The reliability of wind power in the Longyearbyen area

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Abstract

Within this decade the current energy system in Longyearbyen has to be revolutionised. Right now, it relies entirely on fossil fuels, but in the future it is envisioned to be a front-runner of renewable systems in the Arctic. Due to the polar night and restricted renewable resources, the reliability of wind power is of crucial importance in this transition. Additionally, the permafrost and remote location demand high robustness and simple maintenance. In this report, we analyse on-shore wind potential in three different locations over the previous decade, including an evaluation of stability and extreme events in Svalbard's harsh climate. To ensure long-term success of this transition, we look at interannual, seasonal, and sub-monthly variations that should be included in suitability assessments. Based on our analysis, disregarding this could lead to installations that can jeopardise the stability of the system. With generated input data that we feed into an energy systems model, we find that if one considers interannual variability and a set of different locations, one can ensure a viable and reliable renewable energy system for Longyearbyen, with on-shore wind as a key component.

1. Introduction

The town of Longyearbyen is located on Spitsbergen in the Svalbard archipelago at 78°N latitude, which makes it one of the northernmost settlements in the world. With close to 2,500 inhabitants [1], it is the only settlement north of 75° with such a significant population. Initially, Longyearbyen grew due to its coal industry which also secured the energy needs of the town. As many other places on Svalbard, the combination of coal reserves and the generally mild climate for this latitude, allowed long-term settlement and various forms of economic activity. Because of the urgency of the climate crisis and global warming that hits the Arctic particularly strong, a future not powered by coal is one of the most important challenges that Longyearbyen is facing.

Virtually fully renewable electricity systems exist on large scale [2, 3, 4]; on smaller scale, more than 120 million people were served by renewable off-grid energy systems already in 2016 [5]. Therefore, 100% renewable energy systems are realistic in the future [6] and Ringkjøb et al. showed in [7] that this is also feasible for Longyearbyen. Even an entirely self-sustaining system is feasible; however it was shown in [7] that it would be significantly cheaper to partly import hydrogen from mainland Norway or use back-up fossil fuels. Coupled with possible public acceptance issues, it is important to ensure that the energy transition is not only feasible, but viable. Despite its modest size, an effective shift to renewables in Longyearbyen can inspire other remote, arctic communities to follow suit. It is important to include isolated settlements in this common effort in accordance with the United Nations' Sustainable Development Goals (UN SDGs [8]), in particular SDG7 (clean and affordable energy), SDG11 (sustainable cities and communities), SDG12 (responsible consumption and production), SDG13 (climate action) and SDG15 (life on land).

A sustainable energy system in Longyearbyen needs to be affordable and secure, in particular through the 113-day-long polar night. Since the current coal-fired power plant is planned to be decommissioned before 2028 [9, 10], most proposals include wind power to some extent [7]. Wind power is a mature, economically competitive energy generation technology [11, 12], but especially in the recent years public opposition against on-shore wind turbines in Norway has skyrocketed [13]. Addressing public and environmental concern is crucial, yet the success of any compromise will depend whether the expectations on the reliability of wind power can be fulfilled.

2. Problem statement

The intermittency and variability of wind production lies at the core of any planning process of wind turbines. The unique geographic and climatic circumstances in Longyearbyen pose additional challenges: permafrost and exposure to extreme winds require robust construction, and the remote location complicates the logistics and maintenance. In addition, the isolation, cold polar nights and state-of-the-art research and communication facilities require a stable and reliant energy supply. To solve these problems, a detailed assessment of production potential, variability and the susceptibility to weather extremes is needed and conducted in this study.

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Figure 1: Location of the meteorological sites of the airport (LH), Adventdalen (AD), and Breinosa (BR) around Longyearbyen [14].

3. Findings

Key findings

- At the studied locations (described in Section 4.2.1 and shown in Figure 1), we find that wind conditions allow installation and reliable use of wind energy.
- In particular, the periods during the polar night have more stable and higher production potential than the summer, when solar energy is available.
- The number of extreme events that can either endanger the installed turbines (high wind speeds) or the stability of the energy supply (long low wind spells) does not vary significantly with the years. These are challenges that can be overcome.
- Our analysis of capacity factors and verification with an energy systems model throughout different years, suggests location assessments should be based on long-term observation to capture interannual variability.
- Disregarding the variability over the lifetime of wind installations might lead to underestimation of necessary investments. Further increasing the generation or storage capacities can counteract this effect.

Monthly wind speeds

Throughout the study of wind data from 2011 to 2020 studied from the three locations in Figure 1, Adventdalen, Breinosa, and Svalbard airport, we find consistently higher average wind speeds in the winter months. As shown in Figure 2, December has the highest monthly wind speeds in the 10-year-average, at approximately 7 m/s in all three locations. On the other extreme, the month of August is usually characterised by lower average wind speeds, ranging from 4.2 m/s on Breinosa to 5.1 m/s in Adventdalen. These variations can have significant impact on the wind production, as the power curves are nonlinear and can amplify these fluctuations (Figure 8 relates production level to wind speeds). However, it appears that a “bad” August in terms of wind production does not deviate as much as for other months: in particular, March and October being the transition months from polar night to midnight sun, can capture a wide spectrum from “very bad” wind month (in almost absolute terms) to “exceptionally good”. It is possible that a combination of various factors including local phenomena as thermal channelling with synoptic weather effects can tilt the balance one way or another. Here it can sometimes be beneficial to rely on the complex topography and the fact that the surroundings of Longyearbyen can have different local weather and thus wind conditions. For instance, March 2017 had the lowest average wind speeds on Breinosa between 2011 and 2020, while it was a fairly average March in Adventdalen and at the airport. Generally we observe higher seasonal and interannual variation at the measurements on Breinosa, which could suggest that construction at a higher elevation might represent large-scale conditions better, whereas the locations at Adventfjorden (LH) and inside Adventdalen (AD) show stronger correlation. This could be caused by similar local conditions, as they both lie in similar locations at sea level. If wind power is the main source of energy, spreading the locations might attenuate risks as later shown in some of our model results in Section 3. This becomes even more important during the polar night and periods with short daylight when wind power can not be complemented by solar power.

