE) production potential has been calculated by estimating that each of the 113 households would install a 5 kWp PV system.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	RE production (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
PV residential buildings	735	2,12	283	424	28	15-20

1b. Commercial Buildings

Some commercial buildings have solar panels installed, with a total capacity of 31 kWp. However, it is estimated that 65 kWp of new capacity could be installed into commercial facilities that does not yet have solar panels installed.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	RE production (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
PV commercial buildings	80	0,26	20	52	3	10-15

1c. Summer Cottages

There are 197 summer cottages on Kökar, and their consumption is 15 % of the total energy consumption. The RE potential has been calculated by estimating that each summer cottage would install a 0.5 kWp PV system.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	RE production (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
PV summer cottages	788	0.37	0	74	5	+25

1d. Municipal buildings

There are not many municipal buildings on Kökar. However, the school and the nursing home have the potential for roof-mounted PV systems.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	RE production (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
PV municipal buildings	120	0.32	30	64	4	10-15

2. Smart Heating Control for Buildings

Intelligent or smart heating uses energy to heat up buildings in a more efficient way. Heating is optimized which leads to improved indoor comfort and lower heating costs. By using smarter control for heating, around 40 % of the heating energy can be saved. Optiwatti and Fourdeg are two solutions that could be used. IoT-based energy optimization tools are suitable especially for electric heated buildings, which have the highest heating costs.

2a. Residential Buildings

Most households on Kökar use wood as a source for additional heat, and therefore the saving potential and investment in smart heating is only calculated for buildings with direct electric heating in the table below.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Smart heating control in households	90	3.1	Household deduction	142	10	2-5 years

2b. Commercial Buildings

Smart energy management services offer savings for commercial buildings when the heating and the room temperatures can be optimized to follow the usage patterns and the weather forecasts. The investment cost depends on the building type but is approximately around € 300 per room. No total investment is presented in the table below due to uncertainties regarding the cost. Cloud-based services are suitable for accommodation services.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Smart heating control in commercial buildings	n/a	n/a	25%, up to 10 k€ per house	91	6	2-5 years

3. Heat Pumps to Oil-heated Buildings

There is an estimated number of 12 oil-heated houses on Kökar. Contradictory to general assumption, there are no specific restrictions for boreholes on Kökar. Boreholes could be drilled and used as geothermal heat to replace the old heating system in the oil-heated houses. The estimated energy savings from this action is presented in the table below.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Ground heat pumps to oil-heated households	180	1.8	18	160	42	10-15 years

4. A New Energy System for the School

The school building has an old oil heating system and annually consumes approximately 280 MWh of oil and 97 MWh of electricity. Two options for an energy transition to a more sustainable solution are presented below. The school has a significant impact on the energy consumption on the island and could be used as an innovative demo that represents an energy independent sustainable solution, using only local renewable sources. Having such a solution in the school is also a good way to engage students in renewables.

4a. Heat Pump – Solution + PV + Wind + ESS

One option is to electrify the heating by using a ground heat pump as well as renewable resources from wind and sun. All the excess energy production, such as solar power during sunny summer days or wind power during windy days, will be stored and used for heating when needed.

Preliminary calculations were made to determine the needed energy systems for the buildings. However, detailed modeling and a feasibility study is needed to analyze the energy balance and the costs more in detail. The PV system size is designed to cover all available and suitable roof area on the building in the east and west direction the even out the production during the day. The remaining renewable energy is produced by wind power.

The following new technologies are needed for option 4a:

- Ground heat pump system of approximately 40–50 kW
- Roof-mounted PV system of 50 kW
- Small scale micro wind turbine of 50–60 kW
- Seasonal heat-storage (e.g. Polar Night Energy)
- New building automation system

By adding renewable energy production, a heat pump system, heat storage and improving the energy efficiency, around 90 % of the needed electricity and all the heating energy can be produced on site.

There are governmental funds available for the RE production, energy optimization and heat pump systems. Combining these solutions with a new seasonal heating storage, funds could potentially be negotiated to be raised for the whole package.

