ENERGY IN THE WEST NORDICS AND THE ARCTIC

SCENARIO ANALYSIS

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Jakob Nymann Rud, Morten Hørmann, Vibeke Hammervold, Ragnar Ásmundsson, Ivo Georgiev, Gillian Dyer, Simon Brøndum Andersen, Jes Erik Jessen, Pia Kvorning and Meta Reimer Brødsted

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Foreword

The following report is the result of a study undertaken by COWI on behalf of Nordic Energy Research, the platform for cooperative energy research and policy development under the auspices of Nordic Council of Ministers. Nordic Energy Research's mandate for creating knowledge to support energy and climate targets in the Nordics applies not just to the larger countries of the Nordic region, but also the more sparsely populated areas of the West Arctic; Greenland, Iceland, Faroe Islands, Jan Mayen, Svalbard and Arctic Ocean areas nearby these lands. These areas present unique energy challenges, as well as unique opportunities. By studying the energy systems in these areas we can learn how to create a more sustainable, more energy-independent arctic region, and begin to apply the lessons learned from these regions to energy systems elsewhere in the world.

We would like to thank all those who have participated in this process.

Hans Jørgen Koch
Director, Nordic Energy Research

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Additional materials, press coverage, presentations etc. can be found at www.nordicenergy.org

List of abbreviations

- 2DS 2 – Degree scenario
- BAU – Business as Usual
- BKER – Bio kerosene
- CNS – Carbon neutral scenario
- COA – Coal
- DSL – Diesel
- GEO – Geothermal power
- GHG – Greenhouse gas
- GSL – Gasoline
- HFO – Heavy fuel oil. Primarily used for maritime transport.
- HYD – Hydropower
- IEA – International Energy Agency
- KER – Kerosene. Used primarily for aeroplane fuel
- NETP – Nordic Energy Technology Perspectives
- NUC – Nuclear power
- PV – Photo-voltaic
- SLU – Waste
- SOL – Solar power
- WIN – Wind power

1. Executive summary

This report aims to identify the most cost-effective paths for reaching a sustainable 2035 scenario and supporting the Arctic and West Nordic region in reaching its long-term climate and energy commitments. The study focuses on Greenland, Iceland, the Faroe Islands, Jan Mayen and Svalbard.

The Arctic region consists of island nations or regions with no interconnections between national grids or connections to the mainland grids in Europe or North America. As a result, they have developed “off-grid” micro-grids. Therefore, such areas are largely dependent on local generation capacity as well as fuel imports to supply electricity and heat to their populations. This creates opportunities to generate clean distributed energy.

The prospect of connecting the Arctic islands is a recurring discussion. The benefits are security of supply and economies of scale through being able to supply a larger demand from fewer large generating units. However, the costs of laying power cables at sea over stretches of hundreds of kilometres are considerable. This study takes inventory of existing studies on connectors in the Arctic region.

As part of the Arctic, the areas are characterised by long, cold winters and short, cool summers. Such weather conditions usually require heating during the whole year. Thus, a less fluctuating energy demand for heating services provides favourable conditions for optimisation of the available thermal capacities.

The Arctic regions rely heavily on maritime transport. The vast majority of trade in goods to and from the Arctic relies on maritime transport, and fishing is a major economic activity in the region. Fishing constituted almost half of the total value of exports from Iceland in 2016.¹ In Greenland² and the Faroe Islands,³ more than 90% of the total value of exports was generated by fishing. The fishing sector is thus a critical part of the Arctic region. Addressing the challenge of converting maritime transport from fossil fuels to renewable energy is a central aspect of this study.

1.1 The Arctic in numbers

In terms of primary energy consumption, Iceland consumes some 92% of the total energy consumed in the five Arctic regions. The remainder of the energy consumption is split evenly between Greenland and the Faroe Islands. The energy consumption of Svalbard and Jan Mayen is negligible.

¹ Hagstofa.is UTA06105.

² Stat.gl IEX2PROD.

³ Hagstova.fo UH01040.

Figure 1: Total energy consumption in the West Arctic region

In Greenland, the Faroe Islands, Svalbard and Jan Mayen, the share of renewable energy in the primary energy supply is less than 15%, with Greenland at roughly 15%. The energy supply in Iceland has a significantly different profile. Renewable energy covers some 87% of the total primary energy supply, primarily in the form of geothermal energy and hydropower.

Figure 2: Distribution of primary energy sources

1.2 Methodology

The scenario analysis is based on TIMES modelling combined with more traditional techno-economic cost-benefit analyses. Since the five Arctic regions are not interconnected today, the results are based on multiple model runs and cost-benefit analyses, as each area has been analysed separately.

The TIMES model was developed by the International Energy Agency (IEA) through its Energy Technology Systems Analysis Program (ETSAP).⁴ TIMES is an optimisation tool which seeks to minimise system costs subject to any number of user defined constraints, e.g. CO₂ emissions. The tool that IEA-ETSAP provides is devoid of any data. The user must provide the model with all the necessary data to properly reflect the energy system being analysed. The energy systems in Iceland, Greenland and the Faroe Islands have been analysed using TIMES.

Techno-economic cost-benefit analyses were conducted for Svalbard and Jan Mayen. Such analyses work well for less complicated decision-making and to test specific solutions rather than sorting through a broad selection of options. In Svalbard and on Jan Mayen, the energy systems are fairly simple. Power and heat is delivered almost exclusively from one main generating unit. Consumption patterns for heating and electricity are fairly homogenous and predictable, as the number of consumer types is limited, and heating is needed year-round. Thus, identification of the most probable candidate for a least costly path to renewable energy is more or less straightforward.

1.2.1 Scenario definitions

The scenarios analysed in this report concern the future development in greenhouse gas (GHG) emissions from human activity in Greenland, the Faroe Islands, Iceland, Jan Mayen and Svalbard. The scenario definitions are based on the IEA 2050/2100 projections and NETP 2016.⁵ The scenarios have been further transformed to fit the model framework used in this study. The final scenario definitions are shown in the table below.

Table 1: Overview of scenario definitions for all areas

CO ₂ tonnes per capita	Greenland	Iceland	Faroe Islands	Svalbard and Jan Mayen
BAU	<i>Unrestricted</i>	<i>Unrestricted</i>	<i>Unrestricted</i>	<i>Unrestricted</i>
2DS	4	4	5	20
CNS	1	1	1	1

This is described further in section 4.3.

⁴ <https://iea-etsap.org/>

⁵ <http://www.nordicenergy.org/wp-content/uploads/2016/04/Nordic-Energy-Technology-Perspectives-2016.pdf>

1.3 Technologies

1.3.1 *Heat pumps and heat storage*

A unifying theme in the Arctic is the need for year-round heating. Rarely does the temperature reach levels at which indoor heating can be turned off entirely. Electrification of heating also presents a unique opportunity for storing energy from intermittent sources like solar and wind power.

We have provided the TIMES model with two options for electrification of heating. One is a heat pump (HP) with a high CAPEX, but also a very high efficiency (3 units of heat per unit of electricity). The other is a more conventional electric boiler (EB) with a very low investment cost, but correspondingly low efficiency (0.85 units of heat per unit of electricity). Both options include heat storage with the capacity to produce 24 hours' worth of heat during night-time.

In the analysis, heat storage is based on short-term (daily) storage in hot water tanks. The technology is quite common and can be seen in many district heating systems. With daily use, the heat loss is insignificant. In future, new emerging technologies, such as storing heat in the ground and in the rocks/mountains, could be relevant.

1.3.2 *Low Wind Speed turbines*

Conventional wind turbines typically have a narrow range of wind speeds at which they can produce electricity. Outside that range, they either cannot produce electricity or have to be shut down in order to prevent damage. In Greenland and Svalbard, wind speeds do not conform to the standard wind speed ranges (typically, they are too low).

Recent innovations in wind turbine design may allow regions with low average wind speed and high variability to enjoy the benefits of wind power. Cross-flow (CF) wind turbines promise a fast ramp up and high efficiency at very low wind speeds (~1 m/s).⁶ CF wind turbines are still considerably more expensive than conventional wind turbines (in the order of twice as expensive per unit of power), but in regions with weak winds, they offer a higher energy yield per unit of capital expenditure. In Greenland, which is a prime candidate for LWS turbines, a conventional wind turbine would have a utilisation rate of 2–3% (not feasible at all) whereas a LWS turbine would have a utilisation rate of 15–25% (very reasonable).

⁶ <https://www.lws-systems.com/en/>. The cross-flow wind turbine being used in the Igaliku pilot project in Greenland.

1.3.3 *Hydrogen fuel cells*

Hydrogen production, storage and conversion have led a quiet life in the shadows of more straightforward battery technologies. Critics of hydrogen will emphasise security concerns, efficiency losses and the lack of technological maturity. Advocates of hydrogen will emphasise flexibility, energy storage capabilities, synergy with intermittent renewable energy sources like wind and solar power and the lack of any real alternatives for very energy-intensive non-stationary uses, like ocean-going fishing vessels, cargo vessels and aeroplanes.

In the scenario analysis, hydrogen-fuelled ships are not considered available in the Arctic Region before 2025. By that time, hydrogen-fuelled ships are assumed to have moved beyond the pilot testing phase.

1.3.4 *Tidal and wave power*

Because of the vast coastline and most of the population living by the sea in this region, tidal and wave power is quite relevant. However, due to the current status of development these technologies still really only found at the commercial level and is therefore not included in this analysis.

1.4 General results

1.4.1 *Electrification of heating is a must*

In the Faroe Islands, Greenland, Jan Mayen and Svalbard, a very large proportion of all space heating is based on fossil fuels. In Iceland, only a very small proportion (0.5%) of space heating remains based on fossil fuels. The results of the TIMES model runs show that all heating in the Faroe Islands, Greenland, Jan Mayen and Svalbard will be converted to electricity before 2020 and regardless of the remaining technical life of the installations.

The technology is mature, and prices are competitive with fossil fuels. The difference in total cost between electrification and fossil fuels is still so small that consumers may not feel it is worth the effort to convert, and even minor distortions from taxes could tip the scale in favour of fossil fuels.

1.4.2 *Renewable energy will become the least costly choice*

The scenario analysis shows that the technologies needed for a transition to renewable energy exist, and their prices are expected to become competitive within a very short timeframe. The major barriers to a green transition are no longer the availability or price of relevant technologies. What is needed now is not further public funding of R&D, but rather a political focus on removing taxes and regulation that distort the competition between technologies.

1.5 Greenland

From a purely economic planning perspective, Greenland has the potential to make a quick and low-cost transition to a low emission society. The first and most pressing task is to electrify all heating. This is a task that should be economically feasible today.

The main challenges in Greenland consist of regulatory and financial barriers. Energy prices are heavily regulated in order to provide equal opportunities for all Greenlanders regardless of where they live. State subsidies to support private investments must be available to all, even though the same investments may not be relevant in all locations. The average income is generally low, which adds to the challenge of financing the necessary private investments.

The scenario analysis has also shown that there are very large differences between the optimal paths for towns and settlements in Greenland.

In Nuuk, the main challenge will be balancing increased electrification with the need for higher energy efficiency throughout, in order not to exceed the capacity of the existing hydropower plant.

In Ilulissat, there is not much need for energy efficiency, due to the very large excess capacity of the hydropower plant. Instead, heating should be converted to electric boilers at the earliest convenience.

In the small settlements in Greenland, exemplified by Atammik, the path to reduced emissions is less straightforward. The solutions offered in the scenario analysis have a high resemblance to the hybrid system being tested in Igaliku. Even though the exact solution to renewable power generation is still being tested, there is little doubt that the first steps to a low-emission settlement lies in electrification of heating – preferably using heat pumps.

1.6 Iceland

The key to a low carbon emission future in Iceland lies in the transport sector. The scenario analysis suggests that full electrification of the transport sector will become the least-cost path within the next 20 years - making electric vehicles less expensive than fossil fuelled vehicles. This does not mean it will happen by itself. Taxes and regulation can have very serious distortionary effects on crucial investment decisions. As discussed in section 6.2, the prices of renewable energy technologies have reached a level at which they are beginning to be economically competitive with fossil fuel technologies. If taxes and regulation can be designed in a way that does not distort the economic balance between technologies, then electrification of transport will be privately profitable in the near future. This leads to a situation of almost all CO₂ emissions being eliminated by 2035 without subsidising electric vehicles or electrification in general.

Today, Iceland relies almost exclusively on hydropower and geothermal power. However, the utilisation of the existing reservoirs is close to the limit. At the same time, Orkustofnun expects limited development of greenfield geothermal projects and large

reservoirs. In a future with increased electrification of the transport sector and the fishing industry, new electric generation capacity is expected to include wind power and small distributed hydro- and geothermal powerplants. By 2035, the model projections suggest that an additional 130 MW of wind turbines will have been installed.

1.7 Faroe Islands

The scenario analysis shows that the Faroe Islands have a challenge in reaching the carbon-neutral emission target of 1 tonne of CO₂ equivalents per capita. Removal of any distortionary regulation and taxes will create the foundation for large reductions in emissions. However, the dependence on intermittent power generation for a large proportion of the energy supply will require economic incentives to make the final transition to the carbon-neutral emissions target.

Maritime transport and fishing are the primary challenge that must be overcome to reach the 1 tonne target. The scenario analysis suggests that hydrogen fuel cells could be a cost-efficient solution. However, hydrogen production has a very low efficiency, which does not correlate well with an energy system that relies on relatively costly wind power. On the other hand, not all the benefits of the energy storage capabilities of hydrogen could be taken into account in the TIMES model. The dual role of hydrogen as fuel and electric storage medium should be explored further.

As in many of the other Arctic regions, in the Faroe Islands, electrification of heating is a low-hanging fruit. The main barriers to this transition are distortionary energy taxes and lack of private financing options for low-income households. Even today, the total cost (before taxes) of heating from heat pumps and electric boilers is lower than that from fossil fuels. This cost difference will only become greater as the cost of heat pumps continues to decrease.

1.8 Svalbard

The main challenge in Svalbard will be the closing of the local coal mine within the next 10 years. Most electricity and heat in Svalbard comes from the coal-fired plant. The solutions being explored include a transmission cable to mainland Norway, in addition to wind and solar power. Solar energy could be relevant if the power were to feed into a better controlled energy system (fuel-based). During summer, much energy could be produced (almost 24 hours a day) but there will be no solar power production in winter, when power consumption is significantly higher than in summer. A controlled energy system is understood as a fuel-based system in which production of energy can be scheduled, such as with a generator. Wind power looks to be a much more promising solution, as wind is available year-round. If wind power is introduced on a large scale, there will be no demand for solar power in summer. Smart energy consumption and energy efficiencies in consumption will be a very important focus. If the amount of electricity consumed by smart units is increased, it will reduce the need for batteries and increase the utilisation of wind power.

1.9 Jan Mayen

Energy consumption on Jan Mayen is concentrated in the summer half of the year. This provides a clear opportunity to base the energy system on solar power. Solar power will have very high utilisation time because of the island's location north of the Polar Circle; solar power thus seems to be ideal for Jan Mayen. Wind power could be relevant as a supplement during summer, but its utilisation will be very low as there is no energy consumption in winter. Smart energy consumption and energy efficiencies in consumption will be a very important focus. If the amount of electricity consumed by smart units is increased, it will reduce the need for batteries and increase the utilisation of solar power.

2. Introduction

This report aims to identify the most cost-effective paths for reaching a sustainable 2035 scenario and supporting the Arctic and West Nordic region in reaching its long-term climate and energy commitments. The study focuses on Greenland, Iceland, the Faroe Islands, Jan Mayen and Svalbard.

All of these areas have many similarities. For example, they are relatively remote and are not inter-connected with transmission infrastructure to the continents of Europe or North America. As a result, they have developed “off-grid” micro-grids. Therefore, such areas are largely dependent on local generation capacity as well as fuel imports to supply electricity and heat to their populations. This creates opportunities for clean distributed energy generation.

As part of the Arctic, the areas are characterised by long, cold winters and short, cool summers. Such weather conditions usually require heating during the whole year. Thus, a less fluctuating energy demand for heating services provides favourable conditions for optimisation of the available thermal capacities.

All areas are sparsely populated except the capital area of Reykjavik, with the majority of inhabitants located next to the coastal areas due to prospects for fishing and maritime transport. The fishing industry is an essential source of income and also an essential food source for the local inhabitants. The ships in the fishing industry, however, are typically fuelled by fossil fuels, which creates a significant potential for new technologies and would contribute to a reduction of related CO₂ emissions.

