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Perspective on Industrial Electrification and Utility Scale PV in the Arctic Region

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ABSTRACT

Two concurrent trends may fundamentally change how we understand the role of solar PV at high latitudes. Until now, relatively low annual insolation in combination with low electricity demand during the summer months has not favoured PV in the Arctic. However, continued decreases in costs for PVs in combination with increasing electricity demand from industrial electrification is quickly changing the situation. Net-zero climate targets necessitates industrial decarbonisation and low-cost electricity from solar and wind facilitates emission reductions through electrification and hydrogen. While research on PV in the Arctic so far has focused on off-grid and community scale systems, in this perspective article we explore the prospects for utility scale PV in Northern Scandinavia. Research usually identifies regions endowed with rich sun and wind resources at lower latitudes as promising locations for electricity intensive industries. We calculate the levelized-cost-of-electricity for utility scale PV to be 51 EUR/MWh based on recent data and this cost is likely to be below 35 EUR/MWh before 2030 considering the projected continued reduction of the levelized cost of electricity for PV. This makes utility scale PV a highly viable future option to complement wind and hydro in meeting the very large forecasted future electricity demands from the steel industry, data centres, and power-to-X production above the Arctic circle from 2030 and onwards.

Keywords

Utility scale PV at high latitudes;
LCOE PV;
PV in Arctic;
Industrial electrification in Northern Scandinavia

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1. Introduction

The Paris Agreement in 2015 has led to a profound shift in our thinking about climate mitigation. The overarching goal is to keep "the increase in the global average temperature to well below 2 °C" and pursue efforts "to limit the temperature increase to 1.5 °C above pre-industrial levels." This implies very rapid emission reductions and net-zero global carbon dioxide emissions around 2050 (for 1.5 °C) or 2070–2080 (for 2 °C) [1]. Earlier ambition levels, e.g., the EU target to reduce by 20% in 2020 or by 40% and then 55% in 2030 compared to 1990 implied that some sectors, e.g., heavy industry and aviation, could continue emitting greenhouse gases. However, net-zero emissions by 2050 or soon thereafter means that all sectors must reach net-zero, including the so called 'hard to abate' sectors.

While acknowledging the dire situation with increasing greenhouse gas emissions, the most recent IPCC report on mitigation of climate change, from 2022, also identified some positive signs. Not least, from 2010 to 2019, there have been sustained decreases in the unit costs of solar energy (85%), wind energy (55%), and lithium-ion batteries (85%) [1]. This development has fundamentally changed the way we look at future climate mitigation. With inexpensive wind and solar energy, the use of hydrogen and direct electrification are

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now centre-stage mitigation options across all sectors. The largest amounts of electricity will be needed to decarbonise the steel industry, through hydrogen direct reduction of iron oxides, and the chemicals industry, by using green hydrogen as feedstock for organic chemicals, polymers, and ammonia [2]. Electricity based synthetic fuels are identified as key options for shipping and aviation [3]. The shift in attention to electrification and hydrogen over time is illustrated in Figure 1. For example, hydrogen is mentioned ten times more often in the 2022 6th assessment report than in the 5th one from 2014.

The necessity of net-zero emissions in combination with decreasing costs for renewable electricity has led to an increase in the literature on industrial electrification to assess future electricity needs [5,6], how hydrogen production can offer flexibility [7], and how the geographical distribution of renewable resources has implications for the location of industry and new value chains [8,9]. Regions that are rich in solar and wind resources may become exporters of hydrogen or hydrogen carriers such as methanol and ammonia, or home to the production of iron, platform chemicals, and other energy intensive basic materials for export.

Access to inexpensive renewable electricity in northernmost Europe is already now motivating new industries to locate there (e.g., data centres and battery factories) and existing ones to decarbonise through electrification (e.g., iron and steel). Hydro power is currently the backbone of power supply in the region, land-based wind is growing rapidly with a levelized cost of electricity (LCOE) of around 30 EUR/MWh, while solar is yet in its infancy. The rapid cost reductions for PV can make utility scale solar power a promising option to meet the projected increase in electricity demand.