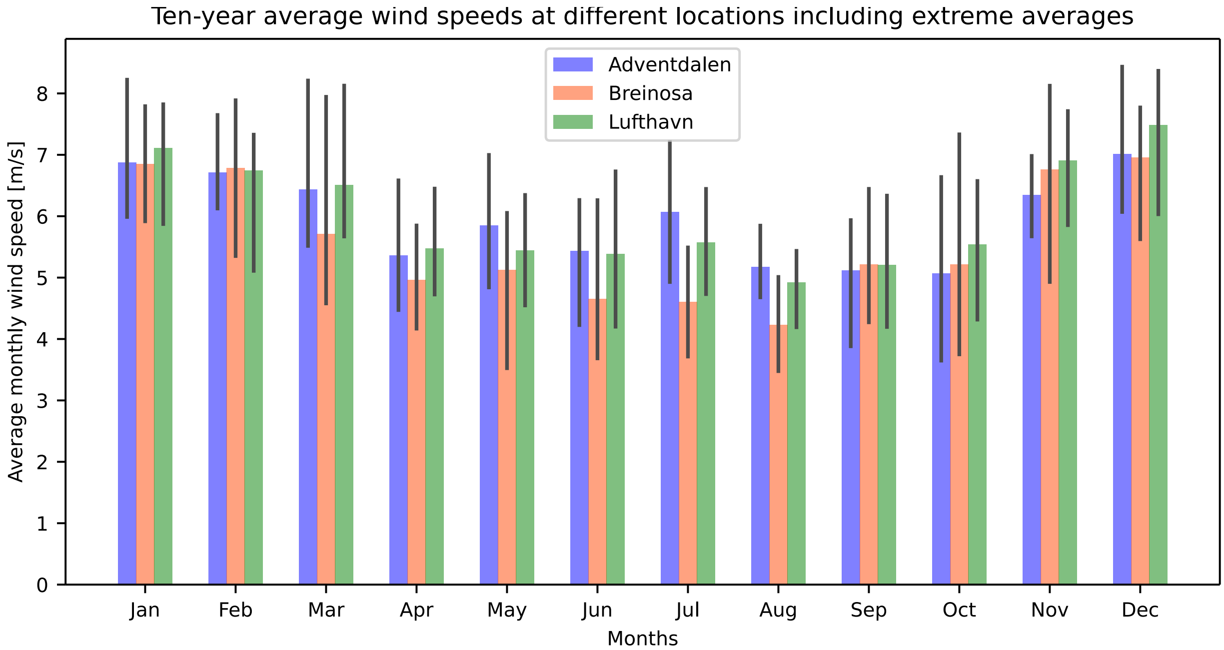

Figure 2: A plot of the average wind speeds at 30 metres height and their variability for each month of the past ten years in the three locations.

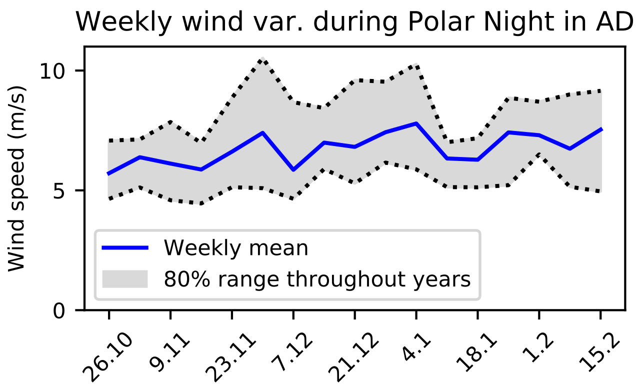

Figure 3: Weekly variations of wind speed in Adventdalen (transformed to a height of 30 metres) during the polar night (26. Oct. - 15. Feb.) averaged over the years 2011-2020. The shaded region depicts the range in which all but the two extreme observations throughout the years can be found.

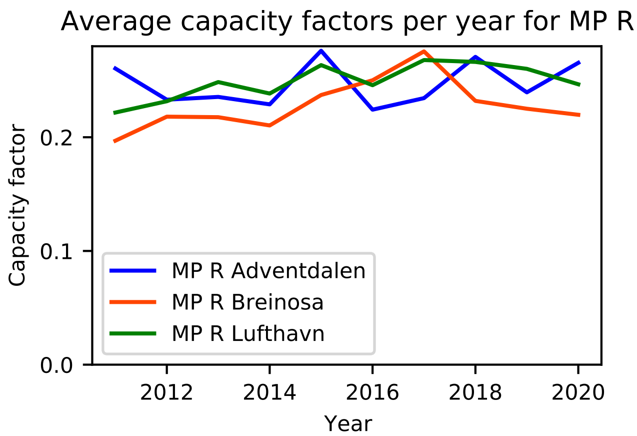

Figure 4: The average capacity factors calculated for the VERGNET GEV MP R wind turbine for each of the ten years of data from Adventdalen, Breinosa, and the airport.

Wind in the Polar Night

One of the main challenges in Longyearbyen's energy transition is the limitation of solar irradiation for a significant part of the year. The sun does not rise for 113 days; wind power should therefore be reliable enough such that an adequate storage system can support a stable energy supply. We show for AD in Figure 3 that even on a weekly basis, average weekly wind speeds at 30 metres' height normally do not fall far below 5 m/s; we chose a 80% confidence rate due to some lack of data and faulty measurements. It is important to note that we cannot rule out weeks or years with significantly below average wind conditions, an issue we address when describing extreme events.