2.1 Energy in the Arctic

In terms of primary energy consumption, Iceland consumes some 92% of the total energy consumption in the five Arctic regions. The remainder of the energy consumption is split evenly between Greenland and the Faroe Islands. The energy consumption in Svalbard and on Jan Mayen is negligible.

Figure 3: Total energy consumption in the West Arctic region

In terms of energy consumption per capita, the picture is reversed. Iceland is still the largest consumer, but Jan Mayen and Svalbard consume more than twice as much per capita as Greenland and the Faroe Islands. By comparison, the average energy consumption per capita in all the Nordic countries is on level with the Faroe Islands and Greenland, and significantly lower than in Iceland, Svalbard and Jan Mayen.

Figure 4: Energy consumption per capita (GJ/capita)

In Greenland, the Faroe Islands, Svalbard and Jan Mayen, the share of renewable energy in the primary energy supply is less than 15%, with Greenland at roughly 15%. The energy supply in Iceland has a significantly different profile. Renewable energy covers some 87% of the total primary energy supply primarily in the form of geothermal energy and hydropower.

Figure 5: Distribution of primary energy sources

Note: Note: In the data for the Nordic countries, "hydropower" covers hydropower and geothermal power. The source data (NETP) did not provide a disaggregation of these two.

Although the renewable share of the energy supply in Iceland is second to none globally, their CO₂ emissions per capita are equal to or higher than those of Greenland and the Faroe Islands. This is mainly due to emissions from industrial processes like aluminium smelting. In Svalbard and on Jan Mayen, there is no renewable energy, resulting in relatively higher emissions per capita.

Figure 6: Key indicators of climate impact

The energy sectors in the five regions in this study face very different challenges in the pursuit of CO₂ reductions and a greener profile. The energy sector in Iceland is basically fossil-free. In Greenland and the Faroe Islands, the energy sector is still dependent on fossil fuel for grid stability and micro-grid supply. On Jan Mayen and Svalbard, fossil fuels are still the primary source of energy.

Aside from the challenges in the energy sector, the regions face similar challenges in transport, fishing and tourism. Electrification of land transport is still under development – especially in the Arctic, where freezing temperatures limit the effectiveness of standard batteries. Sea transport and fishing are essential to the Arctic. At the same time, the energy consumption of large ships strains the limits of how much energy can realistically be

delivered using today's battery technologies. Tourism in the Arctic is rapidly developing, which may be an opportunity as well as a risk to green development.

2.2 Structure

Section 3 discusses a selection of unifying themes in energy consumption in the Arctic. In section 4, we describe the data and method employed in this scenario analysis. Section 5 concerns the most important future technologies which were included in the scenario analysis. In section 6, we describe general results, which apply to all regions in the study. In sections 7 through 11, we elaborate on the results for each region. Section 12 is a comprehensive list of literature and data sources.

3. Cross-cutting themes

In this section, we highlight some of the unifying themes in the Arctic.

3.1 Interconnectors

The Arctic region consists of island nations or regions with no interconnections between national grids or connections to the mainland grids in Europe or North America. The prospect of connecting one or more of the Arctic islands is a recurring discussion. The benefits are security of supply and economies of scale through being able to supply a larger demand from fewer large generating units. However, the costs are considerable when laying power cables at sea over stretches of hundreds of kilometres.

3.1.1 *Trans-Arctic cable*

The most comprehensive interconnection system analysed within this region is study on a cable network from southwest Norway to the east coast of Greenland which would be able to transport electricity between the electricity grids of Norway, the Shetland Islands, the Faroe Islands, Iceland and Greenland. The analysis was a joint effort supervised by Jarðfeingi and Orkustofnunin in 2015 (published in 2016) for a number of authorities and research institutions in Norway, Iceland, Greenland, the Faroe Islands, the Shetland Islands and Denmark.⁷

The North Atlantic Energy Network Project investigated how small isolated energy systems can be connected to an electrical network grid and onwards to the European market. The Project focuses on Greenland, Iceland, the Faroe Islands, Shetland, Norway and offshore companies in the area. The purpose of the Project was to examine whether it is possible to connect these communities via undersea electric cables.

The Faroe Islands, Iceland and the Shetland Islands have great wind power potential. Iceland and Greenland have great hydro-power potential. In addition, Iceland also has greater geothermal power potential than is currently being utilised. In terms of energy balance, it could be relevant for each area to produce power based on its resources and exchange electricity when needed with the neighbouring areas. This would only be possible through a strengthening of the Icelandic and Greenlandic power infrastructure. Especially in Greenland, it would be necessary to extensively upgrade, strengthen and expand the power infrastructure. As of now,

⁷ "North Atlantic Energy Network – January 2016", Orkustofnun (OS) – National Energy Authority of Iceland; Norges Arktiske Universitet (UiT) – The Arctic University of Norway; Energistyrelsen – Danish Energy Agency; Jarðfeingi – Faroese Earth and Energy Directorate; Shetland Islands Council – Economic Development Service; Greenland Innovation Centre.

there is no way to transport the power from the east coast of Greenland to the west coast, where the majority of the population lives. However, the costs of establishing a cable of this length would be extremely high – especially when looking at the actual electricity exchange needs. Most of the areas have rather small electricity demands.

3.1.2 *From The Faroe Islands to the Shetland Islands*

A cable from the Shetland Islands to the British mainland (Scotland)⁸ has been planned for some time and is still a realistic project. If the Shetland Islands are connected to the British mainland, a cable from the Faroe Islands to the Shetland Islands could be relevant. The Faroe Islands (as well as the Shetland Islands) have high wind power potential, which could be utilised with a larger demand. However, a cable would be quite expensive.

3.1.3 *From Iceland to Scotland*

For decades, studies have investigated the feasibility of a cable from Iceland to Scotland.⁹ With regard to utilising the energy system possibilities in Iceland, the project is quite relevant. The project could be feasible as well. However, with planned cables from both Norway and Denmark to the UK, fluctuations in electricity prices in the UK could be reduced. Also, if Iceland electrifies land and sea transportation, the supply potential from Iceland could be reduced. The project is, however, very relevant and, as of mid-2016, both countries still express their interest in the project.

3.1.4 *From the Norwegian Mainland to Svalbard*

A cable from the Norwegian mainland to Svalbard¹⁰ is very relevant – at least as soon as the coal mine at Svalbard is shut down. As of now, there is very low-cost electricity production from coal. When the mine is closed, Svalbard should either convert their energy system to one without coal or be connected to the Norwegian mainland through a transmission line. Both scenarios will result in high investment costs. The company ABB has estimated the investment costs for the cable would amount to approx. EUR 300–500 million. The project could be feasible, but it could very well be cheaper to produce energy locally. An important advantage of the cable, however, is security of supply, which could be an issue if staying off-grid without a local power plant based on local resources (coal).

⁸ <https://www.ssepd.co.uk/ShetlandEnergy/>

⁹ <https://www.landsvirkjun.com/researchdevelopment/research/submarinecablotoeurope>

¹⁰ <http://www.highnorthnews.com/norwegian-government-submarine-power-cable-to-svalbard-not-realistic/>

3.1.5 From Iceland to Greenland's East coast

A cable from Iceland to Greenland would be interesting seen from an energy balance point of view. Iceland has the potential for more renewable electricity production and could supply electricity to Greenland (which has a much smaller electricity demand than Iceland). However, besides the high investment costs of establishing the sea cable, there are still issues regarding the Greenlandic power infrastructure, and that is a project which needs to be addressed as well. The vast majority of Greenlandic settlements are located on the west coast of Greenland, necessitating additional transmission lines down along the southern coast or straight across the Greenland Ice Cap.

3.2 Maritime transport (including fishing)

The Arctic regions rely heavily on maritime transport. The vast majority of trade in goods to and from the Arctic relies on maritime transport, and fishing is a major economic activity in the region. Fishing constituted almost half of the total value of exports from Iceland in 2016.¹¹ In Greenland¹² and the Faroe Islands¹³ more than 90% of the total value of exports was generated by fishing. The fishing sector is thus a critical part of the Arctic region.

Maritime transport is almost exclusively based on fossil fuels and very few renewable alternatives are presently available. As fuel costs are a large part of total costs associated with maritime activities, there are many ongoing activities aimed at increasing fuel efficiency. As an example, Royal Greenland is investing more than DKK 700 million in two new state-of-the-art fishing vessels which will greatly improve the efficiency of the fishing fleet.¹⁴ In Iceland, an innovative whale-watching tourist company has developed a sailboat which also runs on an electric motor connected to a battery that charges while sailing.

3.3 Climate hardening

The Arctic regions in this analysis cover a wide range of climatic conditions, from the very mild Faroe Islands to the bitterly cold North Greenland and Svalbard. In the areas where winter temperatures regularly fall below -10 degrees Celsius the performance of batteries may become a challenge. Several battery developers are investing in R&D on this topic, and a few solutions have reached a pilot testing stage.

For batteries in vehicles, the proposed solutions focus on making the chemical reactions in the batteries more resistant to cold while at the same time maintaining the

¹¹ Hagstofa.is UTA06105.

¹² Stat.gl IEX2PROD.

¹³ Hagstova.fo UH01040.

¹⁴ Royal Greenland Annual Report 2015.

same performance as conventional batteries.¹⁵ For stationary batteries, the same solutions could be applied, but a simpler approach is to insulate the batteries and use excess heat or even heat pumps to keep the temperatures in the batteries stable. This low-tech approach of insulation and heating is already being offered as a “cold weather package” by some producers of large scale battery backup solutions.¹⁶

Any large-scale electrification of the transport sector in the Arctic needs to address the cold temperature capabilities of the batteries and hardware used.

3.4 Biomass

Many countries rely on biomass to reduce carbon emissions. The main advantages are the continuation of energy production based on combustion, where the production is controlled (unlike for wind and solar energy). In the Arctic and West Nordic areas, biomass for energy mainly consists of organic waste. In Greenland and the Faroe Islands, solid waste is primarily converted to district heating. In Iceland, there is an ongoing recycling effort in accordance with EU regulations. As an example, methane is collected from landfills and used to power vehicles and a gas-fired power plant.¹⁷

There is a natural limit to the energy that can be produced from solid waste. Beyond this limit, further use of biomass would require imports. Considering the availability of other renewable energy sources in the Arctic (e.g. wind, hydro, geothermal), importing biomass does not seem economically viable.

Although a very important part of the low-carbon energy system, biomass is also seen as a transition fuel. As the demand for biomass increases significantly, it will be difficult to ensure sustainability. Biomass has a very high CO₂ emission factor which is offset by an equally high absorption when it grows (thus making it “carbon neutral”). If the growth in the use of biomass for combustion results in a situation where the biomass cannot regenerate/grow fast enough to meet demand, then the biomass will no longer be carbon neutral.¹⁸ The long-term objective for many countries is to convert the energy system into fuel-free systems. This is actually what the Arctic and West Nordic countries are doing now, and which also will be central for the scenario analysis in this report.

¹⁵ For an in-depth review of the most promising solutions please refer to the case on land transport in the Case study report.

¹⁶ <https://www.saftbatteries.com/products-solutions/products/intensium%C2%AE-max-megawatt-energy-storage-system>, e.g. NTPC case study.

¹⁷ <https://askjaenergy.com/iceland-renewable-energy-sources/green-fuel/biogas-green-methane/>

¹⁸ <https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/land-use-change>

4. Methodology

This section provides an outline of the methodology employed in the scenario analysis. This includes the main sources of data, definitions of scenarios, a short description of the modelling tools and key simplifying assumptions.

4.1 Data collection

The data collection has covered five separate Arctic regions and many separate sources within each region. In addition, comes all the data collected on future trends in technology, prices and efficiencies. Some data has been available online, other data has been provided by a number of local stakeholders.

4.1.1 *Iceland*

The main source of data for fuel consumption is Eurostat. This data is in tonnes and the conversion to energy (PJ) was carried out in collaboration with the Orkustofnun (National Energy Authority of Iceland) – the original provider of data to Eurostat. Other main data sources are:

- Landsnet (TSO – Transmission System Operator)
- Samgöngustofa (Transportation Institute)
- Þjóðskrá Íslands (Registers Iceland)
- Hagstofa Íslands (Statistics Iceland)
- Landsvirkjun (National power company and the largest producer of electricity in Iceland)
- Icelandic government (energy policies)
- Umhverfisstofnun (Environmental Agency of Iceland)
- The aluminium industry (Alcoa, Rio Tinto, Norðurál/Century aluminium).

4.1.2 *Greenland*

The energy balance for Greenland was constructed based on data from Statistics Greenland. Breaking down the energy balance into the three model areas involved data from Polar Oil on the sales of oil to each village/town in Greenland.

Data on power and heat generation facilities was provided by Nukissiorfiit – the national utility company. Data on transport and fishing came from Statistics Greenland and various annual reports and interviews.

4.1.3 *The Faroe Islands*

Most data concerning the Faroe Islands has been collected through direct contact to relevant institutions. Especially the environmental agency, Umhvørvisstovan (US), and the electricity company, SEV, have contributed with much information and provided assistance.

Oil consumption data is from the Hagstova Føroya (National Statistical Authority). This consumption has been divided by type of consumption (residential heating, electricity generation, fishing etc.) with assistance from the US.

Electricity production data – amount of production along with the production facilities – has been supplied by SEV.

Data concerning the district heating system in Torshavn has been collected from multiple sources. Torshavn Municipality supplied data concerning the heat delivered from the local waste incineration plant and other data regarding this plant. The district heating company (Fjarhiti) supplied data concerning the remaining heat supply to the district heating system and other data regarding the system.

Data concerning the waste incineration plant east of Leirvík was supplied by IRF.

4.1.4 *Svalbard and Jan Mayen*

For Svalbard, some data has been delivered by the chief of energy at the energy plant Kim Rune Røkenes. Other data has been gathered from the Norwegian statistical authority Statbank.

For Jan Mayen, some data has been delivered by the station chief. Other data has been gathered from the protection plan for Jan Mayen.¹⁹

4.1.5 *Future technologies*

The future development in prices and efficiencies of new and existing technologies plays a central role in the scenario analyses. Data for the majority of the technologies comes from two main sources:

1. Alternative fuels for transport from the Danish Energy Agency provides a wide knowledge base on fuels and vehicles for road, air and sea.²⁰

¹⁹ "Verneplan for Jan Mayen" – The Norwegian Directorate for Nature Management, 2007.

²⁰ <https://ens.dk/service/fremskrivninger-analyser-modeller/modeller>

2. *Kostnader i energisektoren* from the Norwegian Water Resources and Energy Directorate is a comprehensive guide to power and heat production technologies with data on prices and efficiencies.²¹

4.1.6 Energy Efficiency

Energy efficiency is central to the EU agenda of reducing its dependency on energy imports and fossil fuels and reducing greenhouse gas emissions.²² Recently, the Energy Efficiency Financial Institutions Group (EEFIG) has published a dynamic and interactive database of energy efficiency projects across the EU called DEEP (De-risking Energy Efficiency Platform).²³ DEEP will facilitate benchmarking and transparency in the calculation of economic benefits of energy efficiency investments.

The DEEP database is used for inputs on the cost and impact of energy efficiency investments in the residential, commercial and industrial sectors. In each of these sectors, the TIMES model was given the choice of investing (or reinvesting) in production technologies with and without energy efficiency measures.

4.2 Analysis tools

The scenario analysis is based on TIMES modelling combined with more traditional techno-economic cost-benefit analyses. As the five Arctic regions are not interconnected today, the results are based on multiple model runs and cost-benefit analyses, as each area has been analysed separately.

The TIMES model has been developed by the International Energy Agency (IEA) through its Energy Technology Systems Analysis Program (ETSAP).²⁴ TIMES is an optimisation tool, which seeks to minimise system costs subject to any number of user defined constraints, e.g. CO₂ emissions. The tool that IEA-ETSAP provides is devoid of any data. The user must provide the model with all the necessary data to properly reflect the energy system being analysed. The energy systems in Iceland, Greenland and the Faroe Islands have been analysed using TIMES.

Techno-economic cost-benefit analyses were conducted for Svalbard and Jan Mayen. Such analyses work well for less complicated decision-making and to test specific solutions rather than sorting through a broad selection of options. In Svalbard and on Jan Mayen, the energy systems are fairly simple. Power and heat is delivered almost exclusively from one main generating unit. Consumption patterns for heating and electricity are fairly homogenous and predictable as the number of different consumer types is limited and heating is needed year-round. Thus, identification of the most probable candidate for a least costly path to renewable energy is more or less straightforward.