Further analysis is needed to study the feasibility of the system; technically, economically, and regulatory aspects such as needed permissions and tax liability. It is important to keep in mind that while improving the energy efficiency and sustainability of the school, the building repair debt also decreases in comparison to the old heating and building automation system. Furthermore, the indoor air quality is improved and the value of the building increased. The investment cost and energy savings with this new system is presented in the table below.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
New hybrid energy system for the school	400-500	5.5	negotiable	360	79	n/a*

*needs further analysis

4b. Micro-CHP + BSS

Another option is to use local biomass, for example wood chips, and combine it with a small-scale combined heat and power system (micro-CHP) and a battery energy storage system (BSS). The micro-CHP produces heat and follows the heat demand in the building as well as producing electricity by running steam through a turbine. The excess electricity can be stored in a new BSS or traded to other users in a future energy community if new legislation makes it possible. By using biomass as the only fuel this process can be completely carbon neutral.

Further analysis is needed to study the technical, economical, regulatory and other feasibility aspects of the investment. Also, possible barriers, such as fuel supply and land-owning issues, should be investigated.

The following new technologies are needed for option 4b:

- Micro-CHP system and seasonal storage for the biomass
- BSS for surplus electricity
- The fuel supply, the needed technology and operational labor must be secured

O&M costs are approximately € 10,000 /year for materials and € 5,000 /year for labor costs. The fuel cost is not included in the table below with the total investments, O&M and energy savings.

Measure	Total investment (k€)	O&M costs (k€/year)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
New hybrid energy system for the school	550	15	negotiable	360	101	n/a*

*Needs further analysis

5. Electric Vehicles

By Edvard Nordlund

72 % of the total yearly energy demand on Kökar is comprised of gasoline and diesel usage. Even though ferries use most of this energy, 6 % of the total energy usage on Kökar comes from land traffic. By replacing the existing 160 passenger cars with electric vehicles a reduction of around 200 tons of carbon emissions could be obtained every year which can be seen in the table below.

Measure	Total investment (k€)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Electric vehicles as passenger cars	4,800	0	600*	197	n/a

* If EV efficiency is assumed to be 80 %, gasoline 20 % and diesel 30 %

Using electric vehicles (EVs) as passenger cars would increase the yearly electricity consumption with 213 MWh. If the cost of electricity is assumed to be 115 €/MWh for consumers, the yearly operation costs would equal approximately € 24,500. To encourage private homes to purchase an electric vehicle, a public charging station could be installed. However, there is still a risk that people would charge their vehicle at home and that a charging station would only have a small impact compared to the investment. There are also limitations to the influence that the Kökar municipality can have in convincing people to purchase EVs. It is important to consider that more electric cars would increase the electricity demand, and that charging EVs often take place the same time as other electricity loads increasing the peaks in the grid.

6. Carpool

By Edvard Nordlund

Another proposal regarding the land traffic that would reduce carbon emissions is a carpool with electric vehicles in Långnäs, where the ferries arrive from Kökar. This could also be done in a different location if the ferry line would move in the future. There are two main benefits to a carpool, one being zero emissions when driving the 60 km distance back and forth from Långnäs to Mariehamn when people visit from Kökar and the second, perhaps even more important, that cars would not be needed to be carried by the ferry. Thus, ferries could be made smaller and would require less diesel to run the same number of routes. They could also more easily be converted to zero-emission ferries. An estimate of the carpool impact was calculated using data on the number of passenger cars on the ferry line as well as considering the number of tourists visiting every year. To validate the results local interviews were conducted. The estimated number of trips is approximately 3000, which roughly correlates to every passenger car making 1-2 trips every month. The energy impact is presented in the table below.

Measure	Total investment (k€)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Carpool	400*	0	120	42	n/a

*If 10 cars are used in the carpool

Further analysis is needed to determine the true impact of a carpool since many uncertainties still remain. The analysis should include the impact on carbon emission from using smaller ferries since this would improve the feasibility of the carpool.

7. Zero-Emission Ferry

By Edvard Nordlund

As previously stated, the diesel consumption from the ferries account for approximately half of all energy used on Kökar. Converting these to zero-emission vessels are therefore the action with the highest impact on reducing carbon emissions, but it is also the most challenging and costly change to make. When it comes to renewable ferries there are two options: a battery driven ferry, or a ferry powered by hydrogen with fuel cells. Batteries are cheaper and there are more available on the market, but they have two disadvantages in comparison to hydrogen ferries. They create a large increase in electricity use when they come into port, causing peaks in the grid since they need to charge the batteries quickly before departing again. For relatively large ferries in a small society like Kökar, this puts a lot of stress on the electricity system and requires a relatively strong grid able to feed this power. The battery weight can also make ferries infeasible if the route is too long. The 50 km distance to Kökar would require large and heavy batteries. The estimated battery weight is 60 tons and up to 5 GWh of electricity capacity. 5 MWh is enough energy to supply the average Kökar electricity consumption for over 10 hours. However, batteries have low operation costs and are still the more economical option if the weight of the batteries is feasible in comparison to hydrogen.