Spatial comparison of average production

We have already touched on the possibility of spatial distribution; Figure 4 shows that the interannual variation makes it difficult to make sense of the notion of the "best" wind location. The simplest way is to relate this to the highest capacity factor, thus the location with the highest ratio of (estimated) production to installed capacity. That is, for a hypothetical installation of a 1 MW turbine, an hourly capacity factor of 0.2 translates to production of 200 kWh = 0.2 MWh. It is important to notice that a high average capacity factor per se might not be decisive, for instance if the production is badly distributed, but it is a fairly simple way to compare locations and years. Each of the three locations studied under this criterion is best in at least one year as depicted in Figure 4, which hints at the potential of using different locations to smooth out production profiles over different years.

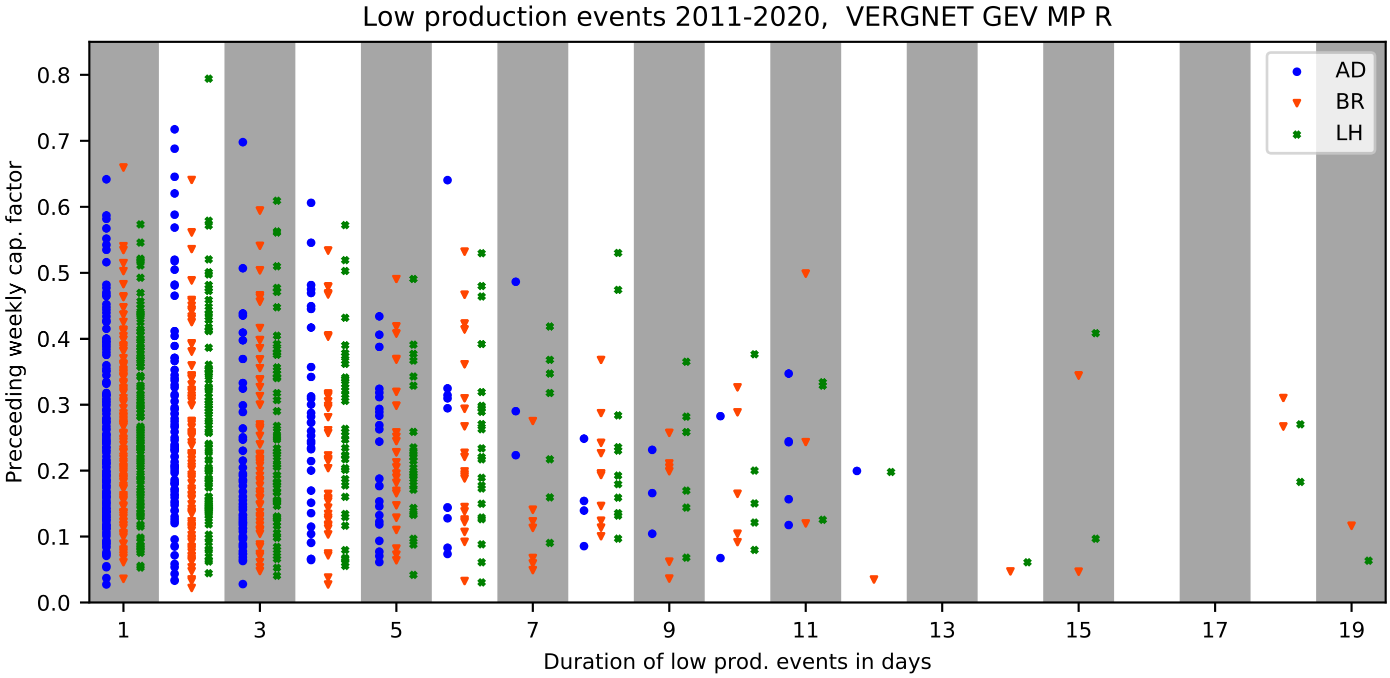

Figure 5: For the three different locations, the duration of low production events (where the average capacity factor per day is below 0.1) in days is scattered against the average capacity factor of the week immediately preceding the beginning of the low production event for the VERGNET GEV MP R turbine.

Further information on the capacity factors of different suitable turbines can be found in Table 1, Table 2, and their related discussions in Section 4.2.2 and Section 4.4. The turbine selected for further study here is the VERGNET GEV MP R 275 kW turbine, at a hub height of 32 metres, which can be seen in Figure 4 to have a capacity factor between 20 % and 25 % for the three studied locations the past decade.

Extreme events

For a remote off-grid system like we have in Longyearbyen, it is especially important not to look solely on the long term average production data, but also take into account short term events with potentially extreme consequences. In the framework of this paper, special consideration has thus been given to periods with particularly low wind speeds (and thus correspondingly low energy production), which might jeopardise the stability of the energy supply, as well as events with very high winds, potentially leading to damages of the installed wind turbines.

Low production events. In what follows, we define a low production event to consist of one or several days in a row having a daily average capacity factor below a threshold of 0.1, which is well below the average capacity factor of almost 0.25 of the turbine used in studying these events. However, the stress imposed on the total energy system by such a period of low production does not only depend on its duration, but also on the conditions preceding such an event. As a measure for this, we analyse the capacity factor of the seven days prior to the beginning of a low production event. While high values for this weekly capacity factor indicate that stored energy due to overproduction can help to withstand the period with low wind speeds, low values signalise that the system is possibly under stress, as for example several periods of low production events could have taken place shortly before the current event.

