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Hydrogen storage for different energy supply and demand scenarios in Longyearbyen

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Abstract

The Norwegian government has a vision to phase out the last coal in Longyearbyen and transition to renewable energies. This transition demands flexibility in the energy system to deal with the variability of renewable generation technologies. Energy storage is one of the proposed solutions to satisfy energy demands during the long season of cold polar night where energy consumption is high. This paper investigates hydrogen as the solution for storage. Large intentions have been stated by industry and various governments. Yet criticism of them is frequent, citing concerns about costs and low efficiency. Previous studies commonly assume a demand pathway for the future development. Getting this right is crucial to their results. Yet this is very difficult and has been found to be off already in the short turn. By using data on energy and climate in Longyearbyen and energy system modelling, we have looked at different energy scenarios. For each scenario, we have devised a recommendation on if and how to store energy in hydrogen in the most efficient way. This way we strive to avoid strong dependence on the correctness of one demand or supply scenario and also hope to show different visions for a future energy system in Svalbard. Results suggest a strong deployment of hydrogen, at least in some scenarios.

Contents

1 Introduction

Longyearbyen is a settlement located on Svalbard, a remote archipelago in the arctic. Because of the geographic position, it has long periods with polar night and midnight sun. The supply of electricity and heat for the more than 2000 residents comes today mainly from a power plant relying on the local mining of coal. This supply is crucial for Longyearbyen because of the arctic climate, therefore the settlement has a reserve based on diesel in case of emergency (Tennbakk et al., 2018).

The power plant is costly in maintenance and has large CO_2 emissions, so the Norwegian government, under whose administration Svalbard falls, is pushing for a transition into a more environmentally-friendly energy supply (Energidepartementet, 2021).

2 Problem Statement

This switch of energy sources to renewables, like solar and wind, whose daily production of energy correlates with the weather, poses difficulties. Energy demand does not have the same daily fluctuations. Therefore, storage is vital to satisfy the demand in renewables based energy systems (Valmot, 2009). This is the case for many systems. What makes Longyearbyen special is the mentioned climate at Svalbard. There are periods without any sun and periods during which the sun never sets. To be able to supply energy sustainably throughout the whole year, seasonal storage might be needed. The wind energy output does not vary as much over a year as the solar power production, so wind power could be an alternative in the period of polar night. Yet, as stated in the report by Tennbakk et al. (2018), it is less favourable than solar power. Part of the reasons are the environmental impacts wind turbines can create. Ideally, the excess energy from solar production in the summer can be stored and either supply the demand fully or contribute as a supplement to other technologies in the winter period.

Due to the high energy density and ability for long storage, hydrogen has been identified as a promising energy carrier. Hydrogen produced through electrolysis from renewable energy has only water as a by-product (Ni, 2006). This makes it attractive for countries transitioning to a sustainable energy system. Yet, critics points towards relatively high costs and the comparatively low round-trip efficiency of the pathway from electricity to (hydrogen)storage and back to electricity compared to other options (Astiaso Garcia et al., 2016).

Both future energy demand and with the renewable power also energy supply are uncertain and difficult to predict. Often policies and economy are deciding factors. Is the government willing to install renewables that could have an environmental impact and possible face resistance from local communities? Do the inhabitants and companies of Longyearbyen have economic incentives to reduce their consumption? By investigating a specific case, like many previous studies have done, chances are that the results are inaccurate or become outdated quickly due to the uncertainty of the future.

3 Key findings

To tackle the mentioned uncertainty about hydrogen, we investigated the usage of hydrogen storage in a new local energy system using a model, which is described in detail in section 4.1.

To be less susceptible to the described problem with future demand and supply, we have created energy scenarios for Longyearbyen. The scenarios are based on renewable energy production by solar and wind on Svalbard. They have been chosen to represent extreme cases, because we wish to investigate a broad part of the demand spectrum. More information about them can be found in section 4.2.

In order to discuss the model results, we briefly have to describe the chosen energy scenarios for Longyearbyen:

1. Scenario 9y-highhigh: high demand and high supply of energy.
2. Scenario 9y-highlow: high demand and low supply of energy.
3. Scenario 9y-lowhigh: low demand and high supply of energy.
4. Scenario 9y-lowlow: low demand and low supply of energy.
5. Scenario 9y-main: default configuration the model ships with.

The two main findings of our study are:

- The scenarios with low supply are not feasible.

  From figure 1 it can be seen that the model uses the curtailment load to generate electricity. Curtailment is a prohibitively expensive source that is only included to be able to finish the model runs in scenarios which include less energy production than demand. The fact that it uses this implies that the energy system needs more capacity from the chosen supplying technology or be allowed to use more technologies. Closer inspection of figure 1 reveals that especially in winter there is a lack of producing alternatives.

- Hydrogen is a used in all scenarios.