With a global weighted average decrease in price for utility scale solar power of 85% between 2010–2020 it is steadily being implemented further and further north [10,11]. Although installed solar power is still very limited at high latitudes, this is likely to change as the average LCOE is predicted to drop by 58% between 2019–2030 in the G20 countries [12]. This reduction is driven by lower manufacturing costs and higher efficiencies [13]. So far, the combination of low electricity prices during summer and limited insolation when demand is high during winter has left utility scale PV unprofitable in the region. However, with electrification and location of electricity intensive industries in this region there will be a large electricity demand year-round.

It is against this background of rapidly changing PV and electricity market conditions that we ask what the future role of utility scale PV in the Arctic may be.

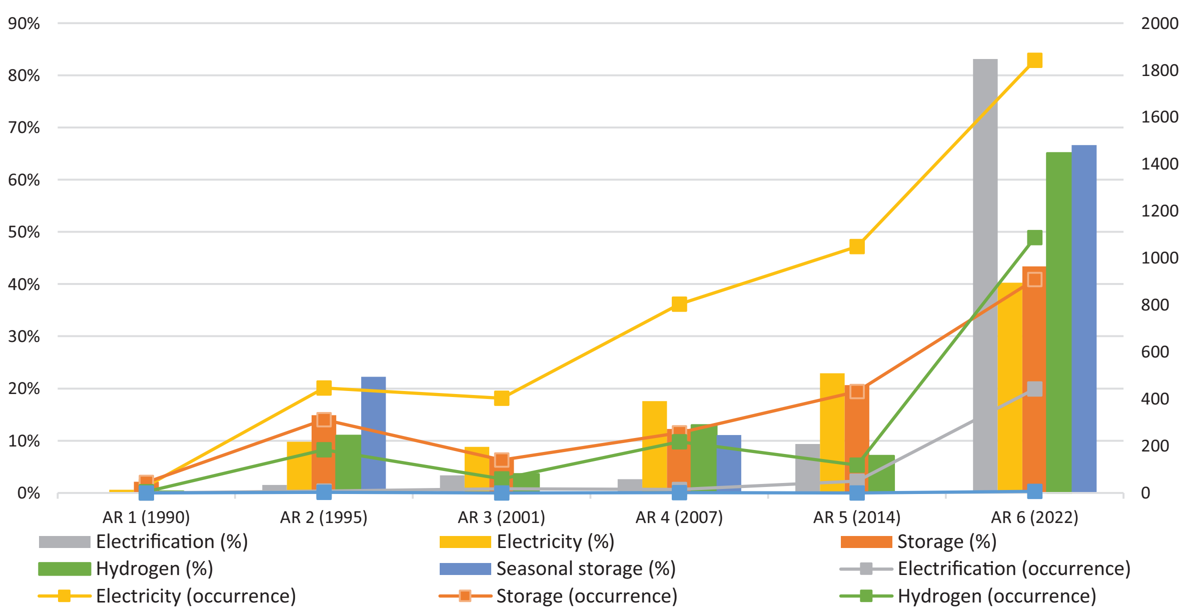

Figure 1: Occurrence of different keywords (right-axis) and their proportions (left-axis) across the six IPCC Working Group III assessment reports, in each edition (1990-2022) [4].

While previous research on PV above the Arctic circle is on community-scale off-grid systems we assess the viability of utility scale grid connected systems (e.g., [10,14,15]). There is a lack of research in LCOE for utility scale PV in Norway (according to the Norwegian Water Resources and Energy Directorate (NVE)). Communication by phone, 2022.). This study aims to narrow this research gap by performing a first viability study of utility scale solar power by combining measured insolation data from an Arctic location together with cost data from utility scale PV projects. It is particularly important to map the viability of renewable power production in the Arctic considering the projected increase in electricity demand, and thus the need for new renewable power developments. The results are important for power market analysts, power companies, policy makers, energy planners as well as other researchers. The viability is evaluated by calculating the LCOE and putting that in the context of future projected increases in industrial electricity demand.

By the Arctic we mean north of the polar circle. i.e., 66 degrees north, above which there are polar nights in the winter and midnight sun in the summer. Historic projections have consistently underestimated the future growth of PV and perhaps the transformative power of PV is underestimated again? In the following we briefly describe current power markets and the expected role of PV in Norway and Sweden. We assume a specific location at 69 degrees north to assess yield and profitability as well as to evaluate performance of different PV-systems at high latitudes. Based on this we discuss the future of industrial electrification and the role of PV in the Arctic as well as identify important areas for future work.