Figure 5 shows a plot of the duration of all such low production events for the VERGNET GEV MP R turbine in the observation period 2011-2020 scattered against the capacity factor in the week preceding the event. Loosely speaking, events located closely to the lower and the right edges of the plot have to be considered as the most severe ones. It can be seen that the majority of the low production events have a duration on the time scale of 1-3 days. This coincides roughly with the autocorrelation time of the analysed time series, with more details in Section 4.2.1. Still, several events were observed lasting for longer than a week, with maximum values even reaching close to three weeks. It is, however, important to note that events with a duration of 7 days or more only occurred between February 26 and October 19, with the biggest share being concentrated around the summer months of May, June, July, and August. During this time of the year, one can employ other energy sources such as solar power to complement and compensate for poor wind periods, thus lessening the impact of the long low production events.

High wind events. The survival speed of a wind turbine specifies the wind speed that the turbine can withstand safely without suffering damage. By analysing gust speed

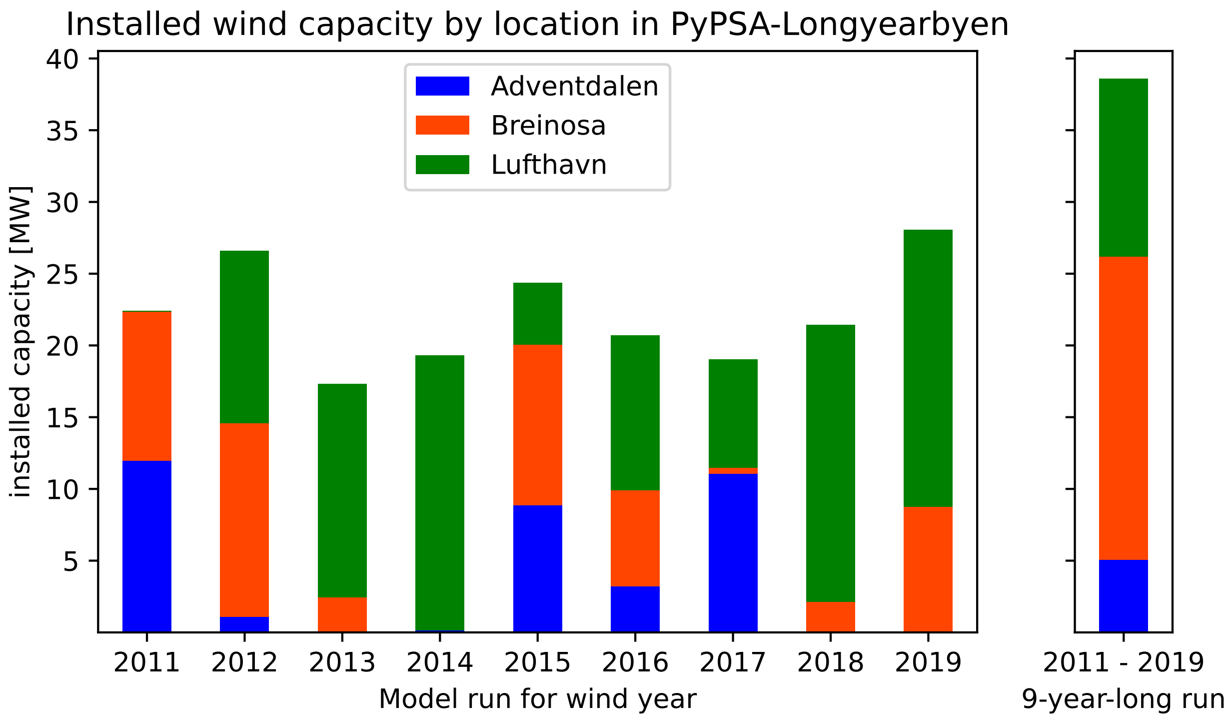

Figure 6: A comparison of installed wind capacities in a fully renewable energy system model for yearly runs from 2011 to 2019, as well as for a nine year run for all these years.

data from Adventdalen and Breinosa, we find that the wind gusts present at these locations are, in general, not approaching the turbine's survival speeds. Values surpassing 90% of the survival speeds for some of the turbines were observed at three occasions: March 2011, March 2015 and November 2016, with the analysis showing a higher susceptibility to strong wind events at Breinosa than in Adventdalen. At each of these dates, wind speeds close to the survival speeds were observed repeatedly over a period of some hours.

To take appropriate measures, such as tilting the wind turbines if technologically possible, or temporarily strengthening the construction in time, it is crucial to predict possible high wind events with enough time in advance. The above results indicate that potentially dangerous wind speeds historically have not shown up suddenly as singular events, but rather appeared in the framework of meteorological processes happening on a larger scale. This behaviour would facilitate the forecast of potential dangers without having to tackle the difficult task of significantly improving the local weather forecast, as the events were governed more by synoptic weather effects than by local processes.

Model results

Based on our analysis, we generate input data as described in Section 4.5 for an open-source energy systems model named PyPSA-Longyearbyen created by van Greevenbroek and Klein. More details about it can be found in [15, 16].

We want to encapsulate our solely wind-based analysis into a more holistic energy systems analysis to see whether our findings hold true after interactions with other technologies and considerations. In Figure 6 we show the cost-optimal installed wind capacities for the years 2011 to 2019. We ran the model for nine single years and then once jointly for the whole time period. We can observe manifold results: first of all, in all years there is significant investment in wind power ranging from 17 MW to 28 MW. This leads to the conclusion that wind power is, indeed, reliable, however subject to interannual variability. It is not only the capacity that varies, but also how it is distributed over the different locations. In all but one year, wind power is installed at Breinosa, and investing to some extent at the airport is optimal in all years. Adventdalen is chosen in five of nine years, however it is possible that this is an artefact of missing data points (more about this in Section 4.5).