For long distances, hydrogen could be the better alternative. Hydrogen can be generated and stored at times when there is overproduction in the electricity grid and then be used when needed. This is an advantage in comparison to batteries. Hydrogen can be used safely as a renewable fuel in zero-emission ferries. The disadvantage with hydrogen is the low efficiency when producing it, which leads to high operation costs. Fuel cells are also costly, even if the price will decrease the more hydrogen and fuel cells penetrate the market. Hydrogen can be generated with electricity from wind power, and fuel cells are the engine that converts hydrogen back to electricity when it is being used to power the ferry. For a ferry like Gudingen, which is in use today, approximately 800 kg of hydrogen would be needed every day. To produce this amount of hydrogen almost 5 MW of installed wind power is required. To put the numbers into perspective, 0,5 MW of wind power is installed as of today and this turbine produces approximately 50 % of the yearly electricity demand. A project like this is more likely to be realizable in the timespan of 2030-2050 when efficiencies have increased, and prices decreased.

A zero-emission ferry is out of the scope of actions that the Kökar municipality can take on on its own. However, it should be mentioned that over 50 % of the investments cost for similar projects have been funded by EU. If hydrogen would be produced with wind power, the potential reduction in carbon emissions for the marine traffic on Kökar would be 1885 tons every year. More research is needed to analyze investment and operation costs for a specific case on Kökar.

8. Sjötrafik AB

By Edvard Nordlund

Since many parameters for the zero-emission ferries above are unknown, but the impact on carbon emissions is very large, a first step would be to go through with small scale pilots for battery driven and hydrogen driven marine vessels before advancing to larger ferries. For a hydrogen demo a boat from Sjötrafik AB could be used. This vessel would require a storage tank of 70 kg of hydrogen and have a yearly consumption of 6,550 kg. If the price of hydrogen is assumed to be 5€/kg, the yearly operation costs equal 32,750 €. The CO_2 savings have been calculated assuming that all hydrogen is being produced from wind power with zero emission. The electricity needed to produce this amount of hydrogen yearly is 370 MWh.

Measure	Total investment (k€)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Hydrogen Sjötrafik AB	850	425	218*	113	n/a

*If fuel cells are assumed to have an efficiency of 60% and the diesel engine 30%.

9. Källskärbåten

By Edvard Nordlund

A vessel which could use a battery electric system is Källskärsbåten, since it has shorter routes and could use a smaller engine as well. A benefit with electric motors is that they can use lower power in general compared to their diesel equivalent due the electric motor's effectiveness. Again, the system has been calculated as a replacement for the current fossil system and not a completely new vessel. To power Källskärsbåten for 1,5 hours with its current consumption a 55 kWh battery would be needed. The electricity consumption on a yearly basis would be 3,3 MWh. Operation costs would equal approximately € 380 if an electricity price of € 115 /MWh is being used. The battery can be increased if the need for longer trips arises, for example 145 kWh for 4 hours of runtime.

Measure	Total investment (k€)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
Battery Electric Källskärsbåten	55+30 (battery + motor)	0	5*	2	n/a

*If battery electric efficiency is assumed to 80% and the diesel engine to 30%.

10. The Coast Guard

By Edvard Nordlund

The coast guard is a large consumer of diesel. They use 109,000 liters or 1,060 MWh on a yearly basis. However, only 10 % of the used energy is allocated on Kökar and it is therefore not included in table 12. The potential reduction of carbon emissions would in total be 250-275 tons annually if the vessel were converted to zero-emission. Since only 10 % is allocated on Kökar the potential carbon savings are approximately 25 tons.

11. Wind Power

By Edvard Nordlund

Wind power should also be expanded to increase renewable electricity production. Installing another 500 kW wind turbine would decrease the CO_2 emissions with 412 tons annually which can be seen in the table below. Wind power is further mentioned in the discussion.