²¹ <https://www.nve.no/energiforsyning-og-konsesjon/energiforsyningsdata/kostnader-i-energiesektoren/>

²² <http://eefig.eu/index.php>

²³ <https://deep.eefig.eu/>

²⁴ <https://iea-etsap.org/>

Figure 7: Overall structure of the TIMES ETSAP model.

4.2.1 TIMES Model Simplifications

The TIMES model is a very large and complex tool, and yet, the results are only as good as the data that is fed into the model. At the same time, it is vital to keep in mind that it is only a model. Models are an approximation of reality meant to highlight a few elements in a complex world. Building a model then becomes a trade-off between details, effort and expected payoff/precision. There is also a need to be very pragmatic in relation to data availability. In order to reach a reasonable balance in the TIMES models of Iceland, Greenland and the Faroe Islands, several simplifications have been made:

Marginal and niche energy consumption is left out

The focus of the model for this scenario analysis is the broad and long-term picture, i.e. “how do we reduce greenhouse gas emissions to a level that complies with international ambitions?”. In that light, some of the more marginal energy consumption has been left out or lumped together. This includes bio-gas production and consumption, minor imports of biofuels and arctic gas-oil for very cold climates.

As described in section 3.4, biomass will most likely provide only a marginal contribution to carbon emission reductions in the Arctic due to a scarcity of local sources. At the same time, the scale of this energy consumption is insignificant today.

The only difference – in modelling terms – between Arctic gas-oil and regular gas-oil is the price difference, but compared to other uncertainties, the precision provided by making this distinction in the model does not justify the effort involved.

No taxes or Regulation

Taxes and regulation can have a highly distorting effect on the economic choices of consumers and private and public enterprises. In countries with e.g. high taxation of

electricity, electric vehicles and heating may be at an economic disadvantage which is much greater than the simple difference in commodity prices.

The energy systems in the Arctic region today are all the result of a complex interaction between regulation, taxes and commodity prices. However, properly reflecting these complexities – specific to each country in the region – in a model environment is a monumental task. Trying to model complex taxes and regulation would also move the focus of the scenario analysis away from technology choices towards policy choices.

As a consequence, no taxes and no regulation are included in this scenario analysis. The underlying assumption is that governments are able to redesign taxes and regulation in a way that ensures the same expected tax revenues while removing any distortionary effects. In that situation, any tax revenues will be a simple transference of wealth, which has no impact on the total system costs of different technology choices. In this environment, technology choices will be made based on the lowest total system cost rather than e.g. the lowest possible tax payment.

As the TIMES model is allowed to optimise the future energy system, the results presented later in this report show that the model predicts substantial changes within a very short time. This happens because the data for the base year 2015 are the result of a long history of taxation and regulation, while the model is allowed to optimise in a future environment without distortions. This could be an indication that taxes and regulation are in fact distorting economic choices today and quite possibly stand in the way of the least costly green transition. This will be discussed further when the results are presented.

Cost premiums for emerging technologies

The technologies employed in the scenario analysis are, to a large extent, off-the-shelf products. Some are proven technologies being applied to new sectors – e.g. fuel cells in ships – others have seen rapid growth in recent years – e.g. heat pumps. In the few cases where we have used emerging technologies that have not yet reached market maturity, we employ significant cost premiums. These cost premiums will decline over time, as the technology matures and, in some cases, comes into direct competition with more established and conventional technologies. Such an evolution in price is often described using a learning curve²⁵ which typically describes an exponential decay in prices. The decline in prices will be greatest in the beginning, and as the price over time converges towards more conventional competing technologies, the decline in price slows down.

One technology which has been subjected to price premiums and learning curves is climate-hardened batteries.²⁶ Since these batteries are still in the R&D phase, there is no available data on prices, so input data for the scenario analysis has been based on estimates of both level and rate of convergence with regular batteries. The materials and processes involved in producing climate-hardened batteries are not excessively expensive, which

²⁵ For more on learning curves see e.g. Norwegian Water Resources and Energy Directorate (2015). "Kostnader i energisektoren" (Costs in the Energy Sector).

²⁶ For further details, see the case on land transport in the Case study report.

means that the primary driver of price premiums on climate-hardened batteries will derive from R&D and market access. With that in mind, the price premium on climate-hardened batteries over regular batteries is estimated to be high (75% in 2020) but expected to decline rapidly (34% in 2035). This corresponds to a 25% reduction in price every 5 years from a level close to twice the price of conventional batteries today.

Another technology that employs learning curves is low wind speed wind turbines. The only available data on prices today is marketing material from the manufacturer. Nevertheless, that is more than what is available on climate-hardened batteries. What remains is to estimate the learning curve. As with the climate-hardened batteries, the main driver for price differentials to conventional wind turbines is R&D costs. There seems to be no exotic materials involved. For that reason, the same learning curve of 25% reduction every 5 years has been employed.

One Technology – Many fuels

All cars, buses, lorries, houses, buildings, ships etc. are essentially different. Without some kind of generalisation, the model work would become indefinite. The TIMES model of the Arctic keeps the level of detail on the technology side to a minimum by assuming that e.g. all cars are identical, all buses are identical, all buildings are identical etc. In many cases, this is not only an active choice, but also a necessity, as the available data does not provide sufficient information for a more detailed segmentation.

As the TIMES model looks forward, it is provided with many different options for using alternative fuels to power the average/standard car/bus/lorry etc. Data for the cost and performance of these alternative fuels is available from several comprehensive studies in the Nordic countries.²⁷

4.3 Scenario definition

The scenarios analysed in this report concern the future development in greenhouse gas (GHG) emissions from human activity in Greenland, the Faroe Islands, Iceland, Jan Mayen and Svalbard. The scenario definitions are based on the IEA 2050/2100 projections and NETP 2016:²⁸

- **Business as Usual (BAU):** Assumes no changes in present policies (also referred to the "Reference Scenario" by IEA). This also includes policies, which have been decided, but not implemented yet. The BAU is similar to the Nordic 4 °C Scenario (4DS), which entails a 42% CO₂ reduction by 2050 (from 1990 levels) and serves as the baseline, representing a future with a global average temperature increase limited to 4 °C.

²⁷ Two major sources for this analysis are the "Alternative fuels for transport" study by the Danish Energy Agency and the "Kostnader i energisektoren" (Costs in the Energy Sector) study by the Norwegian Water Resources and Energy Directorate.

²⁸ <http://www.nordicenergy.org/wp-content/uploads/2016/04/Nordic-Energy-Technology-Perspectives-2016.pdf>

- 2 Degree Scenario (2DS): Describes an energy system with an emissions trajectory broadly consistent with the Paris Agreement pledges and targets, limiting the average global temperature increase to 2 °C. It sets the target of cutting energy-related CO₂ emissions by more than half in 2050 (compared with 2009) and ensuring that emissions continue to fall thereafter. Annual energy-related CO₂ emissions have cumulative emissions of around 1,170 GtCO₂ between 2015 and 2100 (including industrial process emissions). The 2DS continues to be the ETP's central climate mitigation scenario and acknowledges that transforming the energy sector is vital, but not the sole solution: the goal can be achieved if emissions in non-energy sectors are also reduced. The carbon emissions per capita in 2035 are projected assuming an average reduction of 60% (as compared to 2013) levels.
- Carbon Neutral Scenario (CNS): Nordic CO₂ emissions drop by 85% by 2050 (compared with 1990 levels), surpassing the 70% decline projected in the global 2 °C scenario set out in ETP 2016. This corresponds to emitting an average of 1 tonne CO₂ per capita in each area.

These scenario definitions must be transformed into meaningful parameters in the TIMES model and the techno-economic models employed in this analysis.

Especially the *BAU* scenario is difficult, as it involves a continuation of existing policy – including tax regimes and regulation. As taxes and regulation are not included in the model runs in this analysis (see section 4.2.1), creating an exact parallel to the NETP *BAU* is not possible. Instead, the *BAU* is defined as an “unrestricted” model run. This means that TIMES is allowed to minimise total system cost from 2015 to 2035 without any restrictions on GHG emissions. The *BAU* then becomes a baseline which defines what GHG reductions could be realised without any distortionary taxes, preferential treatment or subsidisation of technologies or fuels. The *BAU* is simply the cheapest way to serve all energy demands specified in the models.

The carbon emissions per capita in 2035 in the *2DS* (2 Degree scenario) are restricted by assuming an average anticipated reduction of 60% 2015 levels. The carbon emissions per capita in 2035 in a *CNS* (carbon-neutral scenario) are restricted to 1 tonne per capita, applicable to all areas. The target emissions are summarised in Table 2. These are the targets that the scenario analysis will seek to achieve in the most cost-effective manner. The results of the scenario analysis and the answer to how these emission targets will be achieved are detailed in sections 6 through 11 in this report.

Table 2: Overview of scenario definitions for all areas

CO ₂ tonnes per capita	Greenland	Iceland	Faroe Islands	Svalbard and Jan Mayen
<i>BAU</i>	<i>Unrestricted</i>	<i>Unrestricted</i>	<i>Unrestricted</i>	<i>Unrestricted</i>
<i>2DS</i>	4	4	5	20
<i>CNS</i>	1	1	1	1

The CNS scenario constitutes a very ambitious goal. In the NETP (2016), the Nordic countries do not reach a carbon neutrality before 2050.

4.4 Sensitivity analysis

Sensitivity analysis is used to test the robustness of the technology choices made in the scenario runs. In the sensitivity analysis, we show how the CO₂ emissions vary when prices of technologies change, and thus whether the area still reaches its emission targets. Testing the sensitivity for every parameter in the model (+1,000 separate value) is simply not possible. Instead, parameters have been selected on the basis of greater than normal uncertainty about parameter values and the expected impact on model results from variations in the parameters. The following three paragraphs describe three crucial parameters that have been selected for sensitivity analysis.

Oil prices are highly critical to the economics of renewable energy. As oil prices go up, the profitability of renewable energy increases – and vice versa. In the past decade, oil prices have shifted significantly. From a peak of close to USD 160 per barrel of crude oil in the summer of 2008 to a low of USD 30 in January 2016.²⁹ It is vital to understand how variations in oil prices will affect the results of the model runs.

Low Wind Speed (LWS) turbines are an emerging technology being used in the Igaliku hybrid system in Greenland. LWS promises to solve key challenges of implementing wind power in Greenland and other places with low average wind speeds but intermittent high-speed gusting. The information available on LWS turbines is very limited and input data for the TIMES model is primarily based on best-guess estimates. This makes LWS turbines a prime candidate for sensitivity analysis.

To replace fossil fuel consumption in maritime transport and fishing, the TIMES model relies heavily on hydrogen fuel cells. Like LWS turbines, hydrogen fuel cells in ships is an emerging technology. Recent years have seen an increased interest in fuel cells for ships, and a few large ships with fuel cells have been commissioned and will be finished in 2020–2021. There is very little available technical data on these ships. Hence, most data for fuel cell ships has been adapted from well documented data on conventional ships and fuel cell costs for road vehicles. It will be important to understand how variations in the costs of these ships will affect the results of the scenario analysis.

²⁹ <http://www.macrotrends.net/1369/crude-oil-price-history-chart>

5. Future technologies

This section elaborates on some of the most interesting new technologies explored in the scenario analysis.

5.1 Heat pumps and heat storage

A unifying theme in the Arctic is the need for year-round heating. Rarely does the temperature reach levels where indoor heating can be turned off entirely. Electrification of heating also presents a unique opportunity for storing energy from intermittent sources like solar and wind power.

We have provided the TIMES model with two options for electrification of heating. One is a heat pump (HP) with a high CAPEX, but also a very high efficiency (3 units of heat per unit of electricity). The other is a more conventional electric boiler (EB) with a very low investment cost, but correspondingly low efficiency (0.85 units of heat per unit of electricity). Both options include heat storage with the capacity to produce 24 hours' worth of heat during night time.

In the analysis, heat storages are based on short-term (daily) storages in hot water tanks. The technology is quite common and can be seen in many district heating systems. With daily use, the heat loss is insignificant. In future, new emerging technologies, such as storing heat in the ground and in the rocks/mountains, could be relevant.

5.2 Low wind speed turbines

Conventional wind turbines typically have a somewhat narrow range of wind speeds at which they can produce electricity. Outside the range, they either cannot produce electricity or have to be shut down in order to prevent damage. In some regions of the Arctic, wind speeds do not conform to the standard wind speed ranges (see Figure 8). The data in Figure 8 is based on the CFSR2 climate model and does not represent the full variability of the wind. For one, the climate model (CFSR2) is known to underestimate wind speed and variability. Secondly, the hourly resolution diffuses short duration gusting, which is known to be an issue in e.g. Greenland. Katabatic winds from the icecap in Greenland can, on rare occasions, reach speeds of up to 90 m/s.

Figure 8: Predicted winds speeds, 2016 (model data from CFSR2)

Greenland

The wind looks fairly weak and stable.
The wind is most probably not suitable for conventional wind turbines.

Iceland

The wind conditions in Iceland are suitable for wind energy development due to regular high wind speed with rare extremes.

The Faroe Islands

The wind conditions in the Faroe Islands are suitable for wind energy development due to regular high wind speed with rare extremes. As the figure shows, the wind speed is between 5–15 m/s most of the year (based on forecast system CFSR2 just north of Tórshavn).

Svalbard

Average wind speed is slightly higher than in Greenland but may not be sufficient for conventional wind turbines.

Jan Mayen

The wind profile on Jan Mayen resembles that of the Faroe Islands and thus reveals a large potential for wind power – especially in the winter.

Recent innovations in wind turbine design may allow regions with low average wind speed and high variability to enjoy the benefits of wind power. Cross-flow (CF) wind turbines promise a fast ramp up and high efficiency at very low wind speeds (~1 m/s).³⁰ CF wind turbines are still considerably more expensive than conventional wind turbines (on the order of twice as expensive per unit of power), but in regions with weak winds, they offer a higher energy yield per capital expenditure. In Greenland, which is a prime candidate for LWS turbines, a conventional wind turbine would have a utilisation rate of 2–3% (not feasible at all) whereas a LWS turbine would have a utilisation rate of 15–25% (very reasonable).

5.3 Hydrogen fuel cells

Hydrogen production, storage and conversion have led a quiet life in the shadows of more straightforward battery technologies. Critics of hydrogen will emphasise security concerns, efficiency losses and the lack of technological maturity. Advocates of hydrogen will emphasise flexibility, energy storage capabilities, synergy with intermittent renewable energy sources like wind and solar power and the lack of any real alternatives to very energy-intensive non-stationary tasks, like ocean-going fishing vessels, cargo vessels and aeroplanes.

On the road, it looks as if hydrogen is losing the battle to lithium-ion batteries, which continue to make impressive advances in performance as well as cost efficiency. The operating range of electric vehicles is closing in on that of conventional ICEs. At the same time, prices have steadily decreased, and charging time is approaching manageable levels (~20-minute range).

In the maritime sector, the story is a different one. The amount of energy needed for the propulsion of large ships on long intercontinental voyages simply does not match very well with batteries. Hydrogen offers the prospect of one day being able to bunker hydrogen at sea in the same manner as heavy fuel oil (HFO) or diesel is bunkered today.

In January 2017, the European Maritime safety Agency published a “Study on the use of Fuel Cells in Shipping”.³¹ The study identified a total of 23 projects in the maritime sector covering assessments of potential, rules design, feasibility studies, concept design and actual testing. Nine of these projects involved hydrogen. The same year, Viking Cruises of Norway announced plans to build the world’s first cruise ship powered by liquid hydrogen.³² Another cruise operator, Royal Caribbean will also be testing fuel cells in combination with LNG on their new vessels set to be delivered by 2022 to 2024.³³

Hydrogen fuel cell ships are in a phase of pilot testing. There is also a need for specific regulations for safety procedures and standards for using liquefied hydrogen on ships.

³⁰ <https://www.lws-systems.com/en/>. The cross-flow wind turbine being used in the Igaliiku pilot project in Greenland.

³¹ <http://www.emsa.europa.eu/publications/technical-reports-studies-and-plans/item/2921-emsa-study-on-the-use-of-fuel-cells-in-shipping.html>

³² <https://maritime-executive.com/article/worlds-first-hydrogen-powered-cruise-ship-scheduled#gs.cqjBsk8>

³³ <http://www.motorship.com/news101/fuels-and-oils/cutting-through-the-hydrogen-hype>

This is something The International Maritime Organisation is looking into.³⁴ Although there are a lot of unknowns in regard to these ships, the promise they hold for solving a significant challenge in the transport sector and in the Arctic region makes it interesting to include them in the scenario analysis.