For the longer simulated period, it is remarkable that the installed capacity with 38.5 MW is significantly higher than in any other year. This suggests that throughout the lifetime of different wind locations and turbines, variations are to be expected, and a more conservative calculation of necessary capacities is a trade-off between energy security and cost considerations. In particular in the context of Longyearbyen, reserve capacities appear a worthwhile investment.

4. Details

4.1. Approach

In this white paper, we investigate various aspects of the intermittency of wind around Longyearbyen and what impact this can have on a reliable wind power production in a renewable energy system on Svalbard. We base this on a quantitative analysis of weather and wind observations: we translate the available observations to different hub heights (depending on the turbine), which we then transform into capacity factors. We analyse those, as they are the object of interest when it comes to reliability of wind power production in a renewable energy system of Longyearbyen.

4.2. Data availability

4.2.1. Wind speed data

This study is based on meteorological observations from several locations in the surroundings of Longyearbyen:

- Adventdalen weather station (78°12'10"N, 15°49'41"E, 15mosl, measured at 10m), denoted *AD*,
- Breinosa weather station (78°8'53"N, 16°2'35"E, 520mosl, measured at 4m), denoted *BR*,
- LYR airport weather station (78°14'43"N, 15°28'56"E, 30mosl, measured at 10m), denoted *LH*.

The weather data from the weather stations Adventdalen and Breinosa was obtained from UNIS [17], whereas the observations from Longyearbyen (LYR) airport are based on data from MET Norway [18]. These weather stations were chosen because they lie within 15 kilometres from the city of Longyearbyen, so that they might be considered as possible locations for future wind turbines. Additionally we could ensure that the measurements from these stations cover (most of) the time period 2011-2020, which we investigated. As parts of the available data has not been quality-controlled, we were striving to reduce inconsistencies and eliminate blatant errors in the data. Through this choice of weather stations we can ensure that different altitudes and topographical features are represented. Additional factors that would improve the estimates [19] that are based on the given data are roughness of surface, which was not available for those locations.

The data used for this study consists of average and maximum wind speed (gusts) for the stations in AD and BR and of average wind speed for the data in LH.

Due to the different time steps of the meteorological observations, we select a common resolution of one hour. For the weather stations AD and BR we averaged the higher observation frequencies (1 second and 5 minutes respectively) to a resolution of 10 minutes to ease comparisons after ensuring that the main characteristics are preserved. The temporal resolution of measurements at the station LH changes during the observation period (from two hourly measurements to a 10-minute resolution), this resolution was left unchanged.

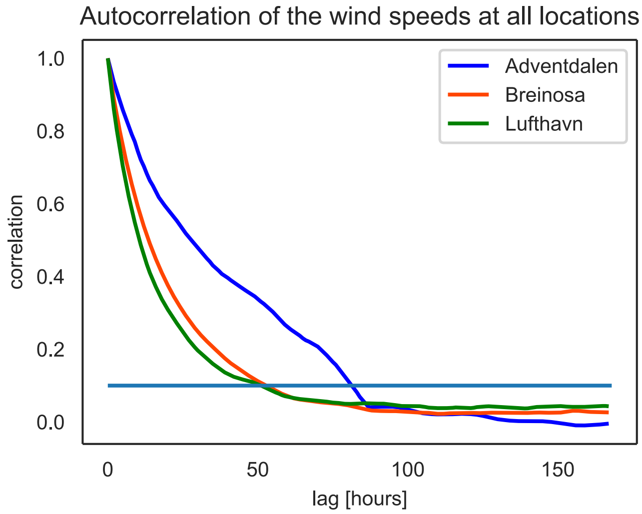

Figure 7: The autocorrelation of the wind speeds at the three locations. A horizontal line shows where the correlation is 10 %.

This procedure resulted in the following amount of analysed time steps: 526,032 for AD and BR (with 25,118 missing data points for AD and 16,303 missing points for BR) and 236,757 data points for LH.

The autocorrelation of the wind speed data was calculated, and the result is shown in Figure 7. It is clear that there is a high correlation for the wind speed for about the first day. Interestingly, the autocorrelation of the measured wind speed for Breinosa and the airport are very similar, becoming less than 10 % correlated after about 2 days. The Adventdalen wind speed stays correlated for longer, lasting approximately three days before having an autocorrelation factor of less than 0.1. This is, as mentioned in the results, also the time for which the majority of "low production events" in Figure 5 last, which is reasonable. Once a low average wind speed, and thus lower production, sets in, the autocorrelation data shows that it is not uncommon for this event to last for a day or three, though longer lasting events will be uncommon.

In order to obtain the wind speeds at hub height of a wind turbine, we assume neutral stability conditions. Although this is an oversimplification, the wind profile power law then becomes

$$u_e = u_m * \left(\frac{z_e}{z_m}\right)^{\frac{1}{7}}, \tag{1}$$

where u_e denotes the estimated wind speed in m/s at the chosen hub height z_e in metres, u_m denotes the measured wind speed in m/s at the measurement height z_m in metres, we translated the measured wind speeds to ones at greater height. As above, the wind speeds at the meteorological stations AD, BR, LH are measured at 10 metres, 4 metres, and 10 metres respectively. The chosen hub heights vary with the wind turbines which we list in Section 4.2.2.

This allows us to translate the estimated wind speeds at hub level into capacity factors through the power curves of the considered wind turbines. This is based on the technical details given by the manufacturers. For each 10-minute segment we can thus come up with a capacity factor that describes the ratio of power production to power capacity. This is a reasonable measure that is normally used in energy systems models ([20]) and allows us to compare relative outputs. It is important to notice, however, that due to different power curve shapes, this varies with the wind turbines. Although this becomes more relevant when installing more than one turbine in one location, our setup is the installation of only one turbine in a fixed location; we therefore do not look at spacing and possible turbulence from grouped turbines that would otherwise have to be taken into account as well.

