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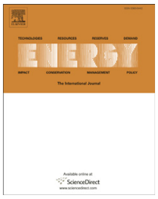

Rethinking the role of solar energy under location specific constraints

Odin Foldvik Eikeland [a], Harry Apostoleris [b], Sergio Santos [a, b, c], Karoline Ingebrigtsen [a], Tobias Boström [a], Matteo Chiesa [a, b, *]

[a] UiT-the Arctic University of Norway, Department of Physics and Technology, 9037, Tromsø, Norway
[b] Laboratory for Energy and NanoScience (LENS), Khalifa University of Science and Technology, Masdar Institute Campus, 127788, Abu Dhabi, United Arab Emirates
[c] Future Synthesis, Adderbury Banbury, Oxfordshire, OX17 3EP, UK

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ABSTRACT

In this manuscript we evaluate the potential of photovoltaic systems to meet some dedicated energy demand in specific geographic locations. Our approach is based on location-specific constraints rather than on pre-established, location-independent methodologies or assumptions. First, we propose that a thorough analysis of the socio-economic and technical possibilities of a location must act as the guide to optimize the deployment of renewables. This requires detailed knowledge of the area. Second, we propose that optimizing the exploitation of renewables by focusing on a particular location can also lead to successful outcomes with global impact. With this in mind we focus our attention on the Arctic region, known for its highly seasonal solar availability, and the challenge posed by increasing cruise ship tourism and corresponding air pollution. Our study targets Tromsø city, Norway, and we show that solar energy generation could be a strong contribution for charging cruise ships in the summer with no need for generation and transmission investments. Our study opens the door to shifting to a location specific paradigm to seek sustainable energy solutions with the possibility to have a global impact.

1. Introduction

Due to the variability of solar energy from winter to summer seasons the Arctic could be easily overlooked as a potential area of application for solar energy systems [1]. In desert regions, electricity from large photovoltaic parks can be produced for less than 3 ¢/kWh [2]. This is competitive even when compared to the cheapest fossil fuel generation. In Arctic settings, the annual solar resource is 3–4 times less, highly unevenly distributed throughout the year, and significantly mismatched to demand in the region. Clearly the prevalence of electric heating means that there are demand peaks during the polar night (when solar power generation is negligible) [3]. [4]. For such reasons, the Arctic seems an unlikely place, at first glance, to develop solar energy. We nevertheless propose that such disadvantages overlook the overall picture and dismiss other potential implementations. In particular, such a view considers local environmental conditions while it fails to recognize, and overlooks, the local economic conditions [5]. When we zoom in on the actual settings in which solar energy systems would be deployed, many situations can be identified where photovoltaics are still economically favorable relative to practical alternatives, even if costs per kWh are far higher than *global* market conditions would allow. This is especially true if systems are designed specifically for applications that are naturally matched to the solar resource [5,6].

The challenges involved in increasing the share of renewable energy resources to the electric grid have been extensively studied. Olauson et al. indicate that a fully renewable Nordic energy system is feasible if the variable power generation is properly balanced by hydropower [7]. Moreover, Ringkjøb et al. studied the potential for transitioning from a delocalized off-grid settlement under extreme Arctic conditions towards renewable energy [8]. Their study suggests that stochastic modelling of this off-grid system is relevant for future implementations in remote Arctic conditions. Solar energy generation in two Scandinavian cities (Uppsala in Sweden and Tromsø in Norway) were considered to be nearly sufficient for charging electric vehicles [9]. Genai et al. presented a study centered in Stockholm to investigate the potential for using a hybrid energy system consisting of solar energy, fuel cells and

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* Corresponding author. UiT-the Arctic University of Norway, Department of Physics and Technology, 9037, Tromsø, Norway.
E-mail address: matteo.chiesa@uit.no (M. Chiesa).

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diesel generators to supply electricity to cruise ships. Their findings show that such systems could reduce emissions and at the same time enable integration of renewables for onboard energy generation [10]. Lee et al. also focused on hybrid energy systems to supply ships with electricity. In their approach a prototype ship consisting of a photovoltaic generation system, a diesel engine, a battery energy storage, a control system and inverters was presented. Their main target was both to minimize fuel consumption and support power grid supplies by exploiting shore power [11].

Despite the above body of knowledge, we have found no study dedicated to sustainable Arctic tourism by considering the specific terms of energy requirements. In this study, we fill this gap by illustrating the potential value of tailor-made photovoltaic systems to satisfy a specific Arctic demand: a booming cruise ship tourism industry in the north of Norway [12].

The Arctic has become an increasingly popular tourist destination in recent years, arguably due to 1) warmer temperatures and 2) an increasing demand for the so-called “last chance” tourism as a consequence of the impact of climate change [13]. In some Arctic areas, cruise ship (CS) tourism is one of the fastest growing economic sectors. The pollution associated with such growth of tourism activity aggravates the local air quality while increases greenhouse gas emissions [14].

European ports have often been reluctant to install shore power facilities for CSs as up-front costs are high and many ships do not have connection capabilities [15]. Consequently, ships generate electrical power by means of auxiliary engines on board. This causes emissions of both greenhouse gases and conventional air pollutants. These have a negative impact on local air quality and contradict the “clean-nature” experience that the tourist industry is marketing. Studies performed by the sustainable transport group (Transport & Environment) state that the cruise ship operator Carnival Corporation emitted nearly 10 times more Sulphur oxide in Europe than all 260 million cars in Europe in 2017 [16].

The future CS industry is expected to retrofit ships to have the possibility to connect to shore power facilities as illustrated in Fig. 1. This could contribute to the electrification of CSs while harbored. When CSs are connected to on-shore power sources, the load on the existing network increases rapidly. In worst-case scenarios the existing network will not handle this load and meet the demand. Consequence are voltage drops and power outages. The implication is that minimizing the load on the existing power grids is mandatory.

In Norway, more than 95% of power production comes from hydropower [17]. In the negative, installing hydropower stations requires major infrastructure developments and impacts the local environment drastically. This consideration arguably suffices to understand the potential value of alternative energy technologies. Solar photovoltaics (PV) and wind power are so far the most prominent technologies for installations from renewables [5,18]. However, there has been great opposition to wind power installations in Norway due to potential disturbance to wildlife and the corresponding infrastructure development. In this sense, solar energy systems mounted on buildings might easily gain support in society.