Measure	Total investment (k€)	Public funds (k€)	Energy saving (MWh/year)	CO_2 savings (tCO_2/a)	Payback time (years)
New wind power 500 kW	400	0	1440	412	8-10*

*Calculated with simple payback, O&M costs of 10 000 €/year and an electricity price of 40 €/MWh

Interesting New Technologies to Follow

By Edvard Nordlund

New interesting renewable concepts are constantly emerging, and this section is on what technologies could be specifically interesting for Kökar to follow in the coming years. Trying the solutions as small-scale pilots before they are on the market is a good way to be a pioneer in renewables and also to get funding from the EU.

Electric Aviation

Electric aviation in the form of airplanes and helicopters is under development, especially in small scale. Introducing this to Kökar would connect the archipelago with the main island in a new way, reducing travel times substantially. As with many innovative technologies, high cost is a challenge. Heart Aerospace and ShureFly are two companies working on these solutions. Another interesting aspect of aviation is the use of drones for supplying goods to the archipelago.

Micro-Wind

In addition to the already installed traditional micro wind power, there is potential for different types of innovative wind power solutions. There is a small-scale solution from TwingTec which is a drone flying where winds are strong, electrically connected to a station on the ground, collecting energy. This solution is small in comparison to traditional wind power. Additionally, using vertical wind turbines is an option, with the main benefits being more quiet operation and having the generator on ground level which allows for easier maintenance and cheaper generators. A solution from Single Wing Energy Oy is similar to the vertical wind turbine, using only one wing instead of three to further decrease costs and maintenance.

Monitoring Strategy

With clear goals and planning for the ambitious energy transition agenda on Kökar, monitoring the transition is a crucial factor in the learning process. It is important to keep track of indicators that are developing as planned but also to update and refine planning regarding indicators that are not progressing.

To monitor the transition process, a self-assessment tool with nine indicators that covers six areas is filled in by a specific monitoring team for Kökar. The team consists of three members, one from Flexens and two from the Kökar municipality council who are experts in the area. Each indicator is graded from 1 – 5. A lower score indicates that more focus is needed in that area. Scoring high indicates that everything is proceeding as planned and no additional actions are required. A template which describes the requirements for each score has been provided to the monitoring team. The monitoring team will repeat this process twice a year, in one-hour long sessions, to re-evaluate the grading of the indicators for Kökar. This way, the progress made towards indicators with a low score can be acknowledged. Also, scoring higher in the next self-assessment is a confirmation that actions taken have had positive effects. It is necessary to keep track on indicators that previously scored high to make sure that they are still progressing.

In the first self-assessment session for Kökar the following results were obtained.

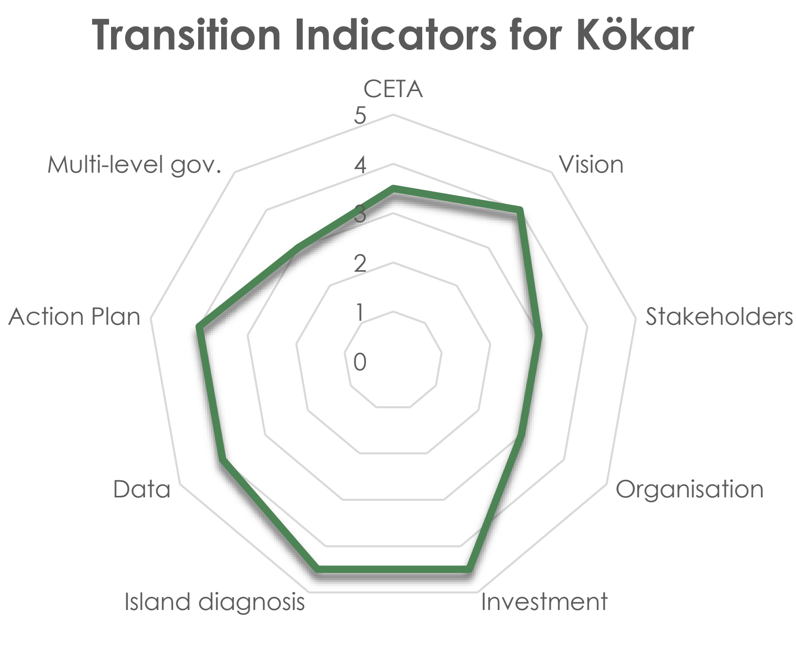

Figure 8. The score from the self-assessment with the monitoring team for Kökar on September 9, 2020.