Finally we compute the hourly average of the capacity factors for the different wind turbines in our chosen locations. This constitutes the basis for our statistical analyses, as from an energy systems modelling perspective this gives us the relevant data: first of all, this is a common time resolution and can thus be easily used as input for energy or power systems models like highRES [21] or PyPSA [22] among many others. Second of all, we decided that the question of production from a reliability perspective is more relevant than an analysis of the actual wind speeds leading to this. Lastly, the cubic shape of the power curve [23] can lead to nonlinearities that can have more drastic outcomes than the variation in wind speed.

4.2.2. Technology data

As the subjects of our study we picked several wind turbines on the market today, with key specifications listed in Table 1. The power curves used to calculate the capacity factors for these turbines is displayed in Figure 8.

There are several issues with the installation of wind turbines on Svalbard due to the remote location of the Arctic archipelago. These include geological factors like the presence of permafrost which makes the construction more difficult and costly, but also logistical challenges like the shipping of the turbine components. Moreover, environmental and social acceptance concerns need to be taken into account, in particular the impacts on the bird population and on the landscape. We therefore focus on mid-range wind turbines of hub heights between 30 and 50 metres, which appear to be a viable compromise with limited visual impact. Certain wind turbines can be tilted over and fastened to the ground on short notice as a security measure against severe storms. One small turbine with this feature, TUGE 10, has been included in this study, as this is a possibility that has been discussed in Longyearbyen as a safety measure for birds. Most birds on Svalbard migrate up after the polar night is over, when energy usage is lower and the possibility to generate solar power becomes viable. This makes the possibility to have operational wind turbines in the winter, that are then tilted down in the summer, an enticing option for the Arctic settlement. If this feature is desirable and given higher priority than the visual impact, other tiltable turbines that are above our height requirement, like the VERGNET GEV MP C, should also be taken into consideration.

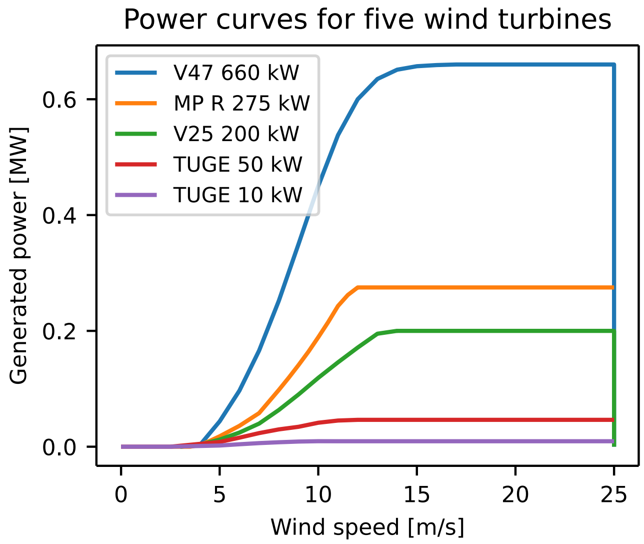

Figure 8: The power curves for the five different wind turbines studied in this assessment.

In addition to the specifications listed in Table 1, the operating temperature for the different turbines is also a key parametre, especially for use in the Arctic winter. The polar editions of the VERGNET turbines operate down to -20 °C, while the TUGE turbines can operate down to -25 °C. The Vestas turbines come in a cold climate edition that operate all the way down to -30 °C. All of these can of course sustain lower temperatures, down to -40 °C, as their survival temperature. As the temperatures around Longyearbyen during the polar night can drop to well below -20 °C, and as these events coincide with the times of highest energy consumption, this parametre must also be considered when evaluating the reliability of wind power on the island.

Another risk event that can be difficult to foresee are icing events, which have a strong impact on productivity of the turbine. Such events can potentially lead to incidents due to ice blocks detaching of the quickly rotating turbine blades can be launched far away from the turbine base, posing a hazard to both equipment and people around the installation. Certain turbines can be adapted with full or partial heating of the blades to mitigate this risk, though this report has not looked into the aspects of these alternatives any further.

Wind turbine	TUGE 10 [24]	TUGE 50 [25]	VERGNET GEV MP R [26]	Vestas V25 [27]	Vestas V47 [28]
Max power	9.9 kW	50 kW	275 kW	200 kW	660 kW
Hub height	18 m	36 m	32 m	30 m	45 m
Cut-in speed	3 m/s	3 m/s	3.5 m/s	3.5 m/s	4 m/s
Cut-out speed	25 m/s	25 m/s	25 m/s	25 m/s	25 m/s
Survival speed	50 m/s	50 m/s	52.5m/s	52.5 m/s	59.5 m/s
Capacity factor AD	0.369	0.348	0.247	0.218	0.271
Capacity factor BR	0.323	0.303	0.228	0.204	0.243
Capacity factor LH	0.377	0.357	0.249	0.220	0.277

Table 1: Maximal production power, hub height, and wind speed tolerances for the five wind turbines considered. In addition, calculated average ten-year capacity factors at three locations Adventdalen (AD), Breinosa (BR), Svalbard airport (LH), are listed.

4.3. Methods and assumptions

A critical assumption made for this study is regarding the shape of wind profile. We have assumed that the wind profile power law holds for our case, and a further, massively simplifying, assumption is that the neutral stability condition is valid for all the data, meaning that the Hellman exponent/power law coefficient is the constant $\frac{1}{7}$ [29]. This is likely not the case, but can be a good first order approximation. An important detail to notice here is that the resulting hub height estimated wind speeds were found from measurements at 10 metres for Adventdalen and the airport, while they were only calculated from measurements at 4 metres for Breinosa. The estimations for the different locations were treated on equal grounds, even though the Breinosa estimations are less certain due to this difference of measurement heights and possibly topography.