In the scenario analysis, hydrogen fuel ships are not considered available in the Arctic Region before 2025. By that time, hydrogen fuel ships are assumed to have moved beyond the pilot testing phase. Hydrogen fuel cell prices are well known in relation to road vehicles. In the early techno-economic models of fuel cells for cars, fuel cells were assumed to be retrofit on existing cars – significantly increasing the total cost of the car. At later stages, as fuel cell cars became commercially available, prices of fuel cell cars would reflect actual cars with no need for retrofitting. As the available data on fuel cell ships is still very scarce, prices have been estimated based on retrofits on newly built conventional ships. All data on efficiency and costs of fuel cells is based on scaling of data on fuel cells for cars.

³⁴ <https://www.ship-technology.com/features/featureis-there-a-future-for-hydrogen-powered-ship-propulsion-5731545/>

6. General results

In this section, we look at the most important issues emphasised by the results of the scenario analysis. These issues derive from similarities between the results from all or most of the regions. It is important to emphasize that the results is based on an economic analysis. If the projection of this fast implementation of the green technologies should become reality it is important for the countries to develop needed incentive schemes, tax schemes, legislation etc.

6.1 Electrification of heating is a must

In the Faroe Islands, Greenland, Jan Mayen and Svalbard, a very large proportion of all space heating is based on fossil fuels. In Iceland, only a very small proportion (0.5%) of space heating remains based on fossil fuels. The results of the TIMES model runs show that all heating in the Faroe Islands, Greenland, Jan Mayen and Svalbard will be converted to electricity before 2020, regardless of the remaining technical life of the installations.

Figure 9: Distribution of primary energy sources for heating in BAU

In Figure 9, the relative distribution of primary energy use for heating is shown. Black or grey colours indicate fossil fuels while shades of green indicate renewable energy sources. In all regions but Iceland (due to the geothermal heat already in place) and the small Greenlandic settlement (Atammik), the transition away from fossil fuels is rapid. Renewable energy sources are fairly easily accessible in these regions and provide cheap electricity. In the small Greenlandic settlements, renewable energy is less

abundant and requires more specialised technology that is not yet commercially viable, e.g. low wind speed turbines (LWS). In Iceland, there is no need to shift to electricity, as ~99.5% of all heating is supplied by geothermal heat.

The very rapid transition from fossil fuels to electricity between 2015 and 2020 should be interpreted in the context of at least two model-specific characteristics:

2020 is the first model year. 2015 is based on historic data. When the model is allowed to minimise system costs without taxes and regulation, results are – all other things being equal – highly likely to deviate from historic data that is the result of many years' historic development in taxes and regulation. This demonstrates that an important tool in the green transition is to redesign taxes and regulation to remove distortions – there is no need to subsidise or otherwise incentivise.

Real-world decision making is likely to involve a minimum threshold for gains versus effort. Electrification of heating is one of those instances, where it may already be marginally viable to switch today, but the economic gains are simply not great enough to be worth the effort. TIMES is an optimisation model. No gain is too small for it.

The main conclusion drawn from these results should be that electrification of heating is highly relevant today. The technology is mature, and prices are competitive with fossil fuels. The difference in total cost between electrification and fossil fuels is still so small that consumers may not feel it is worth the effort to convert and even minor distortions from taxes could tip the scale in favour of fossil fuels.

Electrification of heating is a high priority in many European countries because it has excellent synergies with renewable energy sources such as wind and solar power. The main synergy stems from the demand flexibility that electrification of heating introduces, especially when coupled with heat storage. Demand flexibility is a key to increasing the share of wind and solar power on the grid. Without demand flexibility, the power system will need sources of flexible production, which will often entail burning fossil fuels.

In power grids with high availability of flexible renewable energy production such as hydropower, demand flexibility has less value to the system. Even so, electrification of heating is still cost-efficient. This is especially true in systems with excess installed production capacity where the marginal cost of electricity is virtually zero, e.g. Ilulissat, Greenland.

6.2 Renewable energy will become the least costly choice

The TIMES model for this scenario analysis has been formulated without taxes and levies. This is important to understanding the results of the model runs. The model will act as an economic planner, minimising the total system costs of satisfying all demands. Essentially, the model runs show the least costly solution when no institutional, regulatory or fiscal barriers exist.

In this perfect world, the expected future cost reduction of renewable energy technologies is revealed to be sufficient to drive a transition to a – more or less – fossil-free society. This is interesting because the current debate on climate policy revolves

around regulation and incentive schemes. Rather, true prices free of distorting effects from regulation and taxes would – in almost all the Arctic regions – provide sufficient economic incentives to drive the transition into the 2DS or CNS.

In Figure 10, we illustrate the relative composition of primary energy consumption in the TIMES model regions across all three scenarios for 2015 and 2035. It is immediately evident that there is very little difference between the three scenarios in 2035. The major transition from fossil fuels to renewable energy happens independently of the CO₂ targets imposed in the 2DS and CNS scenarios. It is also evident that regions with access to hydropower and geothermal power have an easier time transitioning to renewable energy than regions that have to rely heavily on wind power for renewable energy.

The results in this scenario analysis are model results. Models are 100% rational and exacting. No gain is too small to pursue. In the real world, there are many factors which contribute to delaying or deviating from the adoption of the least costly path. As mentioned, taxes and subsidies will impact the decision-making. Financing barriers, inertia in public perception and uptake could likewise have a large impact on the adoption rate of and the chosen path towards renewable energy.

Financing barriers are receiving increasing focus globally. Even though renewable energy projects or energy efficiency projects can be demonstrated to be profitable, it can still be a struggle to find private financing for such projects. Private enterprises can be very reluctant to invest in anything with a payback time of more than a year. Along the same lines, financial institutions may lack the necessary knowledge to accurately predict the risks involved in financing such projects. For that same reason, the overarching goal of the DEEP project presented in section 4.1.6 is to increase the knowledge of and reduce the risk of energy efficiency projects.³⁵

Inertia in public perception of renewable energy projects can be a tough barrier. Many of the investments necessary for a transition to renewable energy will be made by households and private enterprises. Examples of such investments are electric vehicles, heat pumps and energy efficiency measures. In the case of electric vehicles, the limits on range and refuelling time have imposed inconveniences which have had a great impact on the commercial viability of electric vehicles for many years – to a degree where range and charging time are the two main parameters in R&D on electric vehicles. In the case of energy efficiency investments or conversions of heating systems, the economic benefit of making the switch may be so low that it is barely worth considering. Unlike machines, humans tend to have a minimum threshold for effort versus payoff.

These results show that the technologies needed for a transition to renewable energy exist, and their prices are expected to become competitive within a very short timeframe. The major barriers for a green transition are no longer the availability or price of relevant technologies. What is needed now is not further public funding of R&D, but rather a political focus on removing taxes and regulation which distort the competition between technologies.

³⁵ <http://eefig.eu/index.php/about-the-project>

Figure 10: Distribution of primary energy consumption

Note: Abbreviations of fuel names are explained in the list of abbreviations in the beginning of the report.

7. Greenland

Figure 11: Map of Nukissiorfiit supply centres and hydro power plants in Greenland.

Note: Hydropower plants are the symbols with little drops of water. The houses are Nukissiorfiit supply centres.

Source: Nukissiorfiit.gl

7.1 Overview

Table 3: Greenland key figures on energy consumption and supply, PJ (2015)

Sector	Electricity	District heating	Fuel	Total
Agriculture	0.00	0.00	0.01	0.01
Commercial	0.63	0.33	0.65	1.61
Industry	0.17	0.00	2.05	2.23
Residential	0.38	0.46	1.39	2.23
Transport			1.57	1.57
Total final energy consumption	1.18	0.80	5.68	7.65
Total primary energy consumption				8.53
Tonnes CO ₂ emissions per capita				9.98

Source: Greenland Statistics @ Stat.gl, tables: ENE1FIN, ENE1ACT, ENE4NUK.

The Energy Sector Plan in Greenland published in 2017 focuses on the following five priorities:

1. All consumers must have access to a stable and low-priced electricity supply.
2. A new proposed electricity pricing structure based on transparency and solidarity principles.
3. Energy sector business opportunities that will in turn will boost employment nationwide.
4. The energy supply shall sustain the climate and the environment.
5. The energy sector shall contribute positively to the socio-economic development.

The government of Greenland aims to achieve a clean and cost-effective renewable energy system. By 2024, 100% of the electricity and heat supply of the national energy company Nukissiorfiit is planned to be based on renewable energy, mainly utilising the hydropower potential. Alternative energy sources for supplying small settlements based on solar and wind energy, combined with energy storage (possibly with the production of hydrogen) are being investigated.

7.1.1 Energy

In 2015, the gross energy consumption in Greenland totalled 8,626 TJ as reported by Statistics Greenland.

In the period 2010–2015, the consumption of energy from gas oil, kerosene and gasoline was generally decreasing, while the consumption from fuel oil and hydropower was increasing. The emissions of greenhouse gases per capita amounted to 9 tonnes of CO₂ equivalents in 2015; they have decreased from 12 tonnes in 2010.

Nukissiorfiit (Greenland's Energy Supply Company) is responsible for supplying electricity and water to all towns and settlements, and district heating in some towns. Due to the remoteness of most communities, it is generally not possible to supply power via a transmission grid, and therefore the power production system is

decentralised. As a result, each town and settlement has its own diesel generator station(s) that supply the necessary electricity through distribution lines that are either buried or laid in steel sleeves at ground level. A current trend is replacing such diesel generator stations with hydropower, as in Ilulissat.

In 2017, five hydroelectric power plants are in operation in Greenland. The most recent, Pakitsoq near Ilulissat, came into use in 2013. As a consequence, Greenland's four largest towns are supplied by hydropower. Table 4 Greenland hydropower plants, presents an overview of the different hydropower plants, their area of supply, total capacity and year of commissioning.

Table 4: Greenland hydropower plants (2017)

Plant name	Area of supply	Capacity	Commissioned
Buksefjorden	Nuuk	45 MW	1993
Tasiilaq	Tasiilaq	1.2 MW	2004
Qorlortorsuaq	Narsaq and Qaqortoq	7.2 MW	2008
Sisimiut	Sisimiut	15 MW	2010
Pakitsoq	Ilulissat	22.5 MW	2013

Commissioning of new hydropower plants is foreseen in the towns of Aasiaat, Qasigianniguit, Maniitsoq, Paamiut and Nanortalik, as well as expansion of the existing ones in Nuuk, Tasiilaq and Qorlortorsuaq. A number of the plants already in operation have sufficient electricity available for district heating. By utilising the hydropower capacity, an increasing part of the heating production is now generated without increased emissions of greenhouse gasses. Feasibility studies of new hydropower capacities are targeting urban areas, where it is possible to supply a larger number of residents without significant energy losses. Transporting electricity across longer distances is associated with greater losses and hence constitutes a barrier to the establishment of hydropower plants in more scarcely populated areas. This is part of the explanation why many smaller towns and settlements are still dependent on an energy supply based on fossil fuels.

The energy company has conducted a number of projects to analyse the business case of connecting towns through transmission lines and interconnectors, but given the large distances, challenging terrain and the relatively small value of energy to be transferred, such projects are not financially feasible.

According to hourly climate data, see Figure 12, there is a potential for solar power. The solar radiation in Nuuk reaches as much as 800 W/m² during the summer. The potential for wind power was discussed in section 5.2, where it was concluded that harnessing the wind in Greenland would require specially designed low wind speed turbines.

Figure 12: Hourly climate data, Greenland (close to Nuuk)

Wind and solar power is being explored by Nukissiorfiit. In particular, a pilot project in Igaliku (located in southern Greenland), which started operation in July 2017, aims to demonstrate an environmentally friendly production model for small settlements. The hybrid system model could be replicated across the country. The system is a combination of solar photovoltaics (PV), micro wind turbine, battery storage pack, and a diesel generator as a backup capacity in case of shortages.

Heating in Greenland is presently based on either oil, solid waste or electricity. Waste incineration plants are connected to district heating networks and additional district heating capacity is supplied by electric boilers. Individual heating is a

combination of oil boilers, electric boilers and electric resistance heaters (available only in Nuuk). In towns with excess energy available from hydropower (e.g. Ilulissat), there is a need to incentivise households with individual heating to switch from oil to electric boilers. In towns with limited power and energy from hydropower (e.g. Sisimiut and Nuuk), Nukissiorfiit is working on limiting the adoption of electric heating and increasing the efficiency of existing electric boilers and resistance heaters.

7.1.2 *Transportation*

The towns and settlements in Greenland are not connected by roads and people and supplies of goods are transported by sea or by air. This naturally limits the use of fossil fuels for transport. The fossil energy consumption in transport was 31 GJ/capita in 2015. By comparison, it was 49 GJ/capita in Iceland.

The main gateway to Greenland is the former American military base at Kangerlussuaq, which is operating as the only international airport. The government is presently planning the simultaneous construction of two additional international airports in Nuuk and Ilulissat to allow easier access internationally.

The major towns have national airports while smaller towns and major settlements are serviced by helicopter. The domestic passenger traffic is mainly by air. In 2015, the total number of passengers travelling by air was 407,526, the volume of cargo transported by sea 733,000 cubic metres, and the number of registered motor vehicles 8,078.

Each town has a commercial harbour owned by the government and usually operated by Royal Arctic Line A/S. Due to ice conditions, many harbours are available for a part of the year only. The sea traffic is of the utmost importance for isolated towns and settlements all over the country. There are no international sea connections for passengers.

7.1.3 *Industry*

Presently in Greenland, the industry consists of fish processing, handicrafts, hides and skins, small shipyards and mining. Finishing and fishery products is the leading sector and make up almost 90% of Greenlandic exports. The government has plans to further develop the industry sector – for example through the development of data centres, which could be supplied by relatively cheap hydropower energy. There are also ongoing mining and oil exploration activities, which could make the country less dependent on imports (mainly transportation fuels).

7.2 Scenario analysis

The results presented below focus on subjects specific to Greenland. Subjects of a more general nature with relevance to all regions are reported in section 6.

Unlike the other regions in this scenario analysis, Greenland consists of many independent energy systems. In order to correctly reflect this challenge in the model runs, Greenland is represented by three separate towns/settlements, each representing a type of Greenlandic system:

- *Nuuk*: The capital is by far the largest city in Greenland with a projected population growing to more than 20,000 within the model horizon. Nuuk cannot really be compared to any other system in Greenland.
- *Ilulissat*: The large towns in Greenland typically have access to hydropower as the main source of electricity.
- *Atammik*: The small villages in Greenland typically have to rely on fossil fuel for all energy purposes.

7.2.1 Scenario definitions

In the TIMES model framework, the *BAU* scenario is unconstrained in terms of CO₂ emissions. The model simply minimises the total discounted system costs of delivering all demands. The BAU results in a baseline of CO₂ equivalents emissions in 2015 of ~150/49/3 (Nuuk/Ilulissat/Atammik) thousand tonnes. According to Greenland Statistics, total CO₂ emissions in for Greenland as a whole in 2015 was 558 thousand tonnes. Specific emissions which the model does not account for are process emissions from agriculture and waste incineration.

In the alternative scenarios *2DS* and *CNS*, the model is restricted in terms of how much CO₂ can be emitted in the target year 2035.

The carbon emissions in 2035 in a *2DS* (2 Degree Scenario) are restricted to 2.5/5.5/8 (Nuuk/Ilulissat/Atammik) tonnes of CO₂ equivalents per capita. This is a 60% reduction in emissions compared to 2015 levels.

The carbon emissions in 2035 in a *CNS* (Carbon-Neutral Scenario) are restricted to 1 tonne of CO₂ equivalents per capita.

7.2.2 Scenario Projections

This section presents the results of TIMES model runs. The results are based on a number of simplifying assumptions described in section 4.2.1 and should be interpreted in that light. In this case, the TIMES model has been specified with focus on technology choices in the absence of distortions from taxes and regulation. The results will point to trends in the relative cost of different technologies and how a green transition can be achieved in the least costly manner. This can be used to guide the political work needed to redesign taxes and regulation in support of the technology choices demonstrated here.

The presentation of the results begins with the total CO₂ emissions in each scenario. The required CO₂ emission reductions naturally lead to a description of the total costs and technologies involved in achieving those reductions. Last, we take a look at the evolution in primary energy consumption over time.

CO₂ emissions

Greenhouse gas emissions in Greenland are projected to decline rapidly over the next 20 years. This decline is driven primarily by electrification of heating and transport. The transition begins with heating, then progresses through light road vehicles, heavier road vehicles (where relevant) and coastal sea transport, ending with hydrogen fuel cells for heavy sea transport around 2030. This development is driven purely by cost efficiency and hence is part of the BAU.