  As can be seen in figure 2 hydrogen is used by the model in all scenarios. While the extent varies, it is present in all of them and a significant provider of storage in the scenarios with high energy supply. It is the main storage option in terms of size in the low demand scenario.

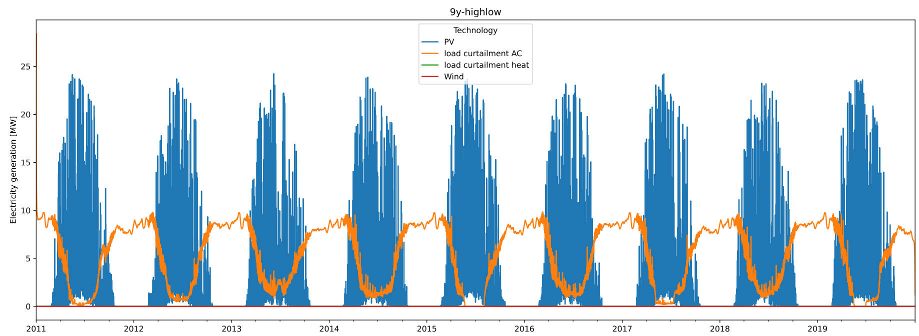

Figure 1: The electricity generation in MW from different sources in scenario 2.

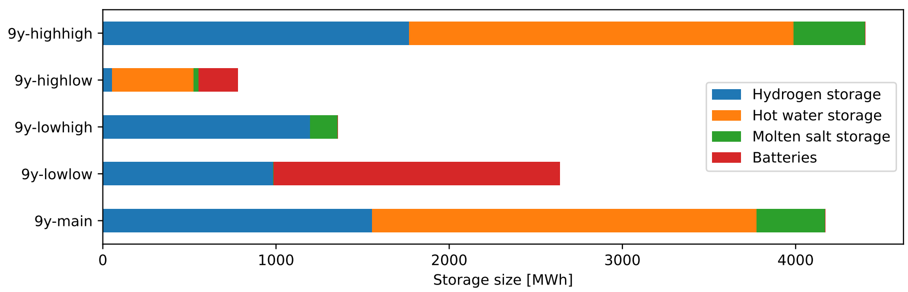

Figure 2: Storage size of different providers in MWh in all scenarios.

4 Details

4.1 Model

The energy system model from Greevenbroek and Klein (2021) was used to implement and evaluate the scenarios over the period from 2011 to 2019. Their paper contains a detailed explanation of the model itself. Additionally, it can be accessed at `gitlab.com/koenvg/pypsa-longyearbyen`. The used data for wind power for Longyearbyen and the surroundings was acquired by Grochowicz, Heineken, and Wennberg (2021). We have acquired solar data from `www.renewables.ninja` (Staffell and Pfenninger, 2016; Pfenninger and Staffell, 2016) and added it to the model.

The hydrogen storage we have chosen to model is compressed gaseous hydrogen in a steel tank, for which the cost and lifetime assumptions are based on Budischak et al., 2013. They draw their data from a presentation by Steward (2009).

4.2 Scenario explanation

The four chosen scenarios for demand and supply are explained below.

4.2.1 Demand

Projected trends in the electricity demand that are common to both scenarios are the electrification of transport and the shut-down of the coal-fired power plant and the mine.

The power plant itself and the coal mine use 30 % of the electricity consumption in Longyearbyen (Tennbakk et al., 2018). Arguably, the shut-down will have a severe impact on the energy demand.

While the current coal based electricity mix is unfavourable for the electric vehicle emissions reduction case, this could well change in the future. If Longyearbyen is mainly supplied by renewables, a change to electric cars could be considered as reasonable by the inhabitants. Charging infrastructure is in place and there is a small share of electric vehicles in the Longyearbyen car fleet already (Kvamme, 2020). An estimate of the electricity consumption for all personal electric vehicles per year was calculated by using the equation (1).

$$\text{kWh/year} = \frac{\text{kWH}}{\text{km}} \cdot \frac{\text{km}}{\text{year} \cdot \text{vehicle}} \cdot \#\ \text{vehicle} \tag{1}$$

	Value	Units	Source
Consumption per distance	0.2	$\frac{\text{kWH}}{\text{km}}$	Fjordkraft, 2021
Average travelled distance	10365	$\frac{\text{km}}{\text{year}\cdot\text{vehicle}}$	Norway, 2021
Number of cars	1200	vehicle	Mogård, 2017

Table 1: Values used in equation (1) to get yearly electricity consumption for personal cars in Longyearbyen.

If all personal vehicles were powered by electricity, it would add 2.5 GWh/year to the consumption. This will apply for both the high and the low scenario, as the assumption is that in the future there will be more incentives for electric vehicles.

Yet predicting future energy demand is complicated and relies on many factors, so these suggested scenarios are only assumptions.