Tromsø in Northern Norway, (latitude 70° north), is characterized by typical Arctic conditions with cold, long winters and polar nights between November and January where the sun is never above the horizon. The summer is short and cold, but it is characterized by long days with midnight sun between May and July where the sun is never below the horizon. Tromsø is well known for its beautiful nature experiences and is a popular tourist destination where the tourism industry continues to increase yearly [12]. A significant part of the tourist traffic comes via cruise ship, with most of the traffic arriving during summer [19]. In 2018, 142 348 people arrived by 119 large ships, and in 2019 the number increased to 155 160 people by 122 ships [20]. In order for Tromsø to maintain its nature-friendly character, greenhouse gases and other pollutant emissions from the harbor must be reduced and ideally eliminated. The electrification of the Arctic cruise tourism presents a promising pathway to achieving this reduction. Our purpose here is to show that Tromsø is an excellent model location to study how a solar energy system can meet the energy requirements of CS tourism in Arctic regions during the summer months.

In Tromsø Harbor, there are still no services for electrifying the cruise ship tourism by employing off shore power facilities [19]. We evaluate the potential for using solar energy systems as the main source to power the cruise ships by shore power facilities and model the solar energy resources which are compared to energy demand from the visiting cruise ships. Solar energy could be an essential contribution for developing a more sustainable tourism industry in the Arctic if proven to be a viable source for powering the cruise ships. Here we aim to answer the following question: are solar energy systems enough as a main source for powering the cruise ship tourism industry in Arctic conditions? We note that the Arctic is particularly known for its highly seasonal solar availability. In addition, we aim to investigate the economic viability of such systems under the particular conditions here. Namely, those

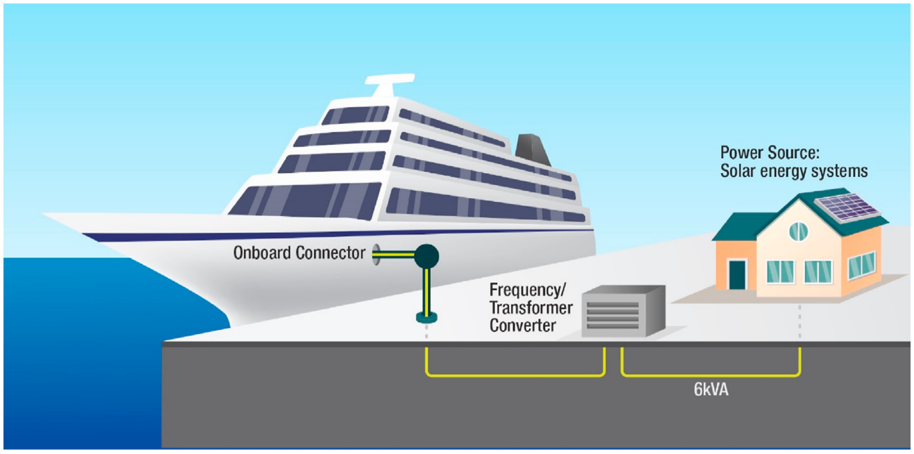


Fig. 1. Typical system for connecting a ship to shore power when in port. This system consists of a power source (PV solar energy here). The energy is transported to a frequency/transformer converter in order to connect onboard. On the ship, the power is transformed and distributed to the different components from a control panel.

conditions where solar energy systems could match the costs of onboard electricity generation by use of fossil fuel. Finally, we discuss conditions and possible solutions for the cost of PV generated power to fall below onboard fossil fuel electricity generation.

By a rigorous consideration of the requirements, costs and opportunities at specific settings, our study also explores, by providing a case example, the potential to expand globally the idea of considering location specific constraints.

2. Methods

We assess the potential of obtaining energy from photovoltaics to meet the needs of cruise ship tourism in the Tromsø harbor. We begin by gaining an understanding of the electricity demand profile of cruise ships in Tromsø harbor over the day and in the year. We proceed to create a high-resolution solar map illustrating solar resources in Tromsø city (Tromsø Island) using the software ArcGIS. We further simulate PV energy generation by employing the software PVsyst. The estimated PV energy yield is matched with the energy demand of harbored CSs in Tromsø to assess the possibility of meeting energy demands with renewable energy from onshore PV systems.

2.1. Cruise ship load assessment

The electricity demand from docked CSs has been estimated based on statistics received from Tromsø harbor in combination with information from a shore power station in the port of Kristiansand. Tromsø is one of Norway's biggest tourist destinations during the year with several tourist CSs docking in at the city. Tromsø harbor has published statistics on the number of ships and tourists arriving each year from 2013 to 2019 [20]. These are provided in Table 1.

The decline in the number of CSs experienced between 2014 and 2016 is probably due to the aftermath of the 2014 oil price collapse, which resulted in slower economic growth [21]. From 2016 onwards, the number of CSs has increased together with number of passengers. The data for the number of visiting CSs per month in the period ranging from 2013 to 2019 has been averaged and listed in Table 2.

This distribution shows how the great majority of CSs arrives during the summer tourist season with a peak in June. The high number of visiting CSs in March is due to the interest for northern light tourism [12] in winter.

When the CSs dock, they enter into "hotel mode". When in hotel mode, the ships require large amounts of energy to operate the air condition, hot water, lights, restaurants and heat. These must be available all the time for the passengers and the crew [22,23]. If a harbor does not offer shore power, the ships run auxiliary engines on board, releasing CO_2, SO_2, NO_x and other pollutants into the atmosphere. In addition, the engines create noise pollution which disturbs residents in nearby areas.

Information regarding power load has been provided upon request from the port of Kristiansand [24]. The port has the facilities to provide shore power to CSs. This information is provided in Table 3.

The statistics in Ref. [25] show an average ship size with a maximum capacity of 1516 passengers. Based on information given in Table 3 and the average ship size, one can assume a typical load of 5 MW. However, this load will vary drastically between different ships based on; size, model, age, different engineering solutions, heating systems and some other contributions arguably less relevant. Therefore, a typical load of 5 MW may not be an accurate estimate, but it is here used to benchmark PV generation. The shore power facility like the one in the port of Kristiansand can provide power up to approximately 13.6 MW something that meets the requirement of the larger ships [24]. Clearly such a load would require a much larger PV system than what has been simulated in this study. Despite this important technical detail, we believe that a more comprehensive analysis of the integration of a PV system with the current grid capacity is out of the scope of our investigation.