The development in CO₂ emissions in all scenarios is shown in Figure 13. The right-hand side of the figures shows a sectoral break-down of emissions in the BAU in 2035. An inspection of the figures reveals that the emission targets in the 2DS and CNS are fulfilled simply by following the least costly path in the BAU in all the Greenlandic regions.

Figure 13: Projected CO₂ emissions in Nuuk, Ilulissat and Atammik

The results show that the main barrier for a green transition in Greenland will be distortionary taxes and regulation. The technologies needed for a green transition exist, and they are expected to become economically competitive within the timeframe of this study. The technologies needed for this green transition are discussed below.

Costs and technology

There is a very rapid decline in emissions by 2020 which is mainly due to an intense conversion from oil-based heating to electrified heating. This trend has also been discussed in section 6.1. In the years after 2020 further reductions in emissions are a result of a gradual conversion of transportation from fossil fuels to electricity and hydrogen. First comes light road vehicles, which are becoming increasingly competitive

today already. Later follows heavy road vehicles, light maritime vessels and finally heavy maritime vessels – in that order. By 2035, almost all transportation has been converted to electricity or hydrogen.

Although all three Greenlandic regions are projected to be able to meet 2DS and CNS targets in the unrestricted BAU scenario, the paths to reduced emissions are very different.

In Nuuk, the capacity of the hydropower plant is a limiting factor in the continued electrification process. During the winter, peak loads may exceed the capacity of the hydropower plant. As a consequence, energy efficiency is a key precondition for further electrification. From 2015 to 2020, all oil-based heating – individual and district heating – will be replaced with either electric boilers or heat pumps. In the same period, diesel consumption in fishing and transport will be reduced by as much as 80% due to widespread electrification of road vehicles and coastal vessels. This leads to the significant drop in CO₂ emissions seen in figure 13, for Nuuk. From 2020 onwards, energy efficiency in commercial and industrial processes is optimised. These efficiency gains along with increased demand flexibility will provide the necessary capacity for electrification of the remaining fossil-based heating and transport. By 2025, the TIMES model begins converting heavy maritime transport to hydrogen propulsion and in 2035 all diesel consumption and almost all heavy fuel oil consumption has ceased.

In Ilulissat, the hydropower plant is running at less than half capacity during peak hours. In this setting, the benefits from investments in energy efficiency are marginal. Heating is produced with electric boilers and energy efficiency is only improved slowly as installations reach the end of their technical life and new and more efficient generations of the technologies become the norm. As in Nuuk, the TIMES model projects an immediate electrification of all heating before 2020. The electrification of the transport sector is implemented faster than in Nuuk due to the higher availability of electricity. By 2035, the TIMES model predicts that all diesel and heavy fuel oil consumption has ceased.

In Atammik, there is no hydropower. Implementing renewable energy requires a great deal of demand flexibility. The TIMES model predicts a steady uptake of wind power throughout the model period, followed by the addition of solar power from 2030 onwards. From 2020, the TIMES model predicts a steadily increasing use of heat pumps for heating, following the rate of expansion of the wind and solar generation capacity. For buildings in close proximity to each other, the TIMES model projects that micro district heating systems could be a viable option. Electrification of transport in Atammik is not projected to pick up until after 2020. An investment in hydrogen production in Atammik would be too costly to be feasible. There is also very little need for hydrogen, as most maritime transport in Atammik is based on small coastal vessels that are better suited for battery/electric propulsion.

In all three Greenlandic model regions, the TIMES model projects a rapid transition to electric propulsion in road and sea transport. This happens because the prices of electric vehicles are expected to converge rapidly towards those of conventional diesel and gasoline vehicles. By 2020, the expected price differential is such that the model prefers electric vehicles to conventional vehicles; this is due to a combination of vehicle and fuel prices. The model results suggest that technology prices – and specifically the price of batteries – should no longer be considered the primary barrier to widespread electrification in the transport

sector. More likely, the main barriers will be public perception and market penetration/availability. The case study report has a more detailed description of the development in and availability of electric vehicles.

Primary energy consumption

Primary energy consumption in Greenland is projected to decline rapidly as a consequence of increased energy efficiency and a considerable migration of the population from the smaller settlements to the larger towns with a higher average base energy efficiency.

Figure 14: Primary energy consumption in Nuuk

Note: Abbreviations of fuel names are explained in the list of abbreviations in the beginning of the report.

The primary energy consumption in Nuuk is projected to be based almost exclusively on hydropower by the end of the model horizon (Figure 14). Bio-kerosene replaces fossil kerosene for aviation and there remains a small share of heavy fuel oil for sea transport.

Figure 15: Primary energy consumption in Ilulissat

Note: Abbreviations of fuel names are explained in the list of abbreviations in the beginning of the report.

As in Nuuk, the primary energy consumption in Ilulissat is projected to be almost exclusively based on hydropower by 2035 (Figure 15). Because of the lower pressure for energy efficiency in Ilulissat, the decline in total primary energy consumption may be less pronounced than in Nuuk.

Figure 16: Primary energy consumption in Atammik

Note: Abbreviations of fuel names are explained in the list of abbreviations in the beginning of the report.

In Atammik, the primary energy consumption is projected to go through a remarkable transformation. From a 100% fossil-based system today, it is projected to become an almost 100% renewable-based system by 2035. Wind power will be the primary source of renewable energy supplemented with a small amount of solar power.

Because of the remoteness and small size of many of the Greenlandic settlements, security of supply is of special concern. For that reason, a system like the one proposed by the model runs should not be implemented lightly. Models like TIMES are not designed for detailed system planning and do not take into account all the complexities of real-time power generation and dispatch. This is especially true in areas like Atammik, where critical power generation must come from a relatively unproven technology like low wind speed turbines.

What the model results can do is to point to trends and patterns among the myriad of technological solutions available. The takeaway from these model runs for Atammik should be a confirmation that the Igaliku test system is working in the right direction.

7.2.3 Sensitivity analysis

This section looks into the sensitivity of technology choices when oil prices change, or the prices of the technologies involved increase relative to each other. Only the most interesting or central sensitivity results are presented in charts.

The effect of changes in the oil prices are most pronounced in Atammik, as this settlement – like most other settlements in Greenland – is 100% dependent on oil today. Low oil prices will slow down the transition to renewable energy. Figure 17

illustrates development in CO₂ emissions over time under different assumptions about the level of oil prices. The tested oil price levels range from 20% (-0.2) lower than the current oil prices to 20% higher. If oil prices should fall more than 15% on average, then Atammik may not be able to meet the CNS emission targets simply by following the unrestricted least costs path. The choice of renewable energy technologies does not change, the rate of adoption simply slows down.

In Nuuk and Ilulissat, the effects are less pronounced, as these areas are less dependent on oil. Even in a situation where the oil price falls 20%, Nuuk and Ilulissat will still be able to reach the CNS targets in the unrestricted BAU scenario.

Figure 17: Sensitivity to changes in oil prices, Atammik

In Atammik, Low Wind Speed (LWS) turbines are a key element in the future power supply. In Figure 18, the results of sensitivity runs on the price of LWS turbines are presented for Atammik. Atammik is the only one of the regions in the TIMES model that uses LWS turbines. Even if prices of LWS turbines are increased by as much as 20% they will still be deployed in Atammik at almost the same rate as in the BAU. By 2035, emissions will be below the CNS target regardless of the price of LWS turbines.

Figure 18: Sensitivity to cost of LWS turbines, Atammik

Note: The curves for a 15% and 20% increase in LWS prices follow the 10% (yellow) curve. The TIMES model has reached a plateau, where these price increases will not change the overall priority in the model.

In Nuuk, the hydropower plant has very little excess capacity, which means that energy efficiency plays a vital role. In that context, the highly inefficient process of hydrogen production for use in fuel cells could possibly be abandoned if the costs of fuel cell ships were to increase. The results of this sensitivity analysis are illustrated in Figure 19. Even a 30% increase in the total cost of the hydrogen fuel cell ships will have very little effect on the main results. In Nuuk and Ilulissat, hydrogen production and consumption on hydrogen fuel cell ships continue in all sensitivity runs, although at a progressively slower pace as prices go up.

Figure 19: Sensitivity to cost of hydrogen fuel cell ships, Nuuk

7.3 Recommendations

From a purely economic planning perspective, Greenland has the potential to make a quick and low-cost transition to a low emission society. The first and most pressing task is to electrify all heating. This is a task that should be economically feasible today.

The main challenges in Greenland consist of regulatory and financial barriers. Energy prices are heavily regulated in order to provide equal opportunities for all Greenlanders regardless of where they live. State subsidies to support private investments must be available to all, even though the same investments may not be relevant in all locations. The average income is generally low, which adds to the challenge of financing the necessary private investments.

The scenario analysis has also shown that there are very large differences between the optimal paths for towns and settlements in Greenland.

In Nuuk, the main challenge will be balancing increased electrification with the need for higher energy efficiency throughout in order not to exceed the capacity of the existing hydro power plant.

In Ilulissat, there is not much need for energy efficiency, due to the very large excess capacity of the hydropower plant. Instead, heating should be converted to electric boilers at the earliest convenience.

In the small settlements in Greenland, exemplified by Atammik, the path to reduced emissions is less straightforward. The solutions offered in the scenario analysis have a high resemblance to the hybrid system being tested in Igaliku. Even though the exact solution to renewable power generation is still in testing, there is little doubt that the first steps to a low emission settlement lies in electrification of heating – preferably using heat pumps.

8. Iceland

Figure 20: Map of energy resources in Iceland

8.1 Overview

Table 5: Iceland key figures on energy consumption and supply, PJ (2015)

Sector	Electricity	District heating	Fuel	Total
Agriculture	0.82	0.55	0.58	1.95
Commercial	7.16	11.54	0.73	19.43
Industry	54.46	0.98	13.78	69.22
Residential	2.97	12.87	0.11	15.95
Transport			16.82	16.82
Total final energy consumption	65.41	25.94	32.02	123.37
Total primary energy consumption				238.08
Tonnes CO ₂ emissions per capita				13.79

Source: Eurostat, Orkustofnun, Statistics Iceland.

Because of the very high share of renewable energy in the energy sector, Icelandic energy and climate policy targets transport as the next big challenge. At present, a new climate policy is being formed with the following targets by 2030:

- Transportation to use 40% renewable energy.
- Ocean transportation to use 10% renewable energy.

It is expected that electricity will be used in land transportation, while biofuel will be used more in the fishing industry and in future also for aviation.

8.1.1 Energy

The overwhelming majority of Iceland's primary energy comes from three sources: Hydropower (50 PJ), geothermal energy (156 PJ) and oil (32 PJ) (the latter including coal which burns off electrodes, explained below). For domestic purposes geothermal energy has been utilised for district heating in Iceland since the early 1900s. The shift from coal and oil was driven by economic reasons as well as a vision of energy security and a decreased in pollution. Oil, in its many forms (gasoline, diesel etc.) is used for transportation (ships, vehicles, aeroplanes etc.) and only in very remote areas is oil used to generate electric power (0.02% of total electricity production) and heating (0.2% of all heating produced), including backup heating and electricity supply.

Figure 21: Hourly climate data, Iceland (Reykjavík)

Figure 21 presents model-generated (CFSR2) climate data for a location close to Reykjavík. Wind speed and variability look very similar to the Faroe Islands (see section 5.2 for a comparison) and solar radiation reaches almost 800 W/m² in the summertime. Orkustofnun (National Energy Authority of Iceland) reports that the average efficiency of the wind turbines at Hafid is 54% in the winter and 30% in the summer.

The total primary energy supply in Iceland was 238 PJ in 2015. However, the total final consumption was just over half of the supply (~60%). The reason is the immense energy stored in the geothermal water that is not fully utilised before it is re-injected

into boreholes or released into the ocean. Several projects are ongoing to improve utilisation of the geothermal resource. For instance, greenhouses and fish farms have been built close to geothermal power plants to harness more energy from the geothermal water. The final energy supply is delivered mostly as electric energy (68 PJ), generated by hydroelectric (73%) and geothermal (27%) power plants, or in the form of heat (28 PJ). Oil and coal is imported for transport and industry use and make up 32 PJ.

Electric power in Iceland is still available at a low price, despite being in considerable demand, and several national and international partnerships or entities are trying to negotiate on more power. With new legislation on environmental impact, any power production development has become more time-consuming and, in recent years, only one hydropower plant over 10 MW has been installed: Búðarhálsstöð (95 MW) owned and operated by Landsvirkjun. Orkustofnun has issued licenses for several smaller hydro power plants in 2017 and many other options are in a research phase or under development. Geothermal power development has also been on hold for some years, but Landsvirkjun is in the final phase of developing 90 MW from the Þeistareykir field, close to a silica metal production factory being set up in the nearby town of Húsavík. On the 18th of November 2017, Þeistareykir power plant started production with installed power of 45 MW.

Even though the hydro and geothermal power capacity is still being expanded, most of the new power plants tap into existing reservoirs or geothermal fields. In the winter, demand for electricity from hydropower reservoirs is low. Orkustofnun expects limited development of greenfield geothermal projects and large reservoirs. The Ministry of the Environment and Natural Resources is looking into turning all the interior highlands into a national park. This natural park will probably include most of the areas where it would be possible to build large scale hydro power. It will probably also affect many possible sites for geothermal energy and thus put a cap on the energy that can be delivered annually by hydropower and geothermal power. Therefore, Iceland is looking into developing wind power and small distributed hydro- and geothermal powerplants to meet the expected future increases in demand for electricity.

Varmaorka is a new player in the electricity market in Iceland that plans to use Geothermal heat power from heat sources of lower temperature (120°C) and at a smaller scale than the existing power plants are based on. Their business will be based on Climeon technology which is a compact and modular design, making it easily scalable from 150kW modules. The system can be configured both in parallel (for different flow) and series (for different temperature difference). Varmaorka sees the fact that lot of already existing boreholes in Iceland are in temperature ranges that works for this technology as an opportunity. The first power plant will start production in the autumn of 2018, the installed power will be 600 kW using 115°C coming from an already existing borehole.

Transportation

Given that all land-based activity can be operated on clean power in Iceland, the transport sector has been targeted as the next opportunity in green energy development. Electric cars have become more popular and receive government incentives of lower tax, but the proportion of electric cars, including hybrids and plug-ins, was still less than 2% in 2016.

The fishing and shipping industry has benefited from improved engine designs in new vessels and improved energy efficiency in many of the energy intensive processes on board the vessels. Fuel prices provide a natural economic incentive for the marine industries to keep improving fuel efficiency. From 2010 to 2014, the oil consumption from domestic fishing vessels in Iceland decreased steadily while total tonnage of fish catch was stable or increased slightly.³⁶ Electric propulsion is also being explored. An innovative whale-watching tourist company has developed a sailboat which also runs on an electric motor connected to a battery that charges while sailing.

Aviation traffic to and from Iceland has increased over the last few years and this has led to an increase in CO₂ emissions. However, the latest jet-planes are more energy efficient than their predecessors. In 2017, Icelandair will take delivery of its first Boeing 737 MAX, which is expected to be 20% more fuel efficient per seat than the company's Boeing 757 aircraft.³⁷

Industry

A very large share (79%) of the electricity produced in Iceland is used in aluminium smelters and in ferroalloy production. The process emissions from aluminium smelters constituted close to 40%³⁸ of the total Icelandic GHG emissions in 2014. For each tonne of alumina produced, half a tonne of coal in electrodes is used up, creating 1.5 tonnes of CO₂. In addition, fluorocarbons (CF₄/C₂F₆) – strong greenhouse gasses – are released in the aluminium production process. The aluminium smelters are located in Iceland because of the access to electricity based on 100% renewable energy, significantly reducing the total emissions related to aluminium production.

From 2013 and onwards, Iceland has committed to the EU ETS (Emission Trading Scheme), which uses tradeable CO₂ allowances to reach greenhouse gas emission reduction targets in the most cost-efficient manner possible. The largest industrial process emissions are covered by the ETS. The emission reduction target for phase 4 of the ETS (2021 to 2030) is expected to be 41%. Because the marginal abatement cost of CCS is very high,³⁹ it is possible that even the 41% reduction target can be reached without reducing emissions from the aluminium industry. In that case, the reduction in total national emissions in Iceland will be lower than in other ETS countries – even though the ETS ensures that emissions on an EU level reach the reduction target.

Since the emissions from the aluminium industry constitute such a large part of the total Icelandic greenhouse gas emissions, the results of the scenario analysis will be very sensitive to what happens in the aluminium industry. For that reason, the main results have been split in two:

- Aluminium industry process emissions *are* included in the reduction target.
- Aluminium industry process emissions *are not* included in the reduction target.

