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Transitioning remote Arctic settlements to renewable energy systems – A modelling study of Longyearbyen, Svalbard

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HIGHLIGHTS

- We present a new stochastic long-term energy model for a remote Arctic settlement.
- We show the importance of a proper representation of solar and wind variability.
- An energy system based on renewables is found feasible, reliable and affordable.
- Energy efficiency plays an important role in a transition to a low carbon settlement.
- Allowing some CO_2 emissions reduces costs and improves energy security.

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ABSTRACT

As transitioning away from fossil fuels to renewable energy sources comes on the agenda for a range of energy systems, energy modelling tools can provide useful insights. If large parts of the energy system turns out to be based on variable renewables, an accurate representation of their short-term variability in such models is crucial. In this paper, we have developed a stochastic long-term energy model and applied it to an isolated Arctic settlement as a challenging and realistic test case. Our findings suggest that the stochastic modelling approach is critical in particular for studies of remote Arctic energy systems. Furthermore, the results from a case study of the Norwegian settlement of Longyearbyen, suggest that transitioning to a system based on renewable energy sources is feasible. We recommend that a solution based mainly on renewable power generation, but also including energy storage, import of hydrogen and adequate back-up capacity is taken into consideration when planning the future of remote Arctic settlements.

1. Introduction

Remote Arctic energy systems are usually characterised by a dependence on imported fossil fuels [1,2]. Concerns about volatile fuel costs, energy security, and climate change give rise to many remote Arctic communities looking towards renewable energy sources as potential solutions. Rapid cost-reductions and technological development have led to renewables becoming an increasingly attractive option. Particularly solar and wind are emerging as mature and cost-competitive technologies, even for energy systems in remote Arctic locations.

The transition to future energy systems is often aided by the use of energy modelling tools. Several tools exist, with various capabilities, features and applications ranging from analysis of detailed power systems to the global energy system (see reviews by Connolly et al. [3], Ringkjøb et al. [4], Hall & Buckley [5] and Foley et al. [6]). Many previous modelling studies have looked at remote isolated communities, but there are only a few focusing on Arctic locations [7,8]. For example, the HOMER (Hybrid Optimization of Multiple Energy Resources) modelling tool [9] was applied to study the electricity system serving the small settlement at the island of Grimsey located north of Iceland (66.5°N) [1]. They analysed three scenarios for delivering electricity, respectively a diesel-wind, diesel-wind-hydrogen and a wind-hydrogen scenario. Their results showed that a system consisting of wind, hydrogen and diesel was recommended, achieving a renewable energy fraction of 92% and a payback period of less than four years. Furthermore, the TIMES (The Integrated MARKAL-EFOM System) modelling framework [10] was used to study the energy system at the Faroe Islands (62°N) [11], highlighting the importance of electrification of heating and concluding that renewable energy technologies will be competitive with fossil fuels in a very short time, even in the Arctic. Streymoy, the largest island on the

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Faroe Islands, was also one of six islands investigated in a study using a MATLAB/Simulink model to determine cost-optimal system configurations [12].

A larger literature has addressed remote and isolated locations at lower latitudes, such as the island of Pulau Ubin north-east of Singapore [13], the island of Dia in the Cretan Sea [14] and other locations in the Mediterranean [15] Even though the climatic conditions in such locations are vastly different from the Arctic, several similarities make these studies relevant also in an Arctic context. Many of these locations are also dependent on imported fossil fuels, have a need of improving energy security and a large distance to highly populated areas. They are therefore evaluating renewables as alternatives [8].

Wind and pumped hydro storage (PHS) was for example evaluated for increasing the share of renewables and aid in desalination of water on the S.Vicente Island in Cape Verde in a study using the modelling tool H_2RES [16]. Furthermore, a 100% renewable electricity supply for Reunion Island was modelled in TIMES [17], with large amounts of solar, biomass, and important contributions from storage and demand response. TRNSYS [18] was used in combination with HYDROGEMS [19] in a modelling study of the former wind/hydrogen demonstration project at Utsira in Norway [20]. The goal of this demonstration project was to demonstrate how hybrid renewable energy and hydrogen systems could provide electricity to communities in remote areas. The authors concluded that the project successfully demonstrated the potential of wind/hydrogen systems to supply remote locations, but that technical improvements and cost reductions were needed to be competitive with existing solutions.