Indicator 1: *Clean Energy Transition Agenda* **Score 3-4**

During the self-assessment session, the report was going through final changes before being ready for publishing and it is aimed to be finalized by October 2020.

Indicator 2: *Vision* **Score 4**

Kökar has a clearly outlined vision with goals for both mid-term and long-term clean energy solutions, however it is not yet approved by relevant authorities.

Indicator 3: *Community – Stakeholders* **Score 3**

There is a commitment from individual actors at the moment.

Indicator 4: *Community – Organization* **Score 3**

Active partnerships and shared activities exist between stakeholders.

Indicator 5: *Financing concept* **Score 4-5**

Several methods of financing have been analyzed and applications to receive funding for specific projects have been submitted. However, currently no formal decisions regarding funding have been made.

Indicator 6: *Decarbonization plan – Island diagnosis* **Score 4-5**

A proper energy analysis breakdown is included in the CETA report for different sectors such as heating, electricity and transportation. The economic analysis is not as detailed.

Indicator 7: *Decarbonization plan – Data* **Score 4**

Sufficient data to make a proper analysis of the different sectors is available. Public marine transport, for example, has well documented consumption data that is being collected regularly. Renewable generation on the island also has data accessible with high granularity. Land traffic has been interpolated from general land traffic on the Åland Islands and the electricity consumption is not measured locally on a periodic basis.

Indicator 8: *Decarbonization plan – Action Plan* **Score 4**

A clear action plan for clean energy that describes necessary actions exists but has not yet been approved by relevant authorities.

Indicator 9: *Multi-level governance* **Score 3**

Interaction with other levels of governance to align the CETA with existing plans is in progress. The process has been slowly moving forward during 2019-2020.

Discussion

The Electricity Sector

By Edvard Nordlund

The modelling tool Plexos has been used to simulate the most feasible way to transition the energy generation on Kökar to 100 % renewable on a yearly basis with the horizon 2030. The simulations were made with hourly resolution, which is important due to the high intermittency of wind power and solar power. Since wind power generates large amounts of electricity on windy days, and very little on calm and quiet days, the generation sometimes exceeds the instantaneous load and sometimes falls short of the instantaneous load. This is true even if the total yearly generation equals the total yearly electricity load. When there is either overproduction or underproduction this energy gap must be regulated, and this can be done either by importing and exporting electricity with the cable between Kökar and Åland or by installing local storage such as batteries or fuel cells powered by hydrogen. Since storage options still are expensive it is not feasible to become fully self-sufficient every hour of the year yet. However, using a smaller battery for outages and voltage regulation would be a step in the right direction.

With this in mind, it is of importance to consider the electricity flow in the cable. By installing more renewable power generation, the overproduction peaks might congest the cable, which means that the full capacity of the cable is being used, as long as no storage is introduced. The already installed wind power on Kökar that uses part of the cable capacity for export should also be considered. Due to how the Nordic electricity market is constructed, the electricity production from this wind turbine cannot be seen as production towards the goal of 100 % renewable generation on Kökar. To explain this in more detail we need to separate the *electricity market* and the *real flow of electricity*. From the perspective of the electricity market, the electricity used on Kökar is seen as the same residual mix as anywhere else on Åland as long as renewable energy certificates are not used. However, a 500 kW windmill is too small to sell separate certificates for use on Kökar. If certificates were to be used it would be from wind power in general on Åland. This is how the market works despite the fact that the real flow of electricity from the wind turbine will primarily be used on Kökar before the remainder is being exported to Åland. When renewable production on Kökar increases, energy certificates could be used for that specific production. A renewable energy certificate does not change the real electricity flow, but is a way to guarantee that, in perspective of the electricity market, Kökar uses renewable electricity. This is a complex and discussed matter for renewables in general, but with this solution the generation will be renewable from both the market perspective and the real flow perspective.

Wind Power Expansion

By Edvard Nordlund

Taking the discussion above into consideration, as well as simulation results to back up the suggestions, this is an example of how Kökar could generate 100 % of their electricity demand on a yearly basis with only renewables.