³⁶ Statistics Iceland: Oil use and catch by types of fishing vessels.

³⁷ Icelandair annual report 2016.

³⁸ Statistics Iceland, hagstofa.is: "Greenhouse gas emissions 1990–2014".

³⁹ CCS is the most likely solution to reducing emissions from the aluminium industry.

This split should allow a more nuanced discussion on the potential for and cost of a green transition in Iceland.

8.2 Scenario analysis

The results presented below focus on subjects specific to Iceland. Subjects of a more general nature with relevance to all regions are reported in section 6.

8.2.1 Scenario definitions

In the TIMES model framework, the *BAU* scenario is unconstrained in terms of CO₂ emissions. The model simply minimises the total discounted system costs of delivering all demands. The BAU results in a baseline of CO₂ equivalents emissions in 2015 of ~1,950 thousand tonnes excluding process emissions from the aluminium industry. According to Statistics Iceland, total CO₂ equivalents emissions in 2014 were 4,595 thousand tonnes. This includes process emissions from the aluminium industry of ~1,900 thousand tonnes. Other specific emissions which the model does not account for are process emissions from agriculture, waste incineration and geothermal power plants.

In the alternative scenarios *2DS* and *CNS*, the model is restricted in terms of how much CO₂ can be emitted in the target year 2035.

The carbon emissions in 2035 in a *2DS* (2 Degree Scenario) are restricted to 3.5 tonnes of CO₂ equivalents per capita. This is a 60% reduction in emissions compared to 2015 levels.

The carbon emissions in 2035 in a *CNS* (Carbon-Neutral Scenario) are restricted to 1 tonne of CO₂ equivalents per capita.

8.2.2 Scenario projections

This section presents the results of TIMES model runs. The results are based on a number of simplifying assumptions described in section 4.2.1 and should be interpreted in that light. In this case, the TIMES model has been specified with focus on technology choices in the absence of distortions from taxes and regulation. The results point to trends in the relative cost of different technologies and how a green transition can be achieved in the least costly manner. This can be used to guide the political work needed to redesign taxes and regulation in support of the technology choices demonstrated here.

The presentation of the results starts off with the total CO₂ emissions in each scenario. The required CO₂ emission reductions naturally lead to a description of the total costs and technologies involved in achieving those reductions. Last, we take a look at the evolution in primary energy consumption over time.

Emissions

Greenhouse gas emissions in Iceland are projected to decline rapidly over the next 20 years. This decline is driven primarily by electrification of transport, both on land and sea. More details on the technologies and the rate of implementation is provided in the next section.

The development in CO₂ emissions in the BAU as well as 2DS and CNS target emissions are shown in Figure 22 and Figure 23. The right-hand side shows a sectoral break-down of emissions in the BAU in 2035. There is a very large difference between the model results with and without the aluminium industry. This difference is driven by the very large process emissions from this industry. In the absence of these, the CO₂ reductions in the BAU are sufficient to reach the 2DS and CNS emission targets. By 2035, the remaining CO₂ emissions will come from industry (primarily fishing) and maritime transport.

Figure 22: Projected CO₂ emissions in Iceland without the aluminium industry

Figure 23: Projected CO₂ emissions in Iceland with the aluminium industry

In the TIMES model, there are no taxes on CO₂ or any other valuation of CO₂ emissions. This means that the only economic incentives to reduce CO₂ emissions are fuel savings. Technologies that increase fuel efficiency or allow the use of alternative fuels such as electricity provide a direct economic incentive in the form of reduced fuel costs. The same does not apply to the technology needed to reduce emissions from the aluminium industry. In fact, CCS is expected to increase energy consumption (electricity) while the only gain is reduced emissions. In such an environment, the process emissions from the aluminium industry persist in the BAU where there are no limits on CO₂ emissions. Under the EU ETS, the market value of CO₂ allowances provides an economic incentive to reduce CO₂ emissions. However, if the cost of reducing CO₂ emissions is higher than the cost of the allowances, the aluminium industry will be better off economically by purchasing allowances to cover the emissions.

Costs and technologies

The projected decrease in Icelandic greenhouse gas emissions in the BAU is mainly driven by a widespread electrification of the transport sector along with increasing focus on energy efficiency. The TIMES model predicts that electrification of land and sea (mostly coastal and small vessels) transport will pick up speed within a few years. The increased electricity demand from the transport sector, coupled with the expectation of continued economic and demographic growth in Iceland, puts increasing pressure on the power supply in the model. In the early model years, this

translates into an increased focus on energy efficiency in electric appliances in all sectors. In the later model years, the pressure for more electricity is met by investments in wind power.

The prices of electric vehicles are expected to converge rapidly towards the prices of conventional diesel and gasoline vehicles. By 2020, the expected price differential is small enough that the TIMES model prefers electric vehicles over conventional vehicles. This is due to a combination of vehicle prices and fuel prices. As a consequence, in the TIMES model results, all road vehicles and coastal vessels that reach the end of their technical life from 2020 and onwards will be replaced by electric vehicles and vessels. The model results suggest that technology prices – and specifically the price of batteries – should no longer be considered the primary barrier to widespread electrification in the transport sector. More likely, the main barriers will be public perception and market penetration/availability. The case study report has a more detailed description of the development in and availability of electric vehicles.

The increased use of electricity for road and sea transport puts a strain on the supply of electricity. The TIMES model resorts to investments in energy efficiency in electric appliances to keep the total demand for electricity within the bounds of the existing hydropower and geothermal power reservoirs in Iceland. By 2025, the model predicts that energy efficiency measures will no longer be sufficient and that a significant expansion of wind power capacity will be needed. During the next 10 years, from 2025 to 2035, more than 130 MW wind power will be installed, delivering close to 1,700 TJ annually in 2035.

CCS in the aluminium industry

The aluminium industry poses a challenge. As the industry is covered by the EU ETS, CO₂ reductions in this industry are a joint EU effort. This section explores what it would take to reduce the CO₂ emissions from the aluminium industry in Iceland in terms of total system costs and relate those costs to the price of CO₂ allowances under the ETS.

The technical options for limiting CO₂ emissions from the aluminium industry are limited. Currently, the main focus of R&D aimed at reducing CO₂ emissions from aluminium industry is carbon capture and storage (CCS). Although CCS is technically possible, it is still an emerging technology which has yet to reach commercial maturity. Currently, the technology is in the stage of pilot and demonstration projects. In the Nordic countries alone, there are at least five pilot projects.⁴⁰ On a global scale, there are more than 85 active CCS pilot projects in operation. Skagestad, Onarheim & Mathisen (2014) explore six specific Nordic cases for implementation of CCS. One of these cases is an Icelandic aluminium smelter. Cost estimates from this study have been used in the TIMES model.

⁴⁰ <https://www.globalccsinstitute.com/projects/pilot-and-demonstration-projects>

Figure 24: Total discounted value of system costs and savings in 2DS and CNS, Iceland

In Figure 24, we present the total discounted value of system costs and savings from achieving the 2DS and CNS emission targets. In some cases, additional system costs incurred in one sector are coupled with savings in other sectors (as is the case in the Faroe Islands), hence the dual nature of the figure. In Iceland, meeting the emission target in the 2DS and CNS requires additional investments and operational costs in the aluminium smelting industry. The total system cost of the 2DS is close to EUR 27 million higher than in the BAU; that of the CNS is close to EUR 120 million higher. This corresponds to an annual cost⁴¹ of EUR 14 million and EUR 62 million in the 2DS and CNS, respectively, after 2033.

The EU ETS provides an economic incentive to reduce emissions which has not been included in the TIMES model. In order to offset the EUR 62 million annual cost of CCS, the price of allowances would have to be 47 EUR/tonne CO₂ (annual cost divided by CO₂ emission reduction – 62 MEUR/1,329,000 tonnes CO₂). This is roughly 4 times as high as the present price of 11.32 EUR/tonne CO₂.⁴²

In Iceland a group of organisations gathered to work on the development of a CCS solution called CarbFix. The current results shows that the Carbfix is more safe and efficient than other CCS projects. This could completely alter the cost of CCS on Iceland.⁴³

⁴¹ Annualised investment costs and operation and maintenance.

⁴² <http://markets.businessinsider.com/commodities/co2-emissionsrechte>

⁴³ <https://www.or.is/english/carbfix/carbfix-project/faqs>

Primary energy consumption

Primary energy consumption in Iceland is not affected by the emission targets in the BAU, 2DS and CNS. Iceland's primary energy consumption segmented by fuel is illustrated in Figure 25.

Figure 25: Primary energy consumption in Iceland

Note: Abbreviations of fuel names are explained in the list of abbreviations in the beginning of the report.

At present, Iceland has one of the highest shares of renewable energy in primary energy consumption in the world. The TIMES model predicts that fossil fuels in the transport sector will disappear altogether either through electrification or conversion to biofuels in those rare cases where electric propulsion is not feasible, e.g. aviation. By 2035, the only fossil fuels being consumed in Iceland are expected to be the coal electrodes consumed in the aluminium smelting process and a small amount of heavy fuel oil in the fishing industry.

Although the population and economic activity in Iceland are expected to continue to grow, energy efficiency gains achieved through electrification are expected to contribute to a slightly decreasing trend in total energy consumption.

The limits to available hydropower and geothermal power have a significant effect on economic priorities and energy consumption. Energy efficiency gains are to a large extent prioritised by the TIMES model over increased wind turbine capacity. That being said, wind power will play a role in the future Icelandic energy system. In 2015, wind power contributed 40 TJ electricity. By 2035, the TIMES model projects wind power to deliver 1,700 TJ electricity. Compared to total hydropower and geothermal power, it is a small contribution, but it is a significant increase from today.

8.2.3 Sensitivity analysis

This section looks into the sensitivity of technology choices when oil prices change, or the prices of the technologies involved increase relative to each other. Only the most interesting or central sensitivity results are presented in charts.

In Iceland, low oil prices have very little impact on the transition to renewable energy. Figure 26 illustrates the effects of oil prices in a range from 20% (-0.2) lower

than the current oil prices to 20% higher. If oil prices drop by 20% or more, the transition to renewable energy will slow down. The choice of renewable energy technologies does not change but the rate of adoption slows down. At price increases below 20%, oil prices have very little effect on the results in Iceland.

Figure 26: Sensitivity to changes in oil prices, Iceland

The prices of ships powered by hydrogen fuel cells have very little impact on technology choice and rate of adoption in Iceland. The results of the sensitivity runs are illustrated in Figure 27.

Figure 27: Sensitivity to cost of hydrogen fuel cell ships, Iceland

8.3 Recommendations

The key to a low carbon emission future in Iceland lies in the transport sector. The scenario analysis suggests that full electrification in the transport sector will become the least cost path within the next 20 years. This does not mean it will happen by itself. Taxes and regulation can have very serious distortionary effects on crucial investment decisions. As discussed in section 6.2, the prices of renewable energy technologies have reached a level where they are beginning to be economically competitive with fossil fuel technologies. If taxes and regulation can be designed in a way that does not distort the economic balance between technologies, then electrification of transport will be privately profitable in the near future. This leads to a situation in Iceland where almost all CO₂ emissions will be gone by 2035 without subsidising electric vehicles or electrification in general.

Today, Iceland relies almost exclusively on hydropower and geothermal power. However, the utilisation of the existing reservoirs is close to the limit. At the same time Orkustofnun expects limited development of greenfield geothermal projects and large reservoirs. In a future with increased electrification of the transport sector and fishing industry, new electric generation capacity is projected to be based on wind power. By 2035, the model projections suggest that an additional 130 MW of wind turbines will have been installed.

9. The Faroe Islands

Figure 28: Map of Faroe Islands with main power cables and power production units

Power grid

Source: SEV Grid accounts 2016.

9.1 Overview

Table 6: Final energy consumption in the Faroe Islands, PJ 2015

Sector	Electricity	District heating	Fuel	Total
Commercial	0.37	0.02	0.47	0.86
Industry	0.40	0.00	3.87	4.27
Residential	0.28	0.06	1.54	1.88
Transport	0.00	0.00	2.67	2.67
Total final energy consumption	1.05	0.08	8.55	9.67
Total primary energy consumption	1.96	0.13	8.55	10.64
CO ₂ emissions per capita				16

The Faroe Islands is a small group of islands in the northern part of the Atlantic Ocean north of Scotland. Most of the islands are populated, although only six of the total of 18 islands have a population exceeding 1,000. The capital of Tórshavn is located on the largest island Streymoy. The total population is approximately 51,000 with approximately 20,000 living in Tórshavn. The islands are mountainous and not suitable for agriculture. Therefore, the main place of settlement is on the coast.

The Faroese government has set a very ambitious target for renewable energy in the power sector:

- By 2030, all power must be produced using renewable energy sources.
- By 2025 oil consumption for heating must be halved (individual oil boilers are the primary source of space heating today).

9.1.1 Energy

The national energy company SEV supplies electricity through two electricity grids, one in the north and one in the south. The northern system provides electricity to approximately 90% of the population and most of the islands in the northern part of the Faroe Islands. The southern system provides electricity to Suðuroy, where approximately 10% of the population lives. A few smaller islands are not supplied with electricity through either of the two main grids.

Figure 29: Hourly climate data, Faroe Islands (Thórshavn)

The wind conditions in the Faroe Islands are suitable for wind energy due to regular high wind speeds with rare extremes. As Figure 29 shows, the wind speed is between 5 and 15 m/s most of the year (based on the forecast system CFSR2, just north of Tórshavn). Today, wind power production covers approximately 16% of the total electricity consumption in the Faroe Islands.

The Faroe Islands have a good potential for harnessing wind power for electricity and heating. Thus, the national power supplier SEV is working on many innovative solutions such as balancing wind power with batteries, storing electricity as heat, pumped storage and using heat pumps and electric boilers as flexible demand.

There are three wind farms in the Faroe Islands, all of them supplying electricity to the northern grid. SEV owns a wind farm at Neshagi, consisting of five turbines from 2012 with a total capacity of 4.5 MW and a wind farm at Húsahagi, consisting of 13 wind turbines from 2014 with a total capacity of 11.7 MW. The private company RØKT owns the third wind farm located at Vestmanna. This wind farm consists of three wind turbines from 2003 with a total capacity of 2 MW.

Another source of electricity with high potential is hydropower. SEV has 10 hydropower plants at four locations. Eight of them (at Vestmanna, Eiði and Strond) are located in the northern electricity grid, and two of them (at Botnur) are located in the southern electricity grid. The total capacity of the hydropower plants is 40 MW. All hydropower plants have a water reservoir. The total electricity storage capacity of the reservoirs is 13,000 MWh. The first hydropower plants were built in Suðuroy in 1921 and in Klaksvík in 1931. The construction of the three power stations and dams in the area north of Vestmanna was done in the period from 1953 to 1961. The hydropower station with two turbines in the northern part of Eysturoy (Eiði) was connected to the system in 1989 and extended with a third turbine in 2003. Their expected total life time is up to 100 years, so most of the plants still have many years of production left. The annual production of hydropower in the Faroe Islands is around 106,000 MWh (or 33% of the annual electricity consumption).

The rest of the electricity is produced by SEV's thermal generators (13 generators at four different locations). The main power plant is at Sund, just north of Tórshavn. The plant has six generating sets (four use HFO, two small high-speed engines uses diesel) with a total capacity of approximately 47 MW, of which 25 MW are supplied by two very old sets. SEV is planning the installation of new generators at this site with a capacity of approx. 37 MW. Besides Sund, the Strond power station is connected to the main grid. Strond has three diesel generating sets of approximately 6 MW in total capacity. The southern electric grid has two power stations, Vágur with three HFO generating sets of approximately 10 MW in total capacity and Trongisvágur with one diesel generator of approximately 2 MW.

There is also a potential for solar power as solar radiation in the summertime peaks at roughly 800 W/m². However, solar radiation is subject to very high variability and is negatively correlated with electricity consumption meaning a high need for energy storage. PV installations do exist in the Faroe Islands and the experiences from these will help clarify whether more PV panels are relevant.

9.1.2 Industry

The Faroe Islands have a large fishing industry and a modern fleet of big fishing vessels which consumes a huge amount of fuel oil and diesel. The fishing industry is a cornerstone in the Faroese economy and is heavily dependent on oil prices. The Faroese fishing industry is starting to investigate the possibilities for transitioning away from oil, possibly towards electrification.

9.2 Scenario analysis

The results presented below focus on subjects specific to the Faroe Islands. Subjects of a more general nature with relevance to all regions are dealt with in section 6.