Table 2
Averaged distribution of the number of visiting CSs in Tromsø harbor between 2013 and 2019.

Month	J	F	M	A	M	J	J	A	S	O	N	D
C.Ss	0	3	8	1	6	36	31	14	3	2	2	1

Table 3
Overview of power loads of CSs when visiting Kristiansand harbor [24].

Ship name	Passenger capacity	Shore Power possible to connect	Power needed [MW]
Rotterdam	1404		4.3–6.0
Nieuw Statendam	2650	Yes	4.7–5.5
Viking Jupiter	930		4.30
Costa Favolosa	3780		4.6–5.5
Regal Princess	3600	Yes	7.2–11.1
Koningsdam	2650	Yes	4.7–5.5
Amsterdam	1380	Yes	5.1–6.0
Noordam	1916	Yes	6.0–7.7
Oosterdam	1848	Yes	6.0–7.7
Zuiderdam	1969	Yes	6.0–7.7
AIDAperla	4350		6.4–8.1
AIDAprima	3300		6.4–8.1
MSC FANTASIA	4900	No	7.70
MSC MERAVIGLIA	4500	Yes	7.70
MSC PREZIOSA	3959	No	7.70
MSC SEASIDE/ SEAVIEW	5429	Yes	11.10
MSC SPLENDIDA	3900	No	11.10

The average number of hours that ships dock in Tromsø varies by month from 25 h in February to 7 h in September [19]. However, almost every CS that visits arrives between 07:00–09:00 in the morning. This suggests a potential good temporal matching between solar energy generation and energy load [19]. Based on a load of 5 MW and the average number of docking hours, it is possible to estimate the aggregated monthly energy consumption by the following equation:

$$\begin{aligned} \textit{Energy load}\ [\mathrm{MWh}] = \textit{No. boats} \times \textit{Hours visited}\ [\mathrm{h}] \\ \times \textit{Power of ship}\ [5\ \mathrm{MW}] \end{aligned} \tag{1}$$

The monthly aggregated energy consumption is provided in Table 4:

Table 1
Statistics showing the number of CSs visiting Tromsø harbor every year since 2013.

	2013	2014	2015	2016	2017	2018	2019
No. of Ships	104	110	103	91	103	117	122
No. of passengers	108 681	111 631	111 190	102 495	125 455	141 945	155 160

Table 4
Aggregated monthly electricity load based on the number of hours of an average visit per month. This assumes a consumption of 5 MWh/h when harbored.

Month	No. of boats	Avg. hours visited	Energy load [MWh]
J	0	9	0
F	3	25	375
M	8	21	840
A	1	4	20
M	6	9	270
J	36	9	1620
J	31	10	1550
A	14	9	630
S	3	7	105
O	2	9	90
N	2	12	120
D	1	12	60

2.2. *Assessment of solar potential*

The available rooftops in Tromsø have been calculated with the use of the ArcGIS Pro software. The solar resource capacity has been derived from an existing high-resolution Light detection and ranging (LiDAR) raster dataset. To ensure higher accuracy in assessing the solar resource, a high-resolution solar map of 0.25-m has been created. We note that lower resolution maps failed to capture the actual tilt of the roofs [26]. In addition, our quantification has been validated against local measurement instruments and common meteorological data from geostationary satellites. Geostationary satellites orbit around the equator and are only slightly inclined on locations at high latitudes. These have already shown to provide wrong estimates of the solar potential in many cases [27].

The LIDAR data has been acquired from the Norwegian mapping authority [28]. The dataset holds all information about surface and surrounding factors that could affect the solar resource, i.e. shading, inclination and orientation of roofs.

ArcGIS Pro provides several built-in tools to use for calculations. We have used the “Area solar radiation” tool to calculate the solar potential in Tromsø. This tool takes into account the sun’s position and trajectory throughout the year, as well as the monthly average weather conditions. The latter must be taken into account by specifying different diffusion and transmission (D&T) values. The procedure for making the solar map in ArcGIS Pro is given in Table 5.

In step 1, the raster dataset was acquired by exploiting Ref [28]. The dataset covers a substantially larger area than needed for this study. For ease of computation, the area of study has been restricted to cover only the Tromsø Island. In step 2, Tromsø Island is extracted from the surrounding area. In step 3, the whole Island is split into 45 evenly sized parts to achieve a more efficient calculation as the “area solar radiation” tool is area-sensitive. Furthermore, larger areas give significantly longer computing time [29]. In step 4, the solar map is created. The solar potential must be calculated each month separately with different D&T values before aggregating each month to form a map for the whole year. To further improve the creation of the final map, calculations were performed on 15 cores at once via access to a server computer. This was provided from digital research services at UiT-the Arctic University of Norway [30]. Steps 5—7 are performed to further modify the solar map. Here the tool “Diff” is exploited to highlight all rooftops. The final result is a map of the global tilt irradiance (GTI) on rooftops on Tromsø Island- The map represents the total solar resource available in terms of roof-mounted PV systems. A detailed explanation of the methodology for creating the solar map can be found in Ref. [29].

Table 5
Tool procedure for creating a solar map in ArcGIS Pro.

Step	Tool
1	"Make raster layer"
2	"Extract by polygon"
3	"Split raster"
4	**"Area solar radiation"**
5	"Make Feature layer"
6	"Feature to Raster"
7	"Diff"

2.3. *Photovoltaic yield simulation*

The energy yield from a typical photovoltaic (PV) system was simulated using the PVsyst software [31]. The simulation was performed using meteorological data from Meteonorm V7 which includes Global horizontal irradiance (GHI), diffuse horizontal irradiance, wind speed and temperature [32]. The Meteonorm V7 data and the solar resource values from the solar map were validated against averaged measurements from a pyranometer (instrument for measuring solar irradiation) instrument at a local weather station at Holt (located 5 km in air distance from Tromsø harbor). The instrument is operated by the Norwegian Institute of Bioeconomics (NIBIO). This is a high-quality instrument that is properly maintained to provide accurate measurements results and it is a valuable instrument for validation purposes of solar radiation at high latitudes. The resulting validation data is provided in section 3.1. The measurement data from the pyranometer has hourly time resolution and has been averaged from 2009 to 2018 to improve data quality. To achieve more accurate results, far shading effects due to the horizon line from the surrounding mountains of Tromsø has been taken into account. The horizon line has been imported into PVsyst from PVGIS 5 [33].