Table 13. Renewable expansion suggestion

Timeframe	Installed power	Annual RES production (GWh/a)	Annual consumption (GWh/a)
2020	Current renewable production (solar 49 kW + small scale wind 30 kW)	0,12	2,96
2020-2025	Purchase certificate for general wind power generation (500 kW)	1,56	2,96
2025-2030	Build new wind turbine (500 kW)	3,00	2,96

Wind power currently has lower levelized cost of energy (LCOE) than solar and is therefore used. Even though the total yearly demand is produced on a yearly basis 1.07 GWh are imported and 1.10 GWh exported which can be seen in the hourly simulation in the figure below. 1.55 GWh were imported and 0.15 GWh exported before new 500 kW wind turbine was installed.

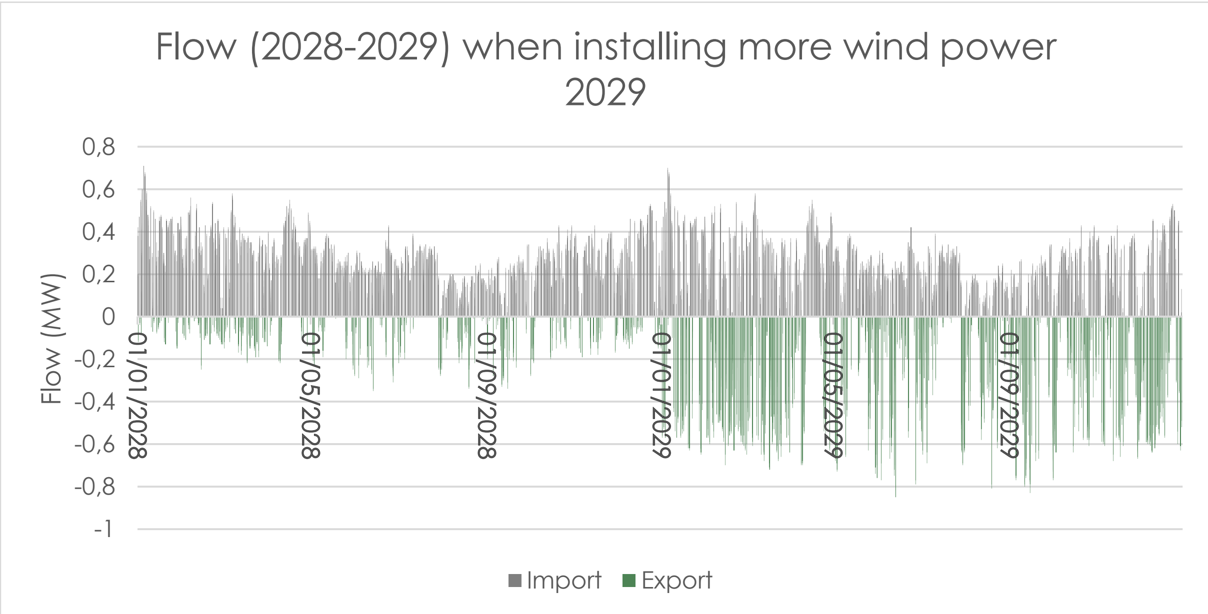

Figure 9. Import and export for Kökar 2028-2029. In 2029 another 500 kW wind turbine is installed.

The cable will not be congested in this scenario since the cable is 1.5 MW and the maximum load in figure 4 is around 0.8 MW. However, Sottunga, a nearby island municipality, should also be considered in calculations for max loading of the cable since that consumption contributes to the same cable. Even if production is increased the need for import still exists. In the timespan 2030-2050 storage options will likely be able to replace the import and export, especially in a future scenario where more electric vehicles are being used and hydrogen production for ferries is necessary. However, this is out of the scope of actions available for Kökar alone. Solar will also be necessary in the future to meet the increasing electricity demand from EVs and electric heating.

Conclusion

By Edvard Nordlund

Flowchart

The flowchart below presents how the future energy system on Kökar could look, visualized in a simplistic way.