In this study, we use the TIMES modelling framework to develop and apply a new stochastic model for isolated Arctic settlements. The model takes into account the variability of short-term solar and wind generation as well as the uncertainty in electricity and heat loads. A common approach, also when modelling larger energy systems, is to treat solar and wind generation as deterministic inputs. This has previously been shown to potentially overestimate the contribution from variable renewable energy sources and lead to suboptimal investments [21–23]. Long term persistence is characteristic for geophysical time series including solar and wind resources [24]. In a harsh Arctic climate, where security of energy supply is crucial for the inhabitants, taking into account the possibility of periods with low solar and wind resources is highly important.

Stochastic modelling of short-term variability in TIMES is a relatively new technique, first applied in a study of the Danish energy sector [22], but which to the authors' knowledge has never been applied to local isolated energy systems. Our hypothesis is that a stochastic approach is even more important in a small isolated energy system than in a large national or international system. As has been pointed out by Connolly et al. [3], TIMES models have mainly been applied to study energy systems on larger scales up to the global energy system, and are not commonly used to assess remote and isolated communities. However, we believe that the stochastic approach enables the use of TIMES-based long-term energy models to study small isolated energy systems, thus widening the range of possible applications of the TIMES modelling tool.

The importance of a stochastic approach is investigated through a case study focusing on the Norwegian high-Arctic settlement of Longyearbyen (78.2°N). Presently, the settlement covers its needs for electricity and heat from Norway's only coal-fired power plant supplied by locally mined coal. With a declining coal industry, an old energy infrastructure, and the use of greenhouse-gas-emitting coal as the main source of energy, there is a need of planning for securing the future energy supply. This makes this study highly relevant to decision-making, and well suited for investigating the importance of a stochastic modelling approach for remote communities in general.

The objective of the present study is to develop a dynamic model to analyse and optimise an affordable and reliable future supply of electricity and heat primarily based on renewable energy sources and test it on a realistic case where necessary data are available. The model selects which energy system components to invest in over time based on bottom-up cost estimates for available components, minimizing total discounted investment and operational costs over the time period. The study demonstrates the importance of a realistic representation of solar and wind variability in long-term energy models, through the application of a stochastic modelling approach.

2. The Longyearbyen case-study

Longyearbyen was founded in 1905 for coal mining purposes, and is located on the Svalbard archipelago barely a thousand kilometres from the North Pole (see Fig. 1). Now, the more than century long coal mining era is coming to an end. Years of low coal prices have led to economic difficulties for the state-owned mining company "Store Norske Spitsbergen Kulkompani». In autumn 2017, the Norwegian government decided a permanent closure of the mines Svea and Lunckefjell [25]. This leaves the smaller mine number 7 as the only Norwegian coalmine to be kept in operation on Svalbard, and its main purpose is to supply the power plant in Longyearbyen. The coal reserves in mine 7 are expected to be able to supply the power plant for 10 more years, after which coal has to be imported if a new energy system is not in place.

Since Longyearbyen houses the only coal-fired power plant in Norway, there is particular political focus on reducing emissions from Longyearbyen. The power plant is the main component of the current energy system in the settlement, providing about 40 GWh electricity and 70 GWh heat to the about 2100 year-round residents and 150 000 person-days of visitors, mostly in summer [26,27]. Most of the electricity is consumed in the industrial sector, whereas households and the service sector consume the majority of heat [28]. The power plant was built in 1982 and faces challenges regarding ageing equipment, though recent and comprehensive upgrades have extended the potential lifetime of the plant for about another 20 years [27].

In addition to the coal-fired power plant, there are five diesel generators to cover peak electricity demand and to serve as reserve generation capacity. There is also a reserve heat-exchanger that can be fed directly with steam from the two coal-fired boilers in case of failure on the back-pressure turbine. Six oil-fired boilers are also placed around in the district heat network for reserve and to cover peak heat demand. There is also a small amount of solar PV installed in the settlement, about 57 kW on the airport and about 28 kW on residential buildings in Longyearbyen [29]. In total, the energy supply in Longyearbyen emits about 60 000 tons CO_2 annually [11].

Against this background, there is a need of planning the future energy supply of Longyearbyen. The Norwegian Ministry of Petroleum and Energy has already started investigating different options, and will decide the future of Longyearbyen's energy system in the near future [30]. The Norwegian Government stresses that the future energy supply in Longyearbyen should be sustainable and cost-effective, as well as provide adequate security of supply.