2. The Power Market and the Role of PV in Sweden and Norway

The electricity system in Sweden and Norway has a high share of renewables and Norway with 95% renewable electricity has the highest share in Europe. In 2022 hydropower accounted for 81% of the total production, followed by wind power with 12% [16]. However, solar power in Norway is yet in its infancy. The production in 2018 was only 0.06 TWh/yr but it has grown exponentially and reached 0.16 TWh/yr in 2022 and 0.45 TWh/yr in 2023 [17]. This is a 167% and 183% increase respectively. In the most recent long term forecast by NVE, from 2021, it is projected to increase to 6 TWh/yr by 2040 [18]. However, the Norwegian government has a new target of 8 TWh/yr by 2030 as of June 2023. Something that is possible without triggering major network investments [19]. This can be seen in the light of a recent study which estimate the technical potential for solar power on buildings and grey areas to 65,6 TWh/yr and 133,3 TWh/yr respectively [20]. Grey areas are represented by agricultural land that may be out of operation, car parks and closed landfills. Norway's first ground-mounted utility scale solar park, 7 MW_p, is currently under construction 500 kilometres south of the polar circle, at latitude 62 °N and is planned to be completed in 2024 [21].

In Sweden, hydro power accounted for 41% of total electricity production, nuclear 29% and wind 19% in 2022 [22]. There has been an exponential increase in installed solar power capacity over the last couple of years. The increase was 46% and 51% in 2020 and 2021, respectively [23]. The production was 1.1 TWh in 2021, 2 TWh in 2022 and is projected to reach 5.4 TWh in 2025 [24]. Thus, the expansion is rapid although current installations only amounted to 1.2% of Sweden's total electricity production in 2022. The most recent long-term market analysis from 2023 projects solar power production to reach 8.4-15 TWh in 2040 and 12.7-32 TWh in 2050, where the range represents lower and higher degrees of electrification [25]. Most solar installations are placed in the southern and central parts of Sweden. The two northernmost installations are in Luleå 66 °N at 0.7 MW_p and Piteå 65 °N at 1.1 MW_p, and they were installed in 2018 and 2017, respectively [26].

Both Norway and Sweden are currently large net exporters of electricity, exporting 33 TWh each in 2022 through interconnectors to Finland, Lithuania, Poland, Germany, Denmark, Netherlands, and Great Britain. It could add more value to the economy if the electricity was used for domestic purposes, e.g., through industrial development, rather than exported.

Substantial increases in electricity demand are projected for Norway and Sweden, especially in the northern parts. The main driver is electrification in the iron and steel industry through hydrogen direct reduction [5] where in Sweden the upcoming conversion of existing production capacity and a planned greenfield plant alone would increase demand by 20-30 TWh/yr. Other investments that increase demand are battery factories, data centres, electrification of oil platforms and power-to-X [27]. The electrification of the transport sector further adds to the increase in electricity needs [18].

Projections for increased electricity use in Norway vary from 36 TWh/yr between 2019-2040 to 94 TWh/yr between 2020-2050 [18,27]. This equals an increase of 66% in total electricity production by 2050 with wind and solar as key production options due to very limited potentials for increasing hydro power [27]. A recent analysis show that the increased electricity use will transform Norway from a net exporter of electricity to a net importer already by 2028 [28]. The Swedish business association Swedenergy and the Swedish Energy Agency both estimate that electricity demand may increase from 134 TWh/yr in 2020 to about 330-349 TWh in 2045-2050 [25,29]. As noted, much of the increase for both Norway and Sweden are expected to be in the north and recent power market analyses already report of an increasingly strained situation in northern Norway and Sweden [29–31]. We have limited our geographical scope to Norway and Sweden but similar increases in demand can be seen in scenarios for Finland [32]. All in all, these changes in demand as well as supply options will change the dynamics of electricity markets in northern Scandinavia.