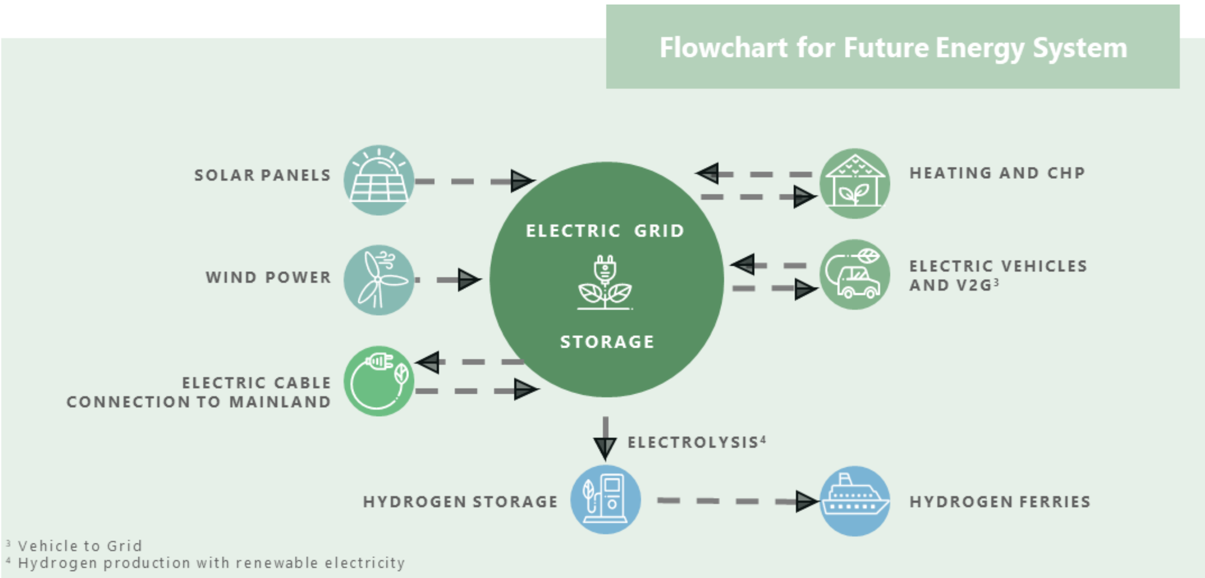

Figure 10. Flow chart of the future energy system on Kökar

Roadmap for Kökar 2020-2050

To conclude this report, the roadmap of suggestions has been visualized as can be seen in the figure below. The suggested years of installation for the different technologies can be varied and are intended as guidelines for the availability of the solution on the market.

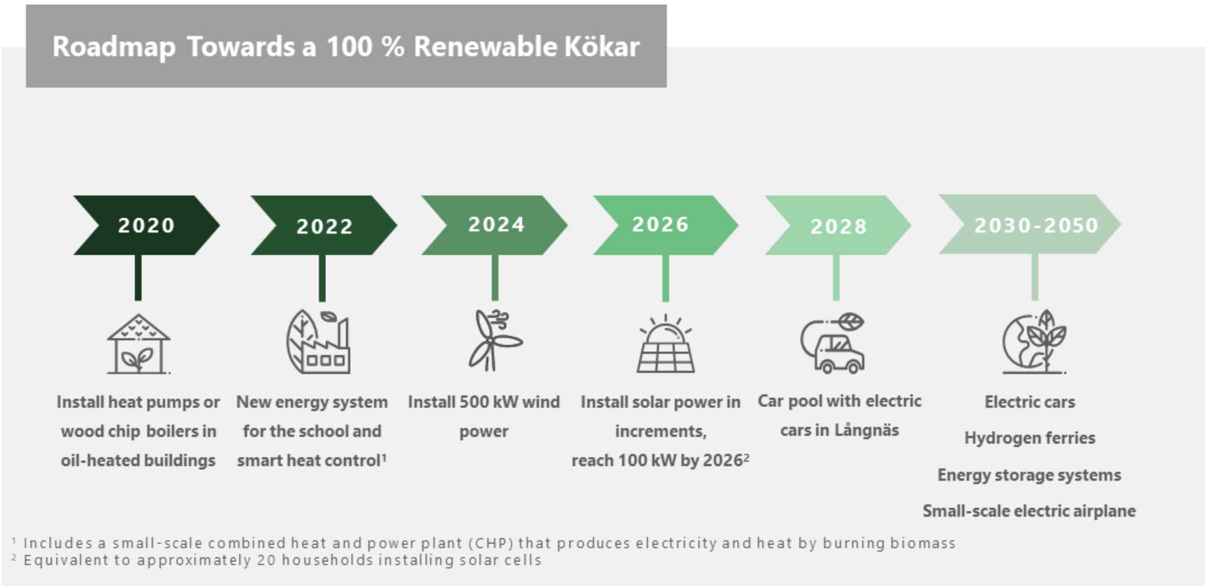

Figure 11. Suggested roadmap for Kökar from 2020-2050

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