On the basis of assuming the average power load from CSs to be 5 MW when in harbor, we have used a 6 MW$_p$ PV system for the simulation. Such a system covers an area of approximately 32 736m^2 and can be installed on the existing rooftops of industrial buildings in Tromsø harbor. This covers a total area of approximately 55 000m^2. An extract of the solar map covering the harbor showing available roof area for PV systems on industrial buildings is shown in Fig. 2. The system was designed with monocrystalline silicon modules. The module type is chosen to be as in Ref. [9], i.e. a JKM300M-60 model from Jinkosolar with an efficiency of 18.42%. The annual relative solar irradiation in Tromsø is highest on a surface tilted between 30 and 65° upward with azimuth angles from -30 to 30° (where 0° is directly southward) [9]. Here we compromised to a solar energy system with a tilt angle of 40° facing directly southward. On the roof of a building at UiT we have monocrystalline silicon PV modules mounted with a 40° tilt. These are facing directly southward and make it possible to compare PV yield simulation data against actual production values from this solar energy system [34].

The details of the simulated PV system are given in Table 6, and the results of the simulation from PVsyst are given in terms of monthly energy generation in Table 8 in section 3.2.

2.4. *Solar fraction*

The temporal matching between PV energy generation and electricity load has been previous studied in Ref. [9,35,36] by considering the self-sufficiency of solar power. Self-sufficiency here should be understood as solar fraction (SF). In this study, the SFs of PV energy generation against electricity load from CSs in Tromsø

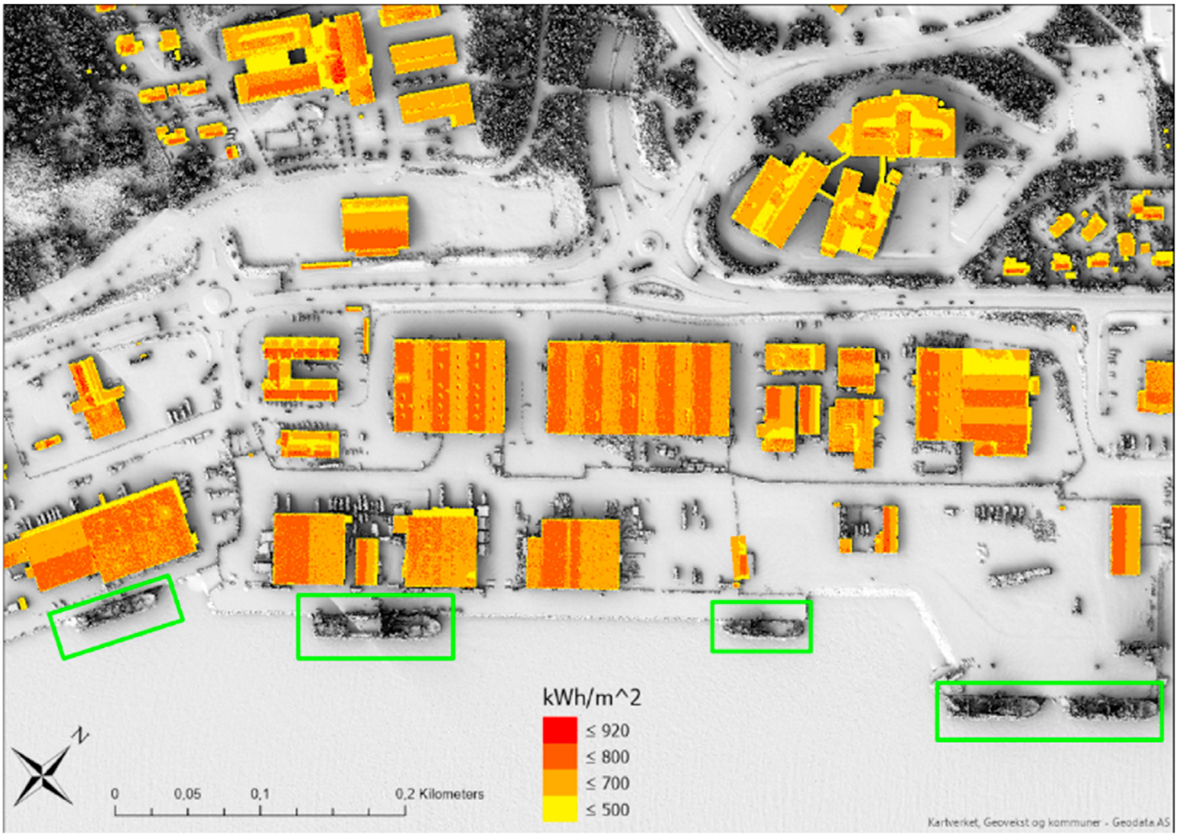


Fig. 2. Extract of the solar map covering Tromsø harbor. Ships are inside the green boxes. The solar potential in kWh per square meter and the year corresponding to the measurements on each rooftop are classified by color. The arrow in the lower left corner indicates the north direction. Based on cadastral data from Geodata, the total area of rooftops in this extract is approximately 55 000 m^2 [37]. This area has also been selected by accounting for proximity of the boats in harbor. Small distances result in lower transmission losses when the power is transported via the electric grid. From Refs. [29], the total solar architecturally available area for the whole of Tromsø island was found to be 1.1 km^2. This total area can be used in future studies for similar purposes as those discussed here. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

harbor have been computed. SF describes the load from CSs that can be covered with PV solar power [9]. SF can be quantitatively computed by using the terminology in [9,35,36].

$$SF = \frac{\int_{t=t_1}^{t_2} M(t)\, dt}{\int_{t=t_1}^{t_2} L(t)\, dt} \tag{2}$$

The integral boundaries represent the temporal period where t_1 is start time and t_2 is end time. P (t) is defined as the PV generation profile and L (t) is the load profile. M (t) is the instantaneously overlapping part of P (t) and L (t) defined as

$$M(t) = min\{L(t), P(t)\} \tag{3}$$

SF varies in the range [0, 1]. The higher the SF, the more energy consumption can be covered by PV solar energy generation. If SF = 1, then the energy load from the CSs is completely covered. In addition to investigating the temporal matching, the SF parameter can be employed for identifying cases with distribution network overload. If the loads are significantly larger than the generation ($L(t) \gg P(t)$), or the generation is significantly larger than the load ($P(t) \gg L(t)$), actions must be taken to minimize the strain on the grid.