In the short term, the increasing demand is by most actors expected to be met by land-based wind power in Sweden while Norway is focusing on offshore wind due to public opposition to land-based wind. The new Swedish Government (since 2022) has revived the idea to build new nuclear power. However, new large-scale reactors may be prohibitively expensive and take a long time to build. Small modular reactors are still many years away from being commercially available and the costs are unknown. Therefore, new nuclear power is very unlikely to make any contribution to Swedish power production before 2035-2040. It is in this context that we explore the potential role of utility scale PV to meet projected demand increases and how PV can be a complement to the already expanding wind power.

3. PV at High Latitudes

There is no literature on the LCOE of utility scale solar power in the Arctic so we use a specific location at 69 °N to assess LCOE. It should be noted that there is a small utility scale bifacial PV system, installed in 2023, in the Svalbard archipelago at 78 °N [33]. However, this system has yet to produce data. In order to assess LCOE of the most profitable PV-system we examine the performance of different mono- and bifacial systems.

3.1. Bifacial PV

Bifacial PV modules convert sunlight into electricity on both the front- and backside of the module. These modules benefit from high albedo, diffuse light and low temperatures which all are characteristics of high latitude areas [10,34]. The bifacial gain (BG) represents how much yield a bifacial PV module produces relative to a monofacial PV module of the same rating and increases strongly with the albedo of the surrounding ground. A theoretical study in Oslo found a linear relationship between BG of 6%-16.5% with respect to albedo in the range of 0-0.5 [35]. BG of 21% has been reported for south facing modules in the Arctic [15]. The price reduction of bifacial modules has been significant lately. Bifacial modules were 21% more expensive compared to monofacial modules in December 2019 but the difference was down to 6% by December 2020 [11]. The market share of bifacial modules is increasing rapidly and is predicted to make up 60% of the global market by 2029 [11].

Soiling by snow is by far the most important parameter for Nordic conditions, yet there is very little experimental data of snow losses available in the literature. Except for one study conducted in Sweden there is no data from systems north of 51 °N [36]. Most other studies are from North America on relatively low latitudes (37–51 °N). A study by Burnham et al. [37] indicate that bifacial modules shed snow faster than regular modules. This is due to a slight warming effect from the back side of the panel as well as the frameless design used for bifacial modules. These modules are also commonly mounted at higher tilt-angles which facilitates shedding further.

4. Methods and Data

In order to evaluate LCOE and power output from different PV-systems a specific location was chosen. The location of the study is set to Gálggojávri, 69 °N, where a pyranometer (SP-230 from Apogee instruments) has gathered global horizontal irradiance data for five years, 2017-2021. Weather data; temperature, wind, humidity and snow cover were collected from the Finnish meteorological institute's observation station in Kilpisjärvi, 10 km south east of Gálggojávri. Monthly albedo values were estimated from vegetation maps and snow cover data. The data was used in PVSyst 7.2 to simulate production from different utility scale PV-systems of 1 MW_p, shown in Table 2.

PVsyst was developed at the University of Geneva in 1992 and is geared towards engineers, architects and researchers. It is widely used in research and has included bifacial models since 2017 [38]. There are mainly two different models used in simulation of bifacial PV systems, 2-D view factor and 3-D ray tracing [39]. PVSyst uses 2-D view factor which is a simplified model that makes computation time more reasonable (minutes), compared to hours or days for the 3-D model. Bifacial solar power systems have not been built in utility-scale until very recently which makes validation of simulation software not readily available [38]. Most validation studies that have been performed have been on smaller systems which omit the prominent self-shading of many and long rows. However, the studies that have been carried out show mostly good agreement between modelled and measured values. A validation study from Denmark (56 °N) performed a comparison between modelled and measured energy production of a utility scale rack. The comparison showed that the 2-D view factor simulated BG within ±1% of the actual BG for the fixed tilt system [40]. Another study compared results from four simulation tools (including PVSyst) with measurements from a fixed tilt site in Albuquerque, USA. The results showed agreement within 1% for all software [41]. The authors argue that the 2D models are accurate enough to predict energy production if the systems are well-characterized in the model. The errors presented above are much smaller than typical errors in PV-yield assessments which lies between 5%–10% [42].

