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Scenarios for a sustainable energy system in the Åland Islands in 2030

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ABSTRACT

A fully sustainable energy system for the Åland islands is possible by 2030 based on the assumptions in this study. Several scenarios were constructed for the future energy system based on various combinations of domestic production of wind and solar photovoltaic power, expanded domestic energy storage solutions, electrified transport, and strategic energy carrier trade. Hourly analysis of scenarios using the EnergyPLAN tool shows that annualised costs of operating a future sustainable energy system for the year 2030 range between 225 and 247 M€/a compared to 229 M€/a for the business as usual case. However, this result is highly dependent on how vehicle and battery costs are accounted. A scenario featuring a highly electrified transport sector, including a wide range of terrestrial and aquatic forms of mobility, was among the most cost competitive solutions due to high levels of flexibility and electric storage harnessed in the energy system. In this scenario cost reductions were achieved as high capacities of electric vehicle battery storage resulted in less need for seasonal storage and synthetic fuel production in the form of Power-to-Gas technologies and offshore wind power capacity. Results also indicate that 100% renewable energy-based domestic energy production can be achieved in Åland, with or without reliance on imported energy carriers, such as sustainable biofuels or electricity. A demonstration of a highly electrified transport sector may also offer Åland society several benefits outside of the boundaries of the energy system. New job creation related to renewable energy production on Åland could total between at least 3100 and 3900 job-years during manufacturing, construction and installation, and between 45 and 59 more permanent jobs related to operations and maintenance, depending on the scenario.

1. Introduction

Islands and regions of archipelago represent interesting case studies on sustainable energy systems. Firstly, they tend to be compact geographic areas with homogeneous populations. Secondly, components of the energy system tend to be less complex and are more easily documented than larger continental systems. Thirdly, islands are generally associated with significant imports of expensive fossil fuels from [1] or power interconnections with continental energy suppliers. Further, eliminating dependency on imported energy through expanded use of domestic renewable resources and storage solutions has been suggested as an alternative for islands around the globe [2]. Importantly, islands may offer blueprints for sustainable energy system transitions that will occur on a larger scale with continental systems.

Several studies describe the benefits of Renewable Energy (RE) based energy systems on islands. Kaldellis et al. [3] propose that RE and Energy Storage Solutions (ESS) can encourage a shift away from oil dependence while promoting environmental benefits and financial advantages. In addition, Franzen et al. [4] demonstrate that optimized renewable energy system configurations up to 100% RE can "generate substantial savings" and eliminate the need for diesel generators on islands while still guaranteeing grid stability and reaching ecological as well as economic goals. The authors also point out that island energy systems may encounter shares of RE beyond 50% much sooner in the future than mainland grids, highlighting further relevance of the study of island energy systems. Further, Hlusiak et al. [5] outline how integration of electric vehicle batteries can add to island grid stability while reducing overall emissions associated with diesel generators. Of interest is the fact that the simulated island energy system demands on electric vehicle batteries did not pose significant restrictions on vehicle range, suggesting potential benefits of coupling RE and electrified mobility. To this extent, Blechinger et al. [2] claim that islands may not only represent a blueprint for future mainland systems, but represent an attractive new business field which can serve as showcases of the "attractiveness of reducing fossil fuel based power generation and GHG emissions".

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Nomenclature

RE	renewable energy
ESS	energy storage solutions
PV	photovoltaic
DC	direct current
AC	alternating current
BEV	battery electric vehicle
V2G	vehicle-to-grid
BAU	business as usual
e	electric units
th	thermal units
gas	gas units
p	nominal or peak capacity
PtG	power-to-gas
Capex	capital expenditures
Opex	operating and maintenance expenditures
O&M	operations and maintenance
MCI	manufacturing, construction and installation
SE	Sweden
FI	Finland

The archipelago of Åland is located in the Gulf of Bothnia of the Baltic Sea (Fig. 1) between Sweden in the east and Finland, of which Åland is an autonomous region, in the west. The Government of Åland has recently established a development and growth plan aimed at achieving sustainability throughout all spheres of life by 2051 [6]. In addition, local stakeholders have begun to envision how an energy system could enable the delivery of reliable, affordable, quality energy services which are free of fossil fuels to local end users [7]. Fundamental to a vision of a future Åland energy system is the consideration of optimal energy flows between Åland, the rest of Finland, and neighbouring Sweden, the latter of which has long been a significant supplier of power to Åland due to its geographic proximity. An 80 MW high voltage AC connection with Sweden is expected remain an important part of the energy system, and a link with Finland was expanded in January 2016 to a 100 MW high voltage DC cable. For these reasons, a transition to a different kind of energy market design is likely to occur in the decades to come. At the same time, local stakeholders would like to determine the optimal balance of the entire energy system (electricity, heat and transport sectors) in order to achieve security of supply, reasonable levels of self-sufficiency, competitiveness of society, and mitigation of climate change. A summary of key Åland facts is presented in Table 1.