By assuming that both CS traffic and the potential for power generation from PV systems are highest in the summer, aggregated SF values have been calculated for the April–September months. This allows us to investigate the monthly energy balance. In this study, as in Ref. [9], the instantaneous SF parameters were used. These have been defined as

$$SF(t) = \frac{M(t)}{L(t)} \tag{4}$$

The solar system is not optimized in terms of solar self-sufficiency and therefore we envision a grid interaction with the existing electric grid as described by grid-integration factors based on the instantaneous power imported from, or exported to, the grid [36]. The grid interaction is taken as the surplus power from the PV

Table 6
Details of the simulated 6 MW_pPV system which includes 20 000 modules and 1020 inverters of the same type as in Ref. [9]. Each module is facing directly south with a tilt angle of 40°.

Module	
Type	Jinkosolar, JKM 300M-60-V
Power	6 MW_p
Efficiency	18.42%
Total module area	32 736 m^2
Number of modules	20 000
Inverter	
Type	AEG, AS-IR01-4600 (4.6kw)
European efficiency	96.80%
Power ratio (PV array/inverter)	1.28
Number of inverters	1020

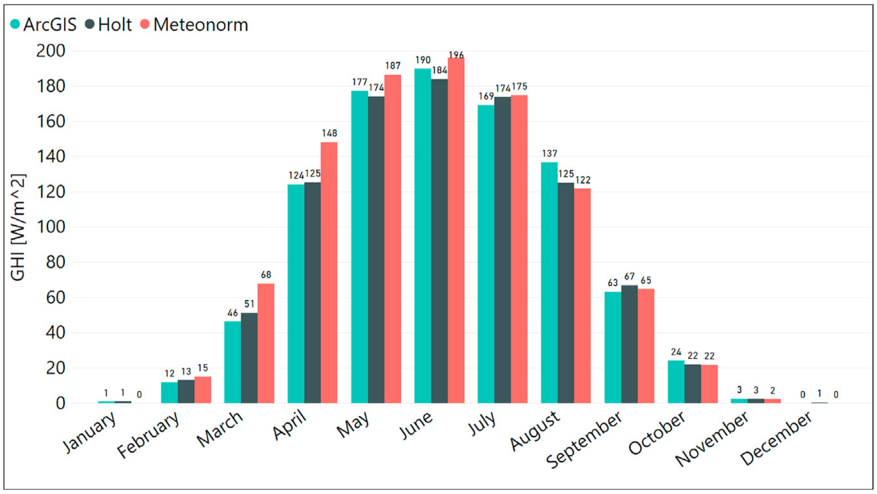


Fig. 3. Monthly averaged GHI values in ArcGIS, Meteonorm and pyranometer installed at Holt.

system exported to the grid. Additional power is imported from the grid when the CS load is not met.

3. Results

3.1. The solar resource in Tromsø

Our final high-resolution solar map is shown in Fig. 2, where an extract of Tromsø harbor and its surroundings are also shown. The roofs have been highlighted to show the potential for installing solar energy systems on the roofs. The color bar indicates the strength of the annual solar resource on the associated surface. Solar potential is significantly influenced by the orientation and tilt angle of the surface, where south-facing roofs have much higher potential than north-facing roofs. This is typical in high northern altitudes. It is also possible to investigate the shadowing effects in this solar map, as the potential is lower where the roof is influenced by shade from surrounding forests or buildings. This solar map could be a valuable asset for many studies when considering where to place a PV system on rooftops. As this extract shows, many of the buildings are large industrial buildings with flat roofs that are suitable for installation of solar energy systems. Cadastral data shows that within this map extract, there are approximately 55 000 m^2 of roof area in total [37]. The available area for façade installations is not considered in this work as it is not possible to visualize it in the solar map in Fig. 2. A main problem relates to the possible shadow losses from surroundings (other buildings, forest etc.). An additional problem is brought by the objects on the façades that might hinder potential installations.

3.1.1. Validation of solar resource simulation in Tromsø

Fig. 3 shows that the monthly solar resource values from the ArcGIS solar map agree with the averaged measured data from the pyranometer located at the weather station at Holt and operated by NIBIO. The Meteonorm data is accurate except for the months of March and April. In these months the Meteonorm data significantly overestimates the solar resource. The root mean square deviation (RMSD) for the solar map and the Meteonorm database are shown in Table 7:

Table 7
RMSD for averaged monthly GHI data aggregated to one year. The RMSD is normalized to the average yearly GHI value from pyranometer measurements. The Meteonorm data has lower accuracy as compared to ArcGIS data. This is due to overestimations in March and April.

Parameter	ArcGIS $[\mathbf{W}/\mathbf{m}^2]$	Meteonorm $[\mathbf{W}/\mathbf{m}^2]$
RMSD	4.54	9.84
Norm. RMSD	0.06	0.12

The statistical analysis and Fig. 3 show high correlation between averaged pyranometer measurements and the ArcGIS solar map. The Meteonorm database shows an overestimation in March. As a positive it has high accuracy for the rest of the year. A normative RMSD of 0.06 for the ArcGIS map and a normative RMSD of 0.12 for the Meteonorm database are typically taken as satisfactory for solar energy potential investigations. The validation process of the solar map and the Meteonorm database indicate that the solar potential measurements are acceptably accurate. Furthermore such measurements could be used in future studies. It is important to notice that both the solar map in ArcGIS and the Meteonorm database use average values; therefore, the averaged pyranometer data must be used for validation. The pyranometer measurements are sensitive for weather differences each year. This will produce considerably larger errors if the data is not averaged over several years.

3.2. PV power output

The monthly values simulated in PVsyst from the 6 MW_p solar energy system in Tromsø are shown in Table 8.

To ensure the accuracy of the simulation, the GHI that penetrates the solar module tilted on a 40° angle (Glob. Inc.) was checked against averaged values from a pyranometer mounted directly on a solar module of 40° tilt. The Effective global irradiance (Glob. Eff. In Table 8) is the Glob. Inc. corrected for angle-dependent reflections from the module surface (incidence angle modifier or IAM) and far shading losses from the horizon line. The energy injected to the grid (E. Grid) is calculated with respect to the effective global irradiance on the solar cell and the ambient temperature. Lower temperatures give higher efficiency. The yield was found to be largest during the summer period between May and July with a peak generation in May.