The meteorological simulation in this paper was based on a synthetic meteorological datafile which is then modified with the following data: global horizontal irradiation (GHI), temperature, wind speed and humidity. This approach is recommended by PVSyst. The horizon is imported from the PV-GIS source in PVSyst. The layout of the system is 30 rows with 79 modules in each, totalling 2375 modules. The rows are placed with 10 m spacing and 1.5 m height above ground. This was decided by comparing the results from yield-optimization in PVSyst with what is planned for the only utility scale system in Norway, a 7 MW_p bifacial PV park [43]. The modules used in the simulation are 420 W_p bifacial monocrystalline modules and 420 W_p monofacial monocrystalline modules. The bifaciality factor is 70% for the bifacial module used. The shed transparent factor is set at 0% which means that the simulation assumes that no irradiance passes through the row of modules and contributes to rear side irradiance through reflection on the ground. This is recommended except for systems with spacing in the row of modules. The rear shading factor determines how much of the backside irradiance that is blocked, this could be from the supporting structure etc. This is left at 5% which is the predefined value.

It is not a trivial task to choose inverters for a PV system. A too small inverter will not be able to transform all the electricity produced at high production times and this will be lost by so called clipping. An oversized inverter will on the other hand be expensive so there is a balance act to choose the right size and configuration. It is more important to avoid clipping than to cost optimize in this simulation and thus a generic 1000 kW-AC inverter was selected. It is slightly oversized according to PVSyst. However, Rodríguez-Gallegos et al. [44] proposes to use an oversized inverter when simulating bifacial modules so that the inverter can handle the bifacial gain. The inverter loss during simulation amounts to 2.4% which is reasonable.

Monthly values for ground albedo and array soiling were used in the simulation and are shown in Table 1. The albedo around the pyranometer is estimated to 0.20 in summertime, to 0.9 for November through March when there is heavy snowfall and 0.7 during April and May when more old snow is present. The mean start of snow cover is on October 17th and its disappearance is on May 28th, which adds up to almost 6.5 months of snow. The array soiling is based on values often used by the construction industry i.e., NS3031:2021, but adjusted after discussions with the local (Tromsø-based) Professor and solar expert Tobias Boström. No guiding values for snow soiling on vertical modules could be found in the literature. Instead, a Swedish study performed at 65°N is used to estimate vertical values. This study showed that the vertical module had 20 days of snow soiling while modules with 25°–45° tilt had 33 days of coverage, a 39% difference [45]. The modified snow soiling values are thus scaled with this percentage to estimate soiling values for the vertical modules.

Table 1: Albedo, soiling and insolation values per month. The pyranometer values are averaged over 2017–2021.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Albedo [-]	0.90	0.90	0.90	0.70	0.70	0.2	0.2	0.2	0.2	0.55	0.90	0.90
Array soiling NS3031 [%]	25	25	25	25	2	2	2	2	2	10	15	20
Array soiling adjusted [%]	50	50	50	25	2	2	2	2	2	10	50	50
Array soiling (Vertical) [%]	30	30	30	15	1.2	1.2	1.2	1.2	1.2	6.1	30	30
Pyranometer [W/m^2]	1	20	81	169	224	221	196	128	69	22	3	0

The economic viability is estimated using the concept LCOE. This is a measure of the average net present cost of electricity generation for a generator over its lifetime. It is the most common approach to compare economic viability of different electricity production technologies and projects. The capital expenditure (CAPEX) and operation and maintenance (O&M) costs were gathered from a costs analysis of recent Swedish projects and compared to a concession application for a 7 MW_p bifacial PV park in Norway [43,46]. CAPEX was set to 684 715 EUR/MW_p and O&M to 8 282 EUR/MW_p/yr. The inverters are replaced after 15 years to a cost of 66 776 EUR/MW_p. A nominal weighted average cost of capital ($WACC_n$) of 3.42% was the average in the cost analysis of PV parks commissioned in Sweden between 2019 and 2020 [46]. This is supported by Egli et al. [47] who reported an average $WACC_n$ of 2.4% for PV parks in Germany in 2017. However, a more recent study reports a calculated $WACC_n$ of 5,4% in Norway, which will be used in this study [48]. The lifetime is set to 30 years with a degradation rate of 0,27%. Northern climates favour low degradation which is reflected in this value [46].