The electrification of much of Åland's transport seems interesting in light of a seeming local willingness to adopt to new, efficient technologies. Already, another area of the Nordic region, Norway, is considering high levels of future transport electrification by making conditions unfavourable for non-electric vehicles by 2025

Table 1
Key Åland statistics.

Åland facts 2014	Unit	Value
Capital		Mariehamn
Population in 2014		28,983
Population expected by 2030		33,000
Number of islands		6757
Number of inhabited island		60
Total electricity supply	GW h_e	288.4
Domestic electricity production	GW h_e	70.1
From oil	GW h_e	11.7
From bioenergy	GW h_e	1
From wind	GW h_e	57.4
From Sweden	GW h_e	200.7
From Finland	GW h_e	17.6
Total heat supply to district heating	GW h_{th}	115
From oil	GW h_{th}	15
From biomass	GW h_{th}	100
Share of district heating in total heat supply		40%
Length of district heating network	km	66.4
Biomass use in households (estimated)	GW h_{th}	20
Total transport demand	GW h_{th}	227
Gasoline demand	GW h_{th}	129
Diesel demand	GW h_{th}	98
Number of cars and vans		26,636
Number of lorries and buses		841
Number of motorcycles, mopeds and tractors		7625
Total road transport demand (estimated)[a]	Million pkm	250
Number of large marine vessels		112
Number of recreational watercraft		~7000

[a] Based on usage of transport fuels stated above and an assumed conversion of 1.5 km/kW h_{th} of fuels (6.7 L/100 km of diesel and 7.4 L/100 km of petrol).

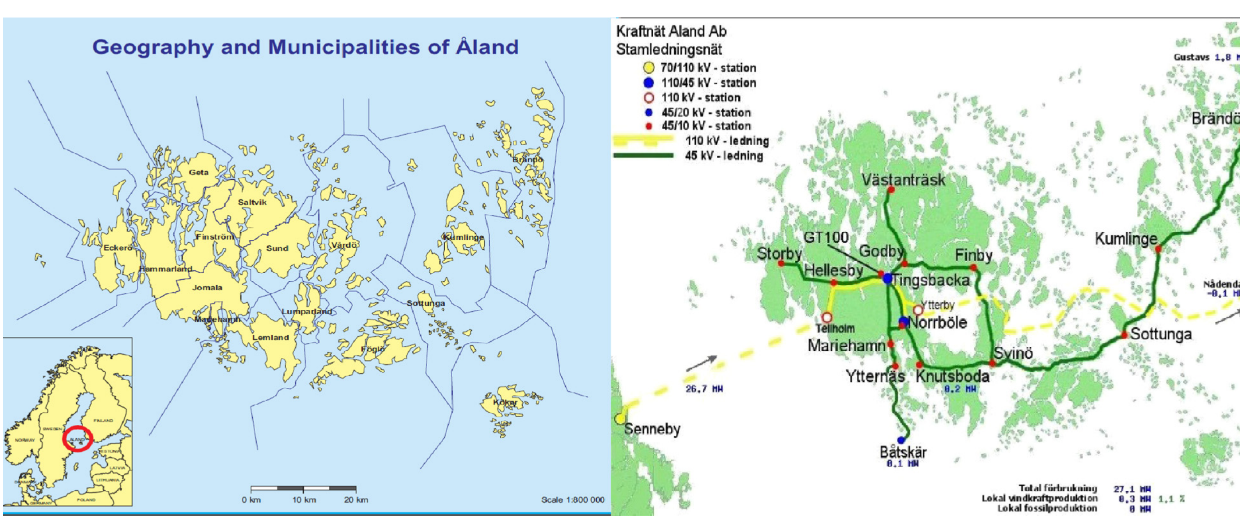

Fig. 1. Location of Åland and interconnections with Sweden and mainland Finland. Source: [8] (left), [9] (right).