3.3. PV power output and charging load from cruise ships

3.3.1. Case studies of daily energy balance

In this study, six case studies are performed to investigate the energy balance between PV energy yield and CSs for specific days in

Table 8
Resulting output from simulations of a 6 MW_p system consisting of 20 000 modules and covering an area of 32 736m^2. The ambient temperature is included in this table as the efficiency of solar cells depends on temperature.

	GHI [$\mathbf{kWh/m^2}$]	Amb. T. [°**C**]	Glob. Inc. [$\mathbf{kWh/m^2}$]	Glob. Eff. [$\mathbf{kWh/m^2}$]	E. Grid [MWh]
J	0.0	−2.3	0	0	0
F	10.2	−3.2	35	28	163
M	50.5	−1.9	111	102	603
A	106.7	1.7	124	118	676
M	138.4	6.1	158	150	827
J	142.1	9.2	146	137	742
J	129.6	12.6	130	122	659
A	90.2	11.6	112	106	575
S	46.3	7.6	68	64	351
O	16.1	3.5	36	31	173
N	1.7	0.2	7	5	26
D	0.0	−1.9	0	0	0
Year	731.9	3.7	927	863	4795

the summer season of 2018. The generation data for the daily case studies has a time resolution of 1 min.

The following cases for specific days of summer 2018 are presented:

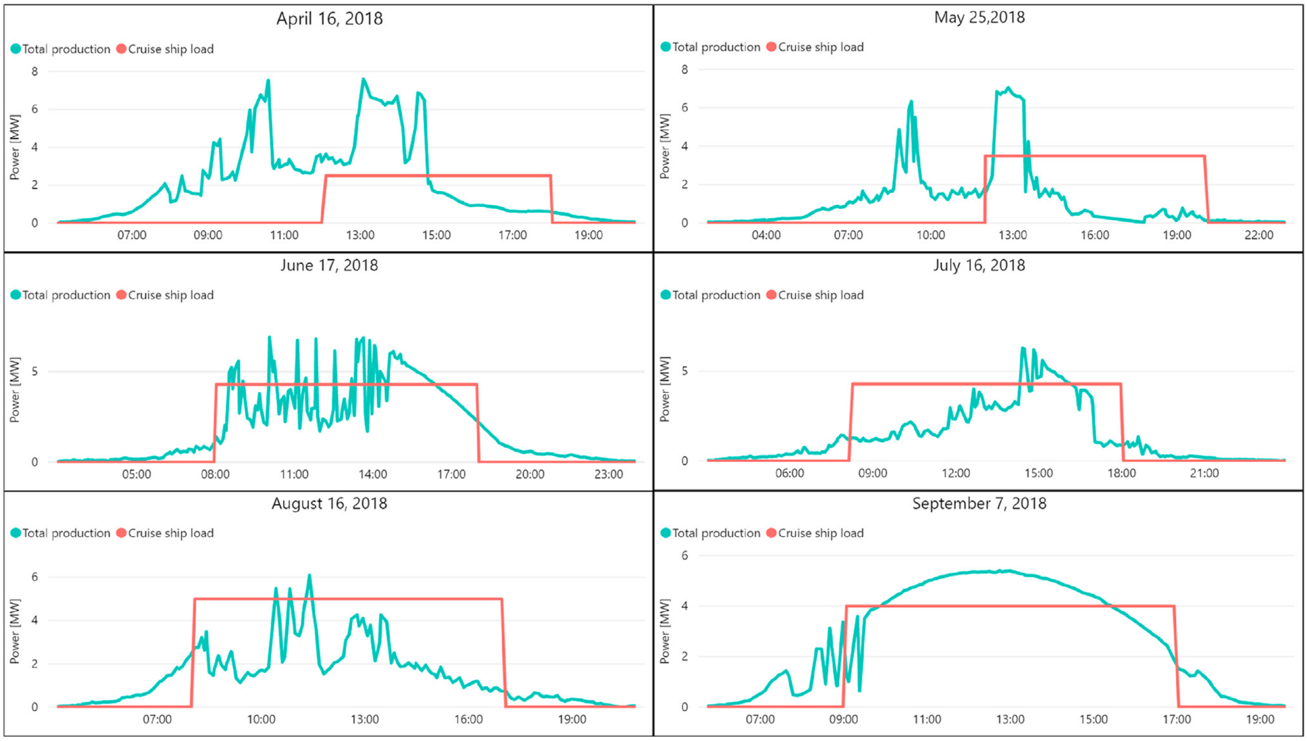
1) On April 16, the Norwegian ship “NORDSTJERNEN LATU3” visited. This is an old and small ship with a maximum passenger capacity of 450. The ship arrived at 12:00 and left at 18:00, i.e. the ship stayed for 6 h. As the boat is so small, a load of 2.5 MWh/h is assumed when docked.
2) On May 25, the ship “OCEAN MAJESTY CQSC” arrived at 12:00 and stayed until 20:00. The ship is also a small with a maximum capacity of 621 passengers. This ship is assumed to have a load of 3.5 MWh/h when in harbor.
3) On June 17, the ship “VIKING SEA” visited. This CS has a maximum capacity of 930 passengers and stayed from 08:00 to 18:00, i.e. 10 h. Based on given information about electric needs, a load of 4.3 MWh/h is assumed when in harbor.
4) On July 16, the ship “VIKING SKY LAYU7” visited. This CS has equal size and passenger capacity to “VIKING SEA”, and stayed from 08:00 to 18:00. A load of 4.3 MWh/h is assumed for this CS as well.
5) On August 16, the cruise ship “ARTANIA ZCDM7” visited. This cruise ship has a maximum capacity of 1260 passengers and stayed from 08:00 to 17:00, i.e. 9 h. Based on passenger capacity for this ship, a load of 5 MWh/h is assumed.
6) In September, only one CS visited on September 7, this was the ship “SEABOURN OVATION”. This ship had a maximum capacity of 604 passengers and stayed in from 09:00 to 17:00, i.e. 8 h. Based on passenger capacity, a load of 4 MWh/h is assumed.