4.2. Results of PV simulation

The yearly average global horizontal irradiance in Gálggojávri is 829 kWh/m^2 which is 13% and 11% less than Stockholm and Oslo respectively. Bifacial systems have higher yields compared to monofacial systems as can be seen in Table 2. The BG is 14% for 45° tilt and 17% for 60° tilt. The bifacial system with 45° tilt and facing true south has the highest yearly energy yield, followed by the bifacial 60° tilt system which is also facing true south. The two vertical bifacial systems show similar yield independent of orientation. The monofacial system of 10° tilt, facing east and west, produces substantially less than all other systems.

The daily production profile varies between the systems. Figure 2 illustrates hourly mean values in June for all systems. The vertical system facing south-north has a similar daily production profile as the non-vertical systems facing south, with a distinct top on mid-day.

Table 2: The specific energy yield (kWh/kW_p/yr) for the different systems simulated in PVSyst.

System	Monofacial PV modules	Bifacial PV modules
10° tilt east and west facing	630	-
45° tilt south facing	822	955
60° tilt south facing	777	936
Vertical south-north facing	-	869
Vertical east-west facing	-	859

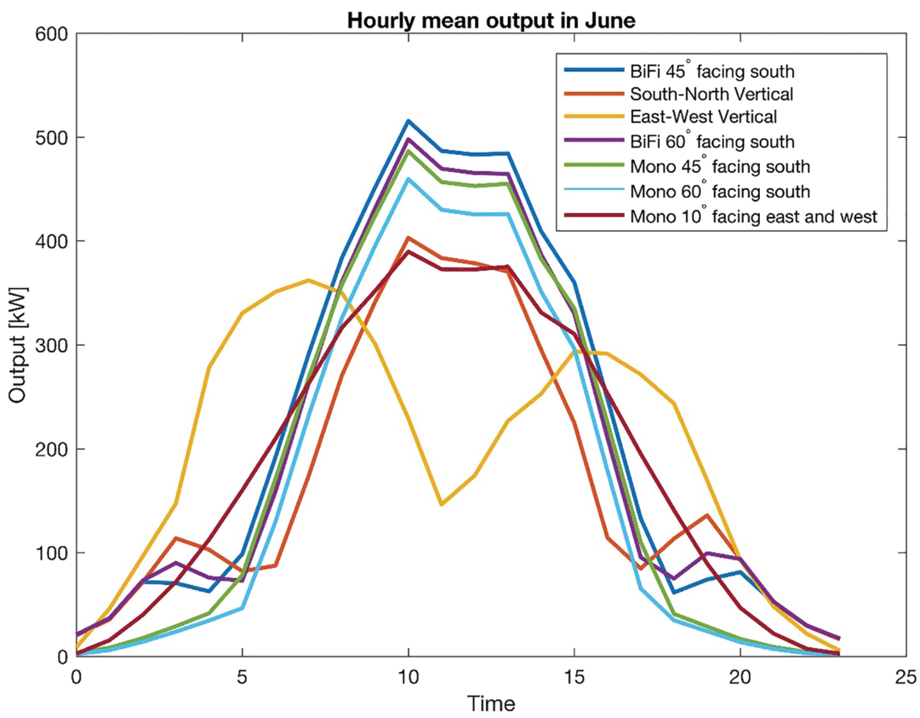

Figure 2: Hourly mean output in June for all simulated systems, average from the 2017-2021 pyranometer dataset. Each system simulated on a 1 MW_p scale in PVSyst.