We also assume that the wind turbines turn off when they detect wind speeds above the cut-off speed of 25 m/s. Since we generate the wind speed data at a resolution of 10 minutes, we assume that the wind turbine is turned off during entire 10-minute-segments, to mimic the detection of this wind speed and the time it takes before it is turned back on.

4.4. Capacity factor analysis

The capacity factors for each turbine and location were calculated at a one hour resolution for the past ten years. The mean capacity factor, along with the median and standard deviation (std) for each year and the full time series was then calculated, and the result from the VERGNET MP R turbine is shown in Table 2. The small TUGE turbines had slightly higher average capacity factors than the former, but the MP R turbine is a modern turbine with a higher peak production capacity that is deemed more desirable in this environment. Additionally, this turbine comes in a taller edition, with the same power curve shape, that can be tilted down in cases of storms and bird-filled summers. It can be seen that the mean capacity factors are around 25% for this turbine in Adventdalen and at the airport, while it is lower at Breinosa. The median capacity factor for Breinosa is also significantly lower than that of the other two locations, being less than half for most years.

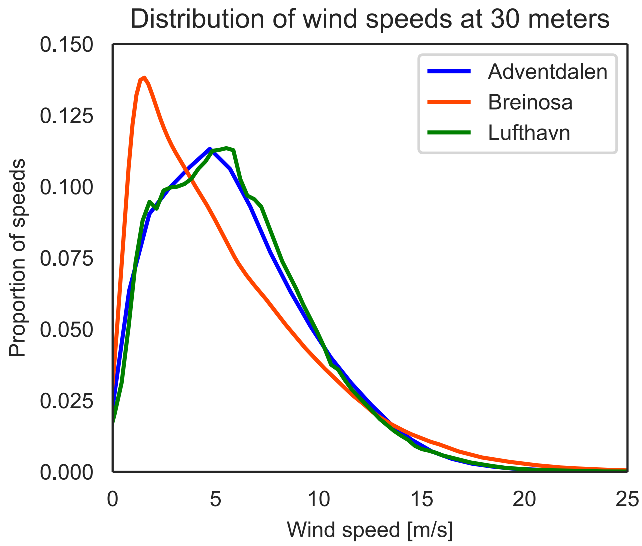

Figure 9: The distribution of the estimated winds at a height of thirty metres for all three weather stations.

The standard deviation is roughly the same for all three locations, with the deviation for Breinosa being slightly higher on average.

The plot in Figure 9 helps shed some light on this data. It is evident that Adventdalen and the airport have very similar wind distributions at a height of 30 metres, which is just below the height of the VERGNET GEV MP R turbine at 32 metres. There is a clear difference between the wind speed distribution in these two locations and the distribution at Breinosa. The latter has significantly more wind at lower speeds, a lot of which is under the cut-in speed of the turbine. This explains both the lower average capacity factor and the much lower median capacity factor for this location. The capacity factor is not a lot smaller, however, owing to the fact that Breinosa also experiences more frequent strong winds, above 13 m/s, than Adventdalen and the airport. The somewhat higher standard deviation of the Breinosa capacity factors can also be attributed to the fact that there are more frequent cases of both high and low wind speeds here.

VERGNET GEV MP R capacity factor variability				
Time	Value	AD	BR	LH
2011	mean	0.260	0.197	0.222
	median	0.085	0.028	0.056
	std	0.336	0.307	0.320
2012	mean	0.233	0.218	0.232
	median	0.089	0.045	0.098
	std	0.305	0.317	0.304
2013	mean	0.235	0.218	0.249
	median	0.088	0.039	0.113
	std	0.308	0.317	0.312
2014	mean	0.229	0.210	0.238
	median	0.095	0.045	0.105
	std	0.299	0.311	0.306
2015	mean	0.276	0.237	0.263
	median	0.110	0.046	0.105
	std	0.340	0.335	0.336
2016	mean	0.224	0.250	0.246
	median	0.084	0.064	0.109
	std	0.296	0.337	0.313
2017	mean	0.234	0.276	0.268
	median	0.093	0.095	0.125
	std	0.306	0.345	0.321
2018	mean	0.271	0.232	0.266
	median	0.133	0.053	0.121
	std	0.312	0.325	0.326
2019	mean	0.239	0.225	0.260
	median	0.090	0.041	0.123
	std	0.318	0.328	0.319
2020	mean	0.265	0.220	0.247
	median	0.106	0.036	0.092
	std	0.330	0.322	0.326
All	total mean	0.247	0.227	0.249
	total median	0.097	0.046	0.105
	total std	0.316	0.325	0.319

Table 2: Average, median, and standard deviation of the capacity factors for the VERGNET GEV MP R turbine for the last ten years calculated from the measurements from the weather stations in Adventdalen (AD), Breinosa (BR) and the airport (LH).

4.5. Modelling

In synergies with reports by van Greevenbroek and Klein and Roithner and Alexandersen, we use our wind output data, together with the technological data, to obtain a glimpse of the potential of our chosen locations. For this, we use PyPSA-Longyearbyen [15], which is a bottom-up, technology-rich power system model, based on PyPSA [22], and enlarged through thermal storage. This techno-economic model strives to minimise the investment and operational costs of a renewable energy system covering both electricity and heating in Longyearbyen. In addition to numerous physical assumptions, it is strongly based on input data concerning technological costs, demand on heating and electricity, and capacity factors of intermittent renewables. It is an open source model that uses methods of linear optimisation to design a cost-optimal energy system.