Further information regarding the case studies above is provided in Ref. [19]. The reason for our selection of dates is context. In particular, we used weather statistics from the weather forecast service “Yr” to make sure that the weather these days would be suitable for PV solar energy production [38]. With all, the PVsyst software used in this study does not offer 1-min high-resolution simulations for the specific days chosen here. In addition, the Meteonorm database uses average climate data. This data is not suitable when comparing solar energy generation under specific weather conditions for particular days. Therefore, to match the solar energy generation with the cruise ship loads at the given dates, we exploited the production values received from the solar energy system on the roof of a building at UiT. This building is located only 500 m from Tromsø harbor. To achieve similar conditions as for the simulated system in PVsyst, the production data from a 40° south-facing module has been further used as a basis. Detailed information about the module is given in Table 10:

A system of the same size as that used in the PVsyst study has also been modeled. The system consists of 20 000 modules. The load is assumed to be constant when the ship is docked. This is reasonable if we ignore small fluctuations such as climate control and lighting. The load is typically 0.1–0.3 MW higher during the first 15 min before stabilizing and as soon as the ships are connected to shore power [24]. The daily energy balance between PV solar generation from 20 000 modules and CS loads for each case is given in Fig. 4.

Fig. 4 shows that the generation from the solar energy system could cover the load at peak production. However, the large variability in production due to weather changes causes longer periods for which the production is far from being enough to fully cover the load. In fact, on September 7, the production was close to stable during the whole day and could almost fully cover the load except from morning hours and afternoon hours. The production from the PV system clearly shows one of the challenges associated with the intermittency of PV solar energy generation. Therefore, this PV system must be used in conjunction with energy storage or interaction with electric grids to provide a more stable and reliable power supply. The challenge with energy storage solutions such as batteries is capacity. In our case, batteries would be required to handle loads in the order of MW. In turn, these load could cause challenges related to storage space and location. In addition, large batteries increase the cost of the system significantly. We suggest a solution in the form of a continuous interaction with the existing electricity grid. Excess energy would be immediately sold to grid. When needed, additional energy could be imported to the system from the grid. From Fig. 4, on September 7, the PV system could profit by selling additional energy to the electric grid before arrival at 09:00. When the ship is sucking energy, the PV system could sell excess energy between 10:00–15:30. When the ships have departed, the PV system could sell excess energy from 17:00–19:00. A potential alternative solution is to install batteries that charge between 10:00–15: 30 and provide additional power to the ship between 15:30–17:00. After the ship departs, the excess PV generation could be stored on the installed batteries. However, the installation of batteries could increase investment costs of the system significantly and will not be considered further in this study.

This shows that for sunny weather conditions, there is a significantly larger amount of excess energy that could be sold than there is a need of buying additional energy. This can be seen as a beneficial economic solution since it implies that there is no need to invest in large and expensive energy storage solutions.


April 16, 2018

May 25,2018

June 17, 2018

July 16, 2018

August 16, 2018

September 7, 2018

Fig. 4. Case studies of temporal energy matching between generation from 20 000 south-facing modules with 40° tilting against load from cruise ships when ported in Tromsø harbor. The CS load is assumed to be constant when the ships are in harbor. In fact, the first 15 min after the ship is connected, the load is approximately 0.1–0.3 MW higher before it stabilizes to a constant load [24].

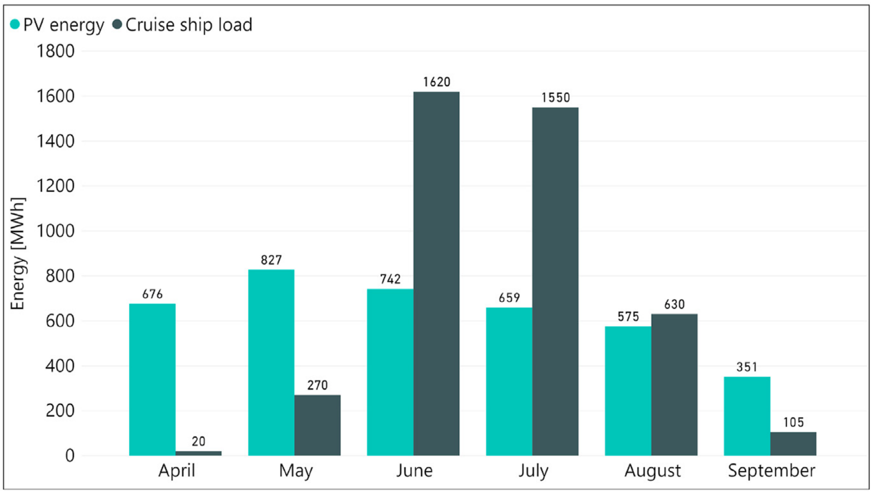


Fig. 5. Energy balance between aggregated values during summer in Tromsø. The PV energy generation is indicated by the green colors. The load from cruise ships in June–August is significantly higher than the generated PV energy. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.3.2. Monthly energy balance

Since the potential for PV power output and CS traffic is highest during summer, the energy balance assessment is primarily of interest during the summer period. This is between April and September. The aggregated energy balance between PV power output from the system in Table 8 and the estimated electric load from Table 4 in section 2.1 are shown in Fig. 5.

This figure shows that for April, May and September the aggregated PV yield is sufficient to fully cover all the consumption from the CS traffic. However, in June, July and August, when the traffic is at its highest, the PV yield from the 6 MW$_p$ system cannot cover the full demand. Again, the result shows that the PV system must be connected with the electric grid to ensure supply. The resulting energy balance from Fig. 5 is presented in terms of the SF in Table 9.

It is clear from both Fig. 5 and Table 9 that the resulting energy balance is negative in June–August when the CS traffic is highest. The SF values of 0.46 and 0.43, for June and July respectively, show that PV solar energy generation should be more than doubled to fully cover the load from CSs. This is if we were to consider a stand-

Table 9
Details of the solar module on the roof of a building at UiT. The module is tilted 40° facing directly southward.

Module	
Type	Prism Solar Technologies Bi60-368BSTC (368W)
Material	Monocrystalline silicon
Peak Efficiency	22.06%
Number of Cells	60
Module area	1.668 m^2

alone system without possibility of connection to an existing grid. Still, the 0.91 SF value in August shows that the PV yield is nearly sufficient to cover the total load in that month. However, as the case studies from Fig. 4 show, PV generation fluctuates rapidly due to sudden changes in weather conditions. This results in periods with lack of available energy for the CSs. To be able to ensure a reliable power supply for the cruise ship when harboring, the PV system still requires grid interaction or batteries to cover the full demand.