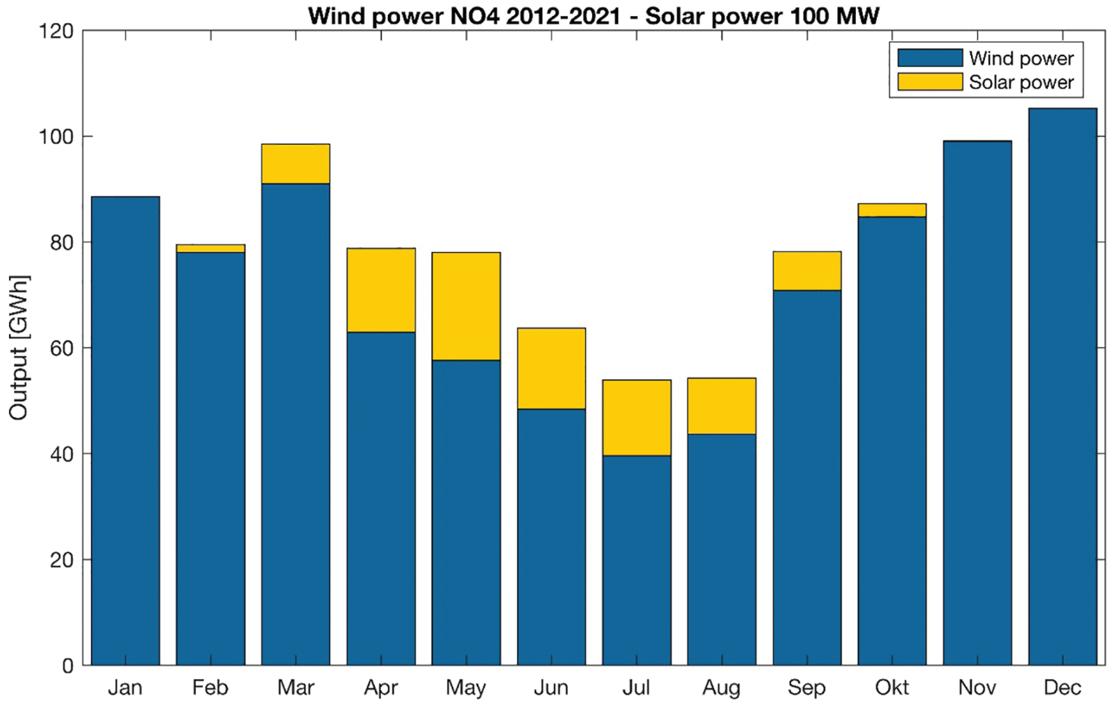

Figure 3: Monthly production values for wind power in price area NO4 averaged over the years 2012–2021. Solar power production profile is taken from the simulation at Gálggojávri and scaled up to 100 MW_p. Bifacial PV-system facing true south with 45° tilt.

However, the vertical system shows slightly more production in the morning and evenings. The vertical system facing east-west has a profoundly different production pattern, with peaks in the morning and afternoon.

Figure 3 shows monthly production values for wind power in Norway's northernmost bidding zone (NO4), averaged over ten years 2012–2021 [49]. On top of this, the monthly production profile of solar power in Gálggojávri has been added and scaled up to 100 MW_p.

The calculated LCOE is 51 EUR/MWh based on the system with highest yield. PV power production in this region is mainly from April through August as seen in Figure 3. The average electricity price has historically been 31 EUR/MWh and 24 EUR/MWh for these months in NO4, averaged over 2008–2022 and 2018–2022, respectively [50].

5. Discussion and Outlook

Utility scale solar PV at very high latitudes has hitherto not been explored in the research literature. Low electricity demand during the summer months and relatively low annual average insolation has not made it an attractive prospect. However, the projected continued reduction of LCOE for PV in combination with increasing industrial year-round electricity demand leads us to conclude that utility scale PV in the Arctic is likely profitable by 2030. We calculate the LCOE for utility scale PV to be 51 EUR/MWh based on recent data, this cost is likely to be below 35 EUR/MWh before 2030 considering the projected continued reduction of LCOE for PV. This equals a reduction of 31% and is in line with the predicted drop in LCOE by 58% between 2019–2030 in the G20 countries. Recent projections suggest that Norway and Sweden together may have a production of about 15–20 TWh of solar electricity in 2040 (see above). Based on our analysis this is likely a substantial underestimate. Much higher levels of production can be expected, and a significant share of this located in the Arctic, given projected increases in total electricity demand.