For cost assumptions of the turbines, we assume that there is a uniform cost of installed capacity, which is a simplification of the reality. This is in particular not realistic if the turbines have special features (as the option of being taken down during summer). In that situation, it should be noted that the capacity factors during that period that the model uses in its optimisation are obsolete, in turn raising the costs of using wind energy. It cannot be ruled out that this pushes wind energy past a profitability threshold. Additionally, we have not included any area or capacity limits for different locations. If the model installs some capacity in Adventdalen, it should be interpreted that it would choose an available location with those capacity factors.

Another caveat that needs to be mentioned is that the model translates missing data points (e.g. due to maintenance of the observation sites or faulty observations) to periods with a capacity factor 0. Keeping this in mind, in presence of missing data the model can be viewed as a conservative and risk-averse policymaker. If this missing data occurs in winter, then due to the lack of alternatives, it will install more wind capacities in other locations than it might optimally. Since there are no occurrences of missing data at all (and almost none for two) locations simultaneously, it is unlikely that this has a large impact on the design of the entire energy system.

Throughout our analysis we have calculated hourly capacity factors for five wind turbines. As described earlier, this was achieved by computing the generated output for each turbine based on its power curve (depicted in Figure 8) and using the estimated wind speeds at their respective hub heights. This procedure created a decade-long time series of capacity factors for each turbine at each location that was fed into the model. We performed 10 runs with PyPSA-Longyearbyen: one for the whole period of 2011-2019 and nine for each of the years in the period. The energy system for 2020 was not simulated due to the lack of reliable solar irradiation data. As load data was only available for the years 2017-18, these are also used as input for heat and electricity demand for the other modeled years.

4.6. Limitations

This report was developed over the period of five days as part of a three-week course at the University Centre in Svalbard (UNIS [31]). On account of this narrow time frame, several important aspects related to the subject of the paper could not be taken into account, and it is important to be aware of the following limitations of our work, which should be addressed in further studies.

As described in more detail in Section 4.3, the translation of the measurements taken at a height of of 10 metres (AD, LH) and 4 metres (BR) to a hub height of 30-50 metres is done using the wind profile power law given in Equation (1), and it relies on several assumptions of which hardly all are met in our scenario. Detailed wind measurements to assess the actual conditions at the prospective height, and how well they correlate with the estimated conditions, are therefore indispensable steps in any further assessment and planning process.

The choice of the analysed weather stations was determined to a large extent by the availability of wind speed data with a high temporal resolution, and the three stations reflect different topographical features, thus allowing for a general assessment of the reliability of wind power. It was, however, not a criterion whether the installation of wind turbines at the precise locations is feasible or whether factors such as limited area availability and already existing infrastructure prevent this. Similarly, the selection of wind turbines considered in the report represents several different solutions viable in the local, Arctic climate, but it is restricted to wind turbines with publicly available data sheets and power curves. It is therefore important to emphasise that this work is not a recommendation for a specific location or turbine, but it should rather be seen as a proof of concept.

Although the modelling approach shows conceptually that wind power is a competitive option as energy source, the absolute numbers obtained as results have to be taken with extreme caution due to several simplifications made in the frame of this project. In particular, we did not assess the costs of the different turbines, but assumed a uniform cost of installed capacity, and did not set limits on area or installed capacity, as mentioned in Section 4.5. Additionally, wind and solar power are the only mature renewable energy generation technologies in the model, as hydro power is not realistic around Longyearbyen. Other technologies like tidal, wave, or geothermal energy are either not yet commercially available on a large scale or unlikely to be implemented here until 2028.

Addressing the question of reliability of wind energy, we naturally focus on production and robustness of wind turbines. Therefore, engineering and logistical issues such as transport, construction in permafrost, maintenance and icing danger, environmental considerations and social acceptance could only be taken into account very briefly. However, solving challenges posed in these areas is of as much importance for the conception of a wind power system as the actual production and reliability itself, and thus the aforementioned aspects are important study subjects on their own.

5. Conclusion

In this paper, we explore the reliability of wind power production in three distinct locations nearby Longyearbyen. Our analysis takes weather observations over a decade under consideration and shows that the wind conditions are satisfying and stable enough to contribute significantly to a green energy transition on Svalbard. Although there is variability throughout the different years, the studied locations complement each other to some extent and the different topographic features have different advantages. The harsh Arctic surroundings complicate installations of large wind turbines, but our estimated wind speeds at hub heights we deem feasible rarely threaten the construction, meaning they do not exceed the "survival speed" of modern turbines of that height. Likewise, low wind spells which can put extreme strain to a wind-reliant energy system almost exclusively happen during the summer months, when complementing measures can more easily be taken. Validating our analysis by different runs of an energy systems model (PyPSA-Longyearbyen), our findings conform with a cost-optimal renewable energy system. Regardless of the simulated time period, wind power can play a key role in sustaining the energy needs of Longyearbyen.

We recommend to seriously consider wind power to be a part of the transition towards renewable energy in Longyearbyen. Nevertheless it is important to bear in mind that this is an intermittent energy source and can thus only be part of a larger coordinated effort that is complemented by other energy generation and storage technologies. As this solution shall serve the population for many years and decades to come, it is vital to keep in mind the variability throughout different seasons and years. The isolated location of Longyearbyen demands particular robustness in the supply, and longer simulations over several years suggest a more cautious approach with greater installed capacities combined with more reserve storage than shorter, yearlong simulations. As our chosen locations are only proxies for prospective wind turbine sites, we strongly recommend long-term measurements at the correct hub height to reduce uncertainties. Placement of wind turbines on Svalbard is not an easy task and should be part of a concerted effort of experts from different disciplines. Perhaps most important in a fully successful energy transition is the involvement of the local population in the planning process to ensure that all technical, social and environmental concerns are properly addressed.

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