9.2.1 Scenario Definitions

In the TIMES model framework, the *BAU* scenario is unconstrained in terms of CO₂ emissions. The model simply minimises the total discounted system costs of delivering all demands. The BAU results in a baseline of CO₂ equivalents emissions in 2015 of ~600 thousand tonnes (~12 tonnes/capita). Specific emissions which the model does not account for are process emissions from agriculture and waste incineration.

In the alternative scenarios *2DS* and *CNS*, the model is restricted in terms of how much CO₂ can be emitted in the target year 2035.

The carbon emissions in 2035 in a *2DS* (2 Degree Scenario) are restricted to 4.7 tonnes of CO₂ equivalents per capita. This is a 60% reduction of the emissions compared to 2015 levels.

The carbon emissions in 2035 in a *CNS* (Carbon-Neutral Scenario) are restricted to 1 tonne of CO₂ equivalents per capita.

9.2.2 Scenario projections

This section presents the results of TIMES model runs. The results are based on a number of simplifying assumptions described in section 4.2.1 and should be interpreted in that light. In this case, the TIMES model was specified with focus on technology choices in the absence of distortions from taxes and regulation. The results will point to trends in the relative cost of different technologies and how a green transition can be achieved in the least costly manner. This can be used to guide the political work needed to redesign taxes and regulation in support of the technology choices demonstrated here. The presentation of the results begins with the total CO₂ emissions in each scenario. The required CO₂ emission reductions naturally lead to a description of the total costs and technologies involved in achieving those reductions. Lastly, we take a look at the evolution in primary energy consumption over time.

Emissions

Greenhouse gas emissions in the Faroe Islands are projected to decline rapidly over the next 20 years. Minimising system costs in an unrestricted model run results in a scenario in which total CO₂ emissions in 2035 are lower than the target emissions in the 2DS. This decline is driven primarily by electrification of heating and transport (both land and sea). In the next section, this transition is described in more detail.

The development in CO₂ emissions in the BAU as well as 2DS and CNS target emissions are shown in Figure 30. The bottom graph shows a sectoral break-down of emissions in the BAU in 2035.

Figure 30: Projected CO₂ emissions in the Faroe Islands

In the Faroe Islands, the TIMES model predicts that the CO₂ reductions in the BAU/baseline are not sufficient to reach the CNS emission target. This is primarily due to emissions from heavy sea cargo and fishing vessels. A Faroese energy system based on large amounts of wind power is not expected to be able to deliver enough energy for these purposes at a sufficiently low cost.

Costs and technologies

The Faroe Islands are projected to go through a rapid transition to electric heating and transport. By 2020, the TIMES model projects that most buildings in the Faroe Islands will be converted to heat pumps to supply heating. The prices of heat pumps and the associated energy efficiency gains are already sufficient to be economically viable in the absence of any distortionary taxes. By 2020, the TIMES model predicts that electrification of transport will also have begun to grow, beginning with light and heavy road vehicles and light maritime coastal vessels. Only after 2030 will the large ocean-going vessels begin a slow transition to hydrogen.

The large-scale electrification of the Faroe Islands projected by the TIMES model results in a considerable growth in demand for electricity. In 2015, the Faroe Islands consumed 0.84 PJ of electricity. By 2035, the TIMES model projects electricity consumption to reach 5 PJ annually. To deliver this electricity, the TIMES model predicts that an additional 240 MW of wind turbine capacity will be installed from 2015 to 2035. This is a massive capacity expansion from the existing 18 MW installed today. Such an expansion is contingent on electricity demand becoming much more flexible than it currently is. Heat storage, flexible load heat pumps and boilers, night-time charging of electric vehicles and other smart grid appliances are all critical if such a large expansion of wind capacity is to succeed. Again, it must be stressed that these results are model results. Models like TIMES are not designed for detailed system planning and do not take into account all the complexities of real-time power generation and distribution. The TIMES results point in a direction. Further studies, simulations and trials will have to be conducted to show if such an expansion of wind generation capacity is possible.

In order to meet the CO₂ emission target in the CNS, a large proportion of sea cargo and fishing vessels must be converted from fossil fuels to hydrogen fuel cells. In the CNS, the TIMES model predicts that additional wind turbines will be installed in 2030–2035, and a larger proportion of the heavy maritime transport will be converted to hydrogen in the same period. Due to the low efficiency of the hydrogen conversion chain (electricity – hydrogen – electricity – propulsion), the Faroese energy system (primarily wind) is too expensive to support this transition in the BAU. Imposing the CNS emission targets will result in an increase in total discounted system costs.

Figure 31: Total discounted value of system costs and savings in CNS

In Figure 31, we present the total discounted value of system costs and savings of achieving the CNS emission targets. The values represent net costs and net savings. Each sector will only be present in one of the two columns, as the sector has either a net savings or a net cost associated with the transition to the CNS. The energy system must be expanded to deliver considerable amounts of additional energy; this results in a net cost in the power sector. At the same time, converting to hydrogen propulsion results in a net savings in the fishing and transport industry due to fuel savings (the model does not transfer the cost of electricity to the consumers). Evaluating the cost levels, it is important to keep in mind that all costs and savings have been discounted to 2015 values. The present-day value of payments and income in 20 years is less than 40% at a 5% discount rate.

The net discounted system cost of the CNS amounts to EUR 1.4 million. This amount covers a much larger redistribution of costs. Increased costs in the power sector are to a large extent expected to offset savings in the fishing and transport sectors. In the real world, power costs would be transferred to the consumer through the price of electricity. In this case, if the price of electricity were to reflect the full cost of the power system, the needed investments in the fishing and transport sectors would not be economically feasible. Thus, the expected cost of EUR 1.4 million would need to be provided to the power sector as a government grant or through some other economic incentive.

Primary energy consumption

The total primary energy consumption is largely unaffected by the change in consumption patterns in the CNS. This is due to the relatively inefficient hydrogen chain, which results in an overall efficiency of ships close to that of fossil fuels. The Faroe Islands' primary energy consumption segmented by fuel is illustrated in Figure 32.

The main difference between the BAU and CNS lies in the distribution of energy consumption in 2035. The consumption of heavy fuel oil is lower, and the electricity consumption is higher.

Primary energy consumption in the Faroe Islands is expected to go through a rapid transformation over the next 20 years. From primarily fossil-fuelled in 2015, wind power takes over to become the most prevalent source of energy by 2030. The biggest change in primary energy consumption is projected to happen almost immediately. By 2020, almost all diesel consumption will have ceased; this diesel is used for heating today. The TIMES model projects a massive conversion of all heating from oil-based to electric heat pumps. After 2020, the decline in fossil fuel consumption slows down, as the transport and fishing sectors are projected to go through a more organic transformation. As vehicles and vessels reach the end of their technical life, they will be replaced by electric vehicles and coastal vessels.

Figure 32: Primary energy consumption in the Faroe Islands, 2035

Note: Abbreviations of fuel names are explained in the list of abbreviations in the beginning of the report.

9.2.3 Sensitivity analysis

This section looks into the sensitivity of technology choices when oil prices change, or the prices of the technologies involved increase relative to each other. Only the most interesting or central sensitivity results are presented in charts.

In the Faroe Islands, the impact of oil prices on the main results is more pronounced than in Iceland and Greenland. Figure 33 illustrates the effects of oil prices in a range from 20% (-0.2) lower than the current oil prices to 20% higher. In the Faroe Islands, the central unrestricted BAU scenario is not enough to meet the CNS emission target. If oil prices increase by more than 15% to 20%, this may change. In all the sensitivity runs, the choice of renewable energy technologies does not change, the rate of adoption simply slows down or speeds up.

Figure 33: Sensitivity to changes in oil prices, Faroe Islands

The prices of hydrogen fuel cell ships have very little impact on technology choice and rate of adoption in the Faroe Islands. The results of the sensitivity runs are illustrated in Figure 34.

Figure 34: Sensitivity to cost of hydrogen fuel cell ships, Faroe Islands

In addition to these sensitivity analyses, a special model run was attempted to test the viability of a transmission cable between the northern grid and the southern grid on Suderøy. The test showed beyond any doubt that there is no benefit from connecting the two grids. This is mainly due to the very similar conditions in the two grids. The

strength of the large transmission cables in Europe lies in the ability to balance different generation types and climatic conditions.

9.3 Recommendations

The scenario analysis shows that the Faroe Islands have a challenge in reaching the carbon neutral emission target of 1 tonne of CO₂ equivalents per capita. The total net cost of the transition to the CNS is quite manageable (estimated EUR 1.4 million), but this net effect covers a more substantial redistribution of costs from industry and transport to the power supplier. Removal of any distortionary regulation and taxes will create the foundation for large reductions in emissions. However, the dependence on intermittent power generation for a large proportion of the energy supply will require economic incentives to make the final transition to the carbon neutral emissions target.

Maritime transport and fishing is the primary challenge that must be overcome to reach the 1-tonne target. The scenario analysis suggests that hydrogen fuel cells could be a cost-efficient solution. However, hydrogen production has a very low efficiency, which does not correlate well with an energy system that relies on relatively costly wind power. On the other hand, not all the benefits of the energy storage capabilities of hydrogen could be taken into account in the TIMES model. The dual role of hydrogen as fuel and electric storage unit should be explored further.

As in many of the other Arctic regions, electrification of heating is a low-hanging fruit in the Faroe Islands. The main barriers to this transition lie in distortionary energy taxes and lack of private financing options for low income households. At present, and in the absence of taxes and other distorting regulation, the total cost of heating from heat pumps and electric boilers is lower than from fossil fuels. This cost difference will only become greater, as the cost of heat pumps continues to decrease.

10. Svalbard

Figure 35: Map of Svalbard (Source: Norwegian Polar Institute)

Table 7: Final energy consumption in Svalbard, PJ 2015

Sector	Electricity	District heating	Fuel	Total
Non-transport	0.15	0.24	0.04	0.43
Transport	0.00	0.00	0.07	0.07
Total final energy consumption	0.15	0.24	0.11	0.50
Total primary energy consumption	0.15	0.24	0.89	1.28
CO ₂ emissions per capita				37

10.1 Svalbard

Svalbard is a group of islands in the North Sea and are part of the Kingdom of Norway. The town of Longyearbyen is the largest settlement in Svalbard with a population of about 2,600. In recent years, climate gas emissions in Svalbard, measured in CO₂ equivalents, have been about 80,000 tonnes (emissions from vessels, air traffic and light vehicles are not included). In Svalbard, more than 37 tonnes of CO₂ equivalents are produced per capita due to local energy consumption being based on coal and mining, while on the Norwegian mainland, the figure was 7 tonnes per capita.

The local government of Longyearbyen owns and operates the Longyearbyen combined heat and power plant. The energy plant was commissioned in 1982 and is based on two coal-fired boilers as well as two generators for the production of electricity and district heating. Maximum power at the plant is 10 MW of electric power and 20 MW of district heating. It produces about 42 GWh of power annually. The power supply from the power station covers the demand of all buildings in Longyearbyen. The number of connected consumers is nearly 1,700. The Longyearbyen power station has been upgraded to extend its lifetime by 25 years to 2040. However, the coal mine is due to close within 10 years. When the mine is closed, the power plant is expected to be displaced. From a climate perspective, it would be unthinkable to continue with the current level of emissions for such a long time, which is why it is essential that the local authorities put Svalbard's energy supply high on their agenda. Many solutions have been investigated – both traditional renewable energy solutions and emerging technologies. Among the suggested solutions are LNG, hydrogen, geothermal energy and bio coal.

The power and heat production in Longyearbyen is in a special situation compared with most power stations on the Norwegian mainland. This is because there are no power transmission lines from the mainland to Svalbard, which makes the island completely dependent on its own capacities. In addition, a robust and harsh climate makes the risk and vulnerability of power supplies in Svalbard greater than on the mainland.

A reserve power station with diesel-powered generators near the main power station is used as a backup capacity. The four diesel engines are designed to cover the need for emergency and short-term reserve power which can be used in case of failures

of the Longyearbyen's coal-fired plant. The diesel generators are also in use if the energy demand exceeds the coal plant's capacity.

Furthermore, a new reserve power station located further east, outside the existing power station area was put into operation in 2009. In addition, there are five external plants with diesel-fired boilers for the supply of district heating in the event of a failure in the supply from the main power plant, as well as a spare boiler inside the main power plant with a capacity of 5 MW.

Figure 36: Hourly climate data, Svalbard (Longyearbyen)

In terms of renewable energy potential, the climate data in Figure 36 shows that there might be a potential for wind power, while the potential for solar power is limited. Solar radiation tops at 600 W/m² in the summer, with high variability.

10.2 Scenario analysis

The results presented below focus on subjects specific to Svalbard. Subjects of a more general nature with relevance to all regions have been dealt with in section 6.

Svalbard lacks – like most of the other Arctic areas – local renewable fuels and natural energy storage (such as hydropower). Imported fuels will therefore probably be necessary in a carbon-neutral scenario to cover the power peak load demands when the wind is not blowing.

In the Svalbard scenarios for 2035, wind power and electrification of the heat and transportation sectors are central in the energy system.

10.2.1 Scenario definitions

In Svalbard, the carbon emissions in 2035 in a *BAU* (Business as Usual Scenario) are projected to be 37 tonnes.

The carbon emissions in 2035 in a *2DS* (2 Degree Scenario) are projected to be 15 tonnes, assuming a 60% reduction in emissions compared to the BAU scenario.

The carbon emissions in 2035 in a *CNS* (Carbon-Neutral Scenario) are projected to a maximum of 1 tonne of CO₂ equivalents per capita, coming only from transportation.

10.2.2 Scenario assumptions

The only power production possibilities (without imported fuels) will be wind and solar power. Because we assume large amounts of electricity consumption during winter due to electrification, PVs have not been included in the scenarios. The cheapest way to use the surplus electricity when present is to produce and store heat. Batteries will still be necessary (also because of the balancing need), but they are much more expensive compared with simple heat storage. Both the batteries and the heat storages will be used daily. Heat production is assumed to be supplied by both electric boilers and ground heat pumps. The heat pumps are very efficient, but also expensive. Therefore, these are limited to supply the base load heat demand.

10.2.3 Scenario projections – Svalbard

Today, most of the energy production in Svalbard is based on coal-fired plants. These provides both electricity and heat. The transportation sector uses oil products. The coal mine is scheduled to close down within approx. 10 years. In the BAU scenario, the energy (for electricity, heat and the transportation sector) is assumed to be based only on oil products.

The conversion from coal to oil products will reduce CO₂ emissions somewhat. For further decreasing the CO₂ emissions – and reach the 2035 targets for the 2DS and CNS scenarios – renewable energy needs to be implemented. PV systems could be useful in the summertime but would not help at all during winter time. Therefore, wind power is considered the needed renewable energy production system.

Converting from inefficient coal plants to diesel plants along with an energy efficiency of 15% on the demand side will reduce CO₂ emissions significantly. To further bring down CO₂ emissions in Svalbard, the energy system could be based on wind power, heat pumps (ground heat), electric boilers, heat storage, batteries and diesel generators as back-up and peak load.

Figure 37: CO₂ emissions in Svalbard, 2035

Going from 2013 with coal as the dominant energy source to 2035 with an energy efficiency of 15% (consumption) and no coal reduces CO₂ emissions significantly. In the BAU scenario, CO₂ emissions are reduced by 56% in 2035 compared with 2013. In the 2DS, the CO₂ reduction is approx. 65% and in the CNS, CO₂ emissions are reduced by 89%. In 2035, in the CNS, CO₂ emissions are reduced to approx. 8 tonnes per capita. To reach the target of 1 tonne per capita, there will be a need for either further development with alternative energy solutions such as wind power, batteries and likewise or import of biofuels. In the figure above, the CNS target of 1 tonne per capita is met. If continuing with the implementation of wind power and batteries, the system will become very inefficient because of brief peak demands. The wind turbines and batteries will therefore have very limited full load hours/cycles. Therefore, biofuels are expected to be a part of the future fossil-free energy system. In the 1 tonne per capita emission scenario this corresponds to approx. 6,000 MWh of biofuels. Today the annual import of oil-based fuels is approx. 31,000 MWh.

Figure 38: Total investments in Svalbard

In all three scenarios, investments are made in diesel generators. In the 2DS and CNS, the generators are mainly used for back-up and peak load capacity. The investments in the transportation sector are assumed equal in all scenarios. In the BAU, an oil boiler is used for additional heating purpose. In the 2DS and CNS, a combination of wind turbines, batteries, heat pumps, electric boilers and heat storage is used to cover most of the energy demand. The rest is covered by diesel generators.