Our study strengthens the conclusions of small-scale experimental studies that has shown bifacial modules to be beneficial at higher latitudes (e.g., [15,51]). Considering the declining price difference between mono- and bifacial modules it is likely that bifacial modules will completely dominate utility scale systems in the Arctic. The vertical bifacial system facing east-west shows an entirely different production profile than the other systems. This can complement other systems on a diurnal basis and prove advantageous depending on overall electricity demand profiles. Our analysis also illustrates the seasonal complementary of wind and solar power in Northern Norway. Such hybrid systems would have the benefit of shared costs for infrastructure, land use, operation and maintenance and possibly also permitting procedures. Swedish research also shows anti-correlation on a diurnal time scale in addition to seasonal complementary [52]. The research also concludes that a hybrid system increases probability of power production predictions which can lower regulation and balancing costs on the power market. Moreover, wind parks are usually located in open areas which are also suitable for PV-parks.

Although previous studies (e.g., [8,9]) suggest that it would be advantageous to locate electricity intensive industries in sun-rich regions with low LCOE for PV, we argue that northern Scandinavia has other competitive advantages. This includes existing industries and infrastructures and access to stable political conditions. However, further experience and research is needed to understand important cultural, regulative and climatic challenges (e.g., the possibility of combining reindeer herding with PV in Sapmi).

Electrification will create stronger sectoral couplings between power companies and industries. For example, Swedish Vattenfall is already in a joint venture with the steel company SSAB and the mining company LKAB to develop and upscale green hydrogen steelmaking in HYBRIT Development AB. With an expansion of utility scale PV, we expect that electricity intensive industries and PV project developers will enter long-term power purchase agreements (PPA:s) that reduce market price risks for both parties. This is already the case for wind power. Typical PPA prices for land-based wind power in northern Sweden (bidding zones SE1 and SE2) 2018-2021 were around 28-32 EUR/MWh (according to a large wind power developer in Sweden who wishes to remain anonymous. Communication by email, 2022.).

We have presented a first analysis that may be strengthened and corroborated by including the development of renewables and industries also in northern Finland and other regions, and a more detailed assessment of solar and wind resources across the whole region. Also, simulation tools need to be adapted to Arctic conditions and to include specific characteristics of bifacial modules. It is currently not possible to simulate electricity production from the rear side while having the front side covered with snow or frost. Pilots and demonstration plants can help reduce uncertainties regarding snow soiling, but vertically mounted bifacial PV is likely to reduce this problem. Assisted snow removal (manual, electrical or other) is an interesting topic as a thick snow layer in spring could obstruct substantial power production if left to thaw. Tracking devices are generally advised against due to harsh climatic conditions but a robust construction for vertically mounted PV, to increase production and reduce mechanical stress from winter storms, would be worth investigating. Solar and wind hybrid systems are promising but the risk of ice falling from turbine blades and damaging the modules, and how to avoid it, needs to be better understood. It has also been proposed that an increase of electric use in district heating systems can work as a price adjustment mechanism for markets with a high share of variable electricity production (i.e. solar and wind) [54]. Such implementation can improve the integration of increasing shares of variable renewable energy and it will be interesting to see how electrification in general will affect market dynamics.

The potential for Arctic PV also has economic and policy implication. Electricity market modelling and analysis, as well as PPA:s and other financial instruments, could reduce uncertainty concerning the commercial viability. The EU Green Deal Industrial Plan and Net Zero Industry Act means that there will be a strong push for scaling up European manufacturing capacity and the deployment of PV and other technologies that are key to decarbonisation. This has implications for regional development and labour policy with new jobs and new needs for societal services also in northern Scandinavia. It also involves agreeing with the indigenous people on land-use and permitting issues in the Sápmi area.

6. Conclusion

Net zero climate targets necessitates deep decarbonisation of emissions intensive industries such as chemicals and steel. Process electrification and use of hydrogen (as feedstock for chemicals or as reduction agent for iron oxide) are emerging as increasingly attractive mitigation options as costs for wind and solar electricity are decreasing. In this perspective article we show that utility scale PV can be an economically viable option for meeting future potentially very large electricity demands also at very high latitudes. We calculated a levelized cost of electricity at 51 EUR/MWh for a utility scale bifacial system placed at 69 degrees north and this cost is expected to decrease with time. The strength of having a complementary mix of solar, wind, and hydro power, together with favourable political and other conditions in northern Scandinavia, may outweigh the relatively limited cost advantage of locating PVs and electricity intensive industries at lower latitudes with higher insolation. Thus, recent projections for solar electricity in Norway and Sweden are probably underestimating, again, the future role of solar PV.

Acknowledgement

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