4.2.1.1 High demand

For the high demand scenario, we have chosen a 10 % increase of the current electricity demand. With the vision of the government to close the coal mine and power plant, which would both reduce demand, this could very well be unlikely. Since we are striving for extreme scenarios, this will serve as a good high demand scenario. We assume that trends of increasing population and tourism, as well as strong electrification, would continue. In addition, higher energy demand could be the result of an increased investment in scientific research and education. The research park is are already nowadays one of the major consumers (Tennbakk et al., 2018).

Based on numbers of published papers, either from or related to Svalbard, more scientific research and education are likely in the upcoming years. Reports like the one from Eeg-Henriksen and Sjømæling (2016) shows a steady increase in tourism, which includes cruise ships and tourist expedition boats as well.

Diependaal et al. (2017) states that the heat consumption has increased by a significant amount, while the electricity consumption has stayed close to constant. They mention that a reason for the increase in heat demand can be seen as a correlation with the increasing population.

In the past 10 years, the population has increased by almost 20% in Longyearbyen and Ny-Ålesund combined (Statistics Norway, 2021).

Yet we chose not to increase the heat demand in our scenario since considerable savings could be achieved through better building insulation, which we consider likely to happen in the next few years.

4.2.1.2 Low demand

For the low demand scenario, we assume that geothermal energy is utilized to provide heating, so we set the heat demand to our model to zero. This is based on the company Store Norske's plans are opening the new folk high school in autumn 2022, and are planning to heat the building by utilizing geothermal heating (Jochmann, 2021). If this is successful, we make the assumption that geothermal heating could become a new standard for heating in Longyearbyen. For electricity, we assume a reduction of 35 % compared to today's demand. Given the initiative to close the old power plant and the coal mine, this might be a more likely scenario. A low demand of energy may happen if the population stays close to constant or even decreases. Optimization of electricity usage, like improved regulation of heating and lighting, may lead to lowering the consumption (Tennbakk et al., 2018).

4.2.2 Supply

The available amount of energy supply depends on a lot of factors, but perhaps mainly on how many solar panels and/or wind turbines the government is willing to install. The environmental impact and visual pollution of wind turbines can be considered significant by some actors. A wind farm requires buildable area, which could disrupt wildlife in the area, and the rotors may be dangerous for birds. Due to this, solar panels are often the more desired choice by policymakers. Yet, solar panels cannot be placed on all house, some may have historical heritage or other restrictions (Tennbakk et al., 2018). While the government would like to avoid new encroachment on Svalbard's nature, their vision is to use renewable sources as the supply of energy (Energidepartementet, 2021). This is why we limit our production assumptions to wind and solar.

Koszuta, Gambhava, and Opedal (2019) provide us with an estimate form a suggested wind park. Multiplying the amount of turbines in the three proposed locations with the design capacity of the turbines gives us the installed capacity, which is about 321 MW. They also estimated the installed capacity when placing solar panels on all rooftops to be 41.6 MW. While the execution of this plan sounds difficult due to the ownership structures of the buildings (mostly not owned by the inhabitants), we follow this assumption.

These estimates are chosen as the upper limit for installed capacity for the high supply scenarios. In the low scenarios, installed solar capacity are scaled down to 30 MW and there are no installed wind capacity.

4.3 Previous research

Tennbakk et al. (2018) stated three different alternatives that seemed the most interesting for the energy supply on Svalbard. A liquefied natural gas (LNG) plant without carbon capture and storage (CCS), a co-generation plant based on pellets and solar power in combination with LNG. Two out of the three proposed solutions rely on energy import. A similar vision was published shortly after by Brekke et al. (2018), who investigated the possibilities that a mainland backed energy system with import of energy through hydrogen from mainland Norway could provide.

Lyngøy et al. (2017) wrote a report during a previous edition of this course on what is needed to store enough hydrogen for the energy demand of ten days in Longyearbyen. Their approach differs from ours as they used a coarse approach (yearly sums) and tried to go into more detail regarding the placement and exact form of the storage.

4.4 Limitations

Due to the limited time that was available to produce this document, many simplifications had to be made. Following good scientific practice, we list some of them here to allow for correction in the future.

- The solar data is not validated with local data.
- Most of the cost data we use is not specific to Longyearbyen. The specific conditions and shipping here require markups.
- The hydrogen cost assumptions are 10 years old.

- The demand curve includes the power plant and the coal mine, which leads to some pattern that might be inaccurate with the future demand curve. Also, electric vehicle charging will probably change the shape considerably.
- The demand data is not available for the whole period and had to be reused.
- The low demand scenarios, include a strong assumption that geothermal heating will be used for all heating. This equipment will demand some electricity, which has not been included.
- In our model, the storage technologies can react very fast, which might not be realistic. This is sometimes called ramping restrictions.

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