In the CNS, the conventional transportation units are converted into electric units.

Figure 39: Primary energy consumption in Svalbard, 2035

In the scenarios in 2035, coal plants are shut down. In the BAU scenario, diesel generators and boilers produce all the energy. In the 2DS, some wind power is added, and in the CNS, wind power produces most of the energy in Svalbard. In the 2DS, wind power produces approx. 23% of the total electricity production. In the CNS, wind power produces approx. 77% of the total electricity production. Much of the electricity is used for heating purposes.

The annual energy costs are presented in the figure below.

Figure 40: Annual energy costs in 2035 in Svalbard

The CO₂ reduction will lead to an increase in the annual energy costs in Svalbard. The scenarios have been developed with a criterion of the least consumption of bio fuels. Since the energy costs of 2DS and CNS are approx. the same, the CO₂ emissions in the two scenarios could be the same if biofuel import is not limited. In this case, the energy system in the two scenarios would be the same. The reason for trying to limit the consumption of biofuels is that it makes the energy system dependent on imported fuels. With an increased global demand for biofuels, this could have negative consequences for Svalbard.

10.2.4 Sensitivity analysis

Wind power as the only way of producing electricity is not very robust and biofuels or diesel oil will be necessary – at least as back-up capacity. Oil generators are not expensive, so this will not have significant influence on the annual energy costs.

The ground heat pumps could lead to higher investment costs than anticipated in this analysis and this will both increase the annual costs of the 2DS and CNS and also move some of the investments from heat pumps to more electric boilers.

10.3 Recommendations

The main challenge in Svalbard will be the closing of the local coal mine within the next 10 years. Most electricity and heat in Svalbard comes from the coal-fired plant. The solutions being explored include a transmission cable to mainland Norway, wind and solar power. Solar energy could be relevant if the power were to feed into a more controlled energy system (fuel-based). During summer, much energy could be produced (almost 24 hours a day) but there be no power production from solar power during winter – where power consumption will be significantly higher than during summer. Controlled energy system is here meant as a fuel-based system where production of energy can be scheduled, such as a with generator. Wind power looks to be a much more promising solution, as the wind is available year-round. If wind power is introduced on a large scale there, will be no demand for solar power during the summer. Smart energy consumption and energy efficiencies in the consumption will be a very important focus. If the amount of electricity consumed by smart units is increased, it will lessen the need for batteries and increase the utilisation of wind power production.

11. Jan Mayen

Figure 41: Map of Jan Mayen

Source: Norwegian Polar Institute.

Table 8: Final energy consumption on Jan Mayen, PJ 2015Sector

	Electricity	District heating	Fuel	Total
Non-transport	0.005	0.005	0.006	0.01
Transport	0	0	0.0006	0.0006
Total final energy consumption	0.005	0.005	0.006	0.01
Total primary energy consumption	0.005	0.005	0.006	0.01
CO ₂ emissions per capita				63

11.1 Jan Mayen

Jan Mayen is an isolated island located 500 km east of Greenland, 550 km northeast of Iceland and 1,000 km west of the Norwegian mainland. Jan Mayen represents the northernmost island on the Mid-Atlantic Ridge and has the world's northernmost active volcano system above sea level. Glaciers cover about 30% of the island's area around the volcano. There are no residents on the island, but a crew of 20 people from the Norwegian military and the Norwegian meteorological institute, who work on the Island in six-month shifts.

Since 2005, there has been a diesel-fuelled combined heat and power plant located near the settlement in Olonkintown, which consist of two tanks of 500 m³ each. As there is no harbour established on the island; supply of diesel takes place from ships from the coastal guard via a 500 metre underground pipe system 1–2 times a year. One bunkering site is established in the area of Båtvika. The average power generation is 200 kW.

Jan Mayen also has three containers with refuelling equipment for aeroplanes at the airport. The three containers of 6 m³ each are placed above the ground and were installed in 2000 and upgraded in 2004.

Figure 42: Hourly climate data, Jan Mayen (east of Beerenberg)

The wind profile on Jan Mayen resembles that of the Faroe Islands and thus reveals a large potential for wind power. However, since Jan Mayen is populated only in the summer, when wind speeds are lowest, wind may not be the best solution for Jan Mayen. Solar radiation is close to 700 W/m² in the summer, which means that PV production is feasible, and it would align better with the seasonal demand.

11.2 Scenario analysis

The results presented below focus on subjects specific to Jan Mayen. Subjects of a more general nature with relevance to all regions have been dealt with in section 6.

Jan Mayen lacks – like most of the other Arctic areas – local renewable fuels and natural energy storage (such as hydropower). Imported fuels will therefore probably be necessary in a carbon neutral scenario to cover the power peak load demands when the sun is not shining.

11.2.1 Scenario definitions

On Jan Mayen, carbon emissions in 2035 in a *BAU* (Business as Usual Scenario) are projected to be 50 tonnes.

Carbon emissions in 2035 in a *2DS* (2 Degree Scenario) are projected to be 20 tonnes, assuming a 60% reduction in emissions compared to the BAU scenario.

The carbon emissions in 2035 in a *CNS* (Carbon-Neutral Scenario) are projected to a maximum of 1 tonne of CO₂ equivalents per capita, coming only from transportation.

11.2.2 Scenario assumptions

The only power production possibilities (without imported fuels) will be wind and solar power. Since energy demand is present only during the summer (with relatively many hours of sun because of the northern location), PVs seem to be an ideal solution for electricity production. Wind turbines could, of course, supplement the PVs. During the summer, this would probably be very relevant, but during the winter, the power could not be utilised. Wind power is therefore not included in the future energy system on Jan Mayen. The cheapest way to use the surplus electricity when present is to produce and store heat. Batteries will still be necessary (also because of the balancing need), but they are much more expensive compared with simple heat storage. Both the batteries and the heat storages will be used daily. Heat production is assumed to be supplied by electric boilers. Heat pumps are very efficient, but also expensive and with a limited number of full-load hours, these are not included in the future energy system. The electric boilers will also support the electricity grid with balancing features.

11.2.3 Scenario projections – Jan Mayen

The primary energy consumption in the BAU in 2035 is the same as today: a diesel generator for electricity production and an oil boiler for heat production. However, due to solar energy being available most of the day in the summertime (midnight sun) and the fact that the island is populated only during the summertime, PVs are very relevant. In both the 2DS and CNS, an energy system consisting of PVs, electric boilers, heat storage and batteries are used as main energy suppliers. In both systems, a diesel generator will be used as back-up and peak capacity.

In both the 2DS and CNS, electric boilers are used during daytime to produce heat for the whole day. Heat that is not used immediately is stored until night-time in a heat storage. The electricity consumed by the electric boilers is primarily produced by PV systems. In the 2DS, the power from the PV systems is mainly used during daytime. During night-time, the diesel generator produces electricity for non-heating purposes. The need for batteries is therefore limited. In the CNS, where diesel needs to be limited further, a battery is used to store electricity until night-time. The diesel generator will mainly be used during night-time in spring and autumn, when power generation from the PV system is limited.

In the BAU scenario and the 2DS, the transportation sector is based on regular diesel vehicles. The diesel consumption of these is quite limited compared with that of the energy sector (electricity and heating). In the CNS, transportation is converted into electric vehicles.

PV systems seem to be very attractive for Jan Mayen. However, due to the huge energy demand per capita, it will be rather expensive to reach the 1 tonne per capita target in the CNS. In the Jan Mayen analysis, the CNS target of 1 tonne per capita is not met. If so, there would be a need for very large investment in units which will only be used for peak loads in spring and autumn. The energy demand is in the area of 10 times that of a regular household.

Figure 43: CO₂ emissions on Jan Mayen, 2035

The CO₂ emissions from the BAU will be the same in 2035 as today. In the 2DS, the use of PVs as the main energy producer has reduced the CO₂ by approx. 60%. Most power production from the PVs will be used. In the CNS, CO₂ emissions are reduced by approx. 84% compared with the BAU. This corresponds to approx. 8 tonnes per capita. If the capacity of the PV system was increased from 3 to 4 MW and the battery capacity were increased from 2 to 3 MWh, this would reduce CO₂ emissions by a few tonnes per capita. However, the extra capacity would only be used very rarely and would therefore be very expensive. To reach the target of 1 tonne per capita, approx. 800 MWh of bio-oil/biodiesel could be imported to replace the current oil-based consumption in the energy system. Today, Jan Mayen imports approx. 6,000 MWh of diesel. In the figure above, biofuel is included to reach the target of 1 tonne per capita.

Figure 44: Total investments on Jan Mayen

In the BAU and 2DS, the transportation sector will still be based on fossil fuels. This is due to the fact that the energy system is still largely based on fossil fuels and the use of electric vehicles is not found to be appropriate. In the CNS, there will be a surplus of electricity production from renewable sources, which makes electric vehicles much more relevant.

In all three scenarios, investment costs for diesel generator capacity are assumed to be the same, assuming that there will be a need for back-up capacity from diesel.

The difference in the scenarios is therefore the investments in PV systems, batteries, heat storage and electric boilers. In the 2DS, the energy system is based on 1.7 MW PV systems, 1.5 MW electric boilers, 500 m³ heat storage, only a minimum of battery capacity and a diesel generator for back-up and peak load capacity. In the CNS, the energy system is based on 3 MW PV systems, 3 MW electric boilers, 1,000 m³ heat storage, 2 MWh battery capacity and a diesel generator for back-up and peak load capacity.

In the CNS, the transportation sector is electrified.

Figure 45: Primary energy consumption on Jan Mayen, 2035

In the BAU scenario, all energy and all fuel consumed are oil products in 2035 (just as today). In the 2DS, approx. 76% of the electricity produced (including electricity for heating purposes) is from the PV systems. In the CNS, the power produced from the PV systems amounts to approx. 96%.

The annual energy costs are presented in the figure below.

Figure 46: Annual energy costs in 2035 on Jan Mayen

The CO₂ reduction will increase the annual energy costs on Jan Mayen. The scenarios have been developed with a criterion of the least consumption of bio fuels. In the current 2DS, there is no use of imported bio fuels. The reason for trying to limit the consumption of biofuels is that it makes the energy system dependent on imported fuels. With an increased global demand for biofuels, this could have negative consequences for Jan Mayen.

11.2.4 Sensitivity analysis

Electric boilers are quite stable and will therefore be safe as a heat production technology. However, being dependent on PV/batteries, will make the system more unstable.

PVs, as the only way of producing electricity, are not very robust and biofuels or diesel oil will be necessary – at least for back-up capacity. Oil generators are not expensive, so this will not have significant influence on the annual energy costs.

11.3 Recommendations

The energy consumption on Jan Mayen is concentrated in the summer half of the year. This provides a clear opportunity to base the energy system on solar power. Solar power will have very high utilisation time because of the location north of the Polar Circle and is therefore ideal for Jan Mayen. Wind power could be relevant as a supplement in summer, but the utilisation will be very low because there is no energy consumption in winter. Smart energy consumption and energy efficiencies in consumption will be a very important focus. If the amount of electricity consumed by smart units is increased, it will reduce the need for batteries and increase the utilisation of solar power.

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Sammenfatning

Scenarieanalyse

Formålet med at udarbejde denne scenarieanalyse har været at identificere den økonomisk mest fordelagtige vej til at opnå et bæredygtigt 2035 scenarie og samtidig støtte den vestnordiske og arktiske region i at nå deres langsigtede klima- og energimål. Projektet omfatter områderne Island, Grønland, Færøerne, Svalbard og Jan Mayen.

Regionen består af øer, der ikke er forbundet til hinanden eller til fastlandet i Europa eller –Nordamerika. Hertil er der flere af områderne, hvor der findes flere uafhængige elsystemer. På grund af disse mange mindre systemer er de fleste områder yderst afhængige af lokale produktionsanlæg og brændselsimport. Da en stor del af brændselsforbruget til energiproduktion kommer fra olie, er der et stort potentiale i konvertering af disse energisystemer til vedvarende energisystemer.

Udsigterne til en kobling såvel internt i regionen som til fastlandene er en tilbagevendende diskussion. Fordelene vil være en øget forsyningssikkerhed og brugen af større anlæg til produktion i stedet for mange decentrale anlæg. Omkostningerne til etablering af kablerne vil dog blive meget høje på grund af de store afstande og de udfordrende forhold. Dette analyseprojekt fokuserer på en fremtidig forsyning uden inter- eller intraregionale udbygninger af elforbindelserne områderne imellem.

Alle områderne er karakteriseret ved lange, kolde vintre og korte kølige somre. Dette medfører typisk, at der vil være behov for varmforsyning hele året. For nogle områder kan de klimatiske forhold dog give et mindre fluktuerende energiforbrug, da forskellen mellem varmebehov om sommeren og om vinteren ikke er væsentligt (eksempelvis Færøerne). For andre områder vil dette ikke være tilfældet (eksempelvis det nordlige Grønland).

Hele regionen er dybt afhængig af skibstransport. Langt størstedelen af handlede varer til og fra regionen sker gennem skibstransport. Hertil er fiskeri en væsentlig økonomisk aktivitet i regionen. Fiskeri udgør næsten halvdelen af den samlede eksport fra Island i 2016. I Grønland og Færøerne udgør fiskeri mere end 90 % af den samlede eksport. Skibstransport er således afgørende for økonomien i regionen. Skibstransport er dog samtidig er stor udfordring i forbindelse med omstillingen til et fossilfrit samfund, da mulighederne i dag stadig er ringe for konvertering til biobrændsler eller el til fremdrift. Skibstransport er derfor, udover el, varme og landtransport, en central del af analysen.

Fordeling af energiforbruget i de fem områder i regionen fremgår af nedenstående figur. Til sammenligning vises fordelingen også for de nordiske lande.

Figur 47: Fordeling af energiforbrug

Af de fem områder i regionen udgør Island langt den største andel i forhold til indbyggerantal. Islands el- og varmeforsyning er i dag næsten 100 % baseret på vedvarende energi (vandkraft og geotermi) og der er derfor ikke nogen udfordringer for Island i forbindelse med at opnå en el- og varmeforsyning baseret på vedvarende energi.

I Grønland, Færøerne, Svalbard og Jan Mayen udgør vedvarende energi dog mindre end 15 % af energiforbruget. Færøernes elforsyning indeholder en stor del vand- og vindkraft, men varmeforsyningen og transportsektoren er stort set udelukkende baseret på olieprodukter. I Svalbard er energiforsyningen i høj grad baseret på kul på grund af en lokal kulproduktion.

Der er udarbejdet scenarier for alle fem områder, hvor CO₂-reduktionsmål har været i fokus. Udover et business as usual scenarie, som skal repræsentere en situation uden væsentlig nye tiltag, er der blevet foretaget analyser for et såkaldt 2-graders scenarie og et CO₂-neutralt scenarie. Målene har her været hhv. en reduktion af CO₂-emissionen med 40 % i 2030 i forhold til 2015 og en CO₂-emission på 1 ton per indbygger.

Resultaterne af analysen peger i høj grad på, at de fleste områder vil kunne foretage rentable implementeringer af vedvarende energi i deres el- og varmesystemer, således at CO₂-emissionen reduceres markant. Der er ikke taget højde for de politiske og adfærdsmæssige tiltag der vil skulle kræves, for at indpasningen af vedvarende energi realiseres.

Fremtiden for el- og varmeforsyningerne i regionen vil baseres på brændselsfrie elproduktionsteknologier og varmepumper. For Island vil geotermi fortsat være en central del af energiforsyningen. På grund af elektrificeringen af varmesektoren og de høje oliepriser peger analysen ligeledes på en elektrificering af transportsektoren som en rentabel fremtidig løsning.

Tilbage er primært skibstransport som udfordringer for at nå CO₂-målene i analysen. I forhold til skibstransport, herunder fiskeri, findes brændselsceller i analysen at være en relevant lavemissionsløsning. Dette vurderes ikke umiddelbart at være billigere end den nuværende forsyning, men dog en teknisk mulig løsning med begrænsede CO₂-emissioner.

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ENERGY IN THE WEST NORDICS AND THE ARTIC

This project explores the energy systems and their development towards 2035 in the West Nordic areas and the Arctic. The objective of the project was to contribute to a knowledge base that can be shared and used in developing a sustainable and competitive energy systems that fulfil the goals and obligations for 2035 on climate, emissions and renewable shares. "Energy systems" in this case covers the potential for different renewable energy resources, infrastructure, the demand for energy in different sectors, and relevant policies.

Along with the scenario analysis, five case studies have been developed: land transport; a small hybrid energy system in Igaliku, Greenland; electrification of fishing vessels; tourism; and the future energy system in Svalbard.

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