To get a rough indication of the monthly earnings the PV system could gain in the summer months by selling excess electricity to the CSs harbored, the costs of the power produced and consumed have been calculated by using monthly average electricity spot prices in Northern-Norway. These were provided by NordPool [39]. The spot price in EUR/MWh are multiplied by the energy generated from the solar energy system and by the energy consumed from the cruise ships. The energy saved will be the overlapping amount of energy between supply and demand. The monthly euros saved per month are given in Fig. 6.

If the solar energy system produces more than the aggregated consumption (April and May), the excess energy can be sold to the grid. If the energy produced is lower than the consumption (rest of the months), all the energy is used to power the cruise ships. Any additional energy needed would be imported from the grid. These calculations only consider the overlapping part of supply and demand, therefore, the additional costs related to buying extra capacity from the grid, or provisions from selling excess energy to the grid are not considered here. In addition, taxes to the Norwegian state and network fees are not taken into account.

4. Economic considerations

So far, the benefits from an environmental standpoint of transitioning cruise ships from onboard power to renewable shore power have been investigated. However, in order to gain an understanding of what measures would be needed to implement this solution in practice, it is necessary to consider the cost of the structure of the proposed system. This should be further compared to the current standard.

At present, CSs are using their auxiliary engines as generators to provide onboard power while docked. These engines are fueled, for the most part, by maritime fuel oil (MFO); a low-cost but highly polluting petroleum fuel. The lowest grades of fuel oil are banned in the Arctic for environmental reasons [40]. Marine Gasoil (MGO), a refined maritime fuel, is therefore assumed as the energy source for onboard power generation [41]. Global market data suggest a global average price of ~$650 for this fuel per metric ton [42]. High quality oil and new diesel engines at ships are recorded to have efficiencies up to 45% [43]. However, as the ships are assumed to

Table 10
Monthly energy balance between PV energy generation and CS electricity load. Green colors indicate that the load can be fully covered by solar energy. Red indicates insufficient generation of energy from the PV system to cover the load. In this case an alternative power supply must be considered.

Month	SF
April	1.00
May	1.00
June	0.46
July	0.43
August	0.91
September	1.00

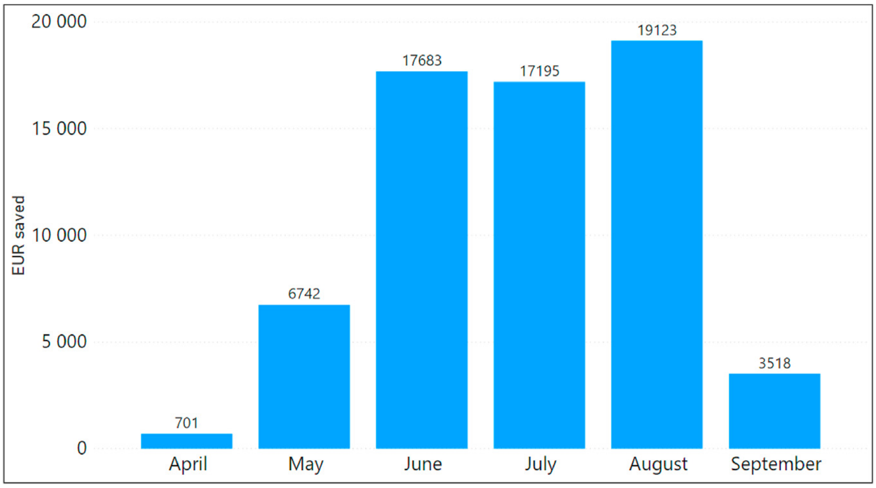


Fig. 6. Euros saved per month by employing the solar energy system. In August, maximum savings are expected but we recall that this is a sample study that only provides an indication for the prediction (26.1 EUR/MWh in July and 33.3 EUR/MWh in August [39]).

use MGO for onboard electricity generation, and as the engines on the ships are most likely not going to be new high quality engines, an efficiency in the range of 30–45% could be assumed as reasonable. To match near future scenarios, an efficiency of 45% was chosen.

Based on this we can calculate the dollar cost of a business as a usual scenario in which ships continue burning MGO for electricity.

Beginning from an energy content for MGO of 45 kJ/g = 12.500 kWh/ton and assuming an efficiency of 45% for onboard electricity generation [43], the fuel cost per kWh would be:

$$F = \frac{\$650}{0.45 \times 12.500\ \mathrm{kWh}} \cong 12\ ¢ \Big/ kWh \tag{5}$$

However, the Brent price can oscillate rapidly due to several market events. In turn, these will affect the on-board electricity cost considerably. However, here, the global market data suggestions are used to get a rough estimate of fuel electricity cost for CSs. For comparison, we consider global standard costs of rooftop photovoltaic systems under the conditions modeled in this study. According to the International Renewable Energy Agency, total installation costs of rooftop photovoltaic systems fell below \$2/W across most of Europe in 2017 [44]. As both hardware prices and other costs continue to fall, this value now represents a conservative estimate for rooftop PV costs. On the other hand, there are vast differences in hardware prices between different countries, which in turn could lead to significantly higher prices than indicated by IEA. Therefore, a price of \$2/W is considered reasonable for the PV system analyzed in this work. Using the value above, the energy yield simulation results given in the previous section, and a few additional cost assumptions, we can calculate the levelized cost of electricity (LCOE) from the rooftop system:

$$LCOE = \frac{C + \sum_{i=1}^{N} \frac{O_i}{(1+r)^i}}{\sum_{i=1}^{N} \frac{E_i}{(1+r)^i}} \tag{6}$$

Where C is the installation cost including all hardware, labor and soft costs; O_i the operating cost for year I in USD/kW$_p$/year; E_i is the energy produced in year i in kWh/kW$_p$/year; and *r* is the discount rate which is related to the cost of financing the project. NREL estimates suggest annual maintenance costs for rooftop PV systems at \$20/kW$_p$ [45]; international experience in solar energy project finance has seen PV projects in countries with pro-solar policies financed heavily by loans with interest rates of 4% or less [46]. The simulation results for the 6 MW system in Section 3 gave an annual energy delivered to the grid of 4 795 MWh in the first year, or 800 kWh/kW/year. Calculating the LCOE based on these values, and assuming a 1% annual escalation of O&M costs and 0.5% degradation of PV output per year, we find that the cost of electricity from the PV system would be 22.5¢/kWh (in USD) over 20 years. If the system is properly maintained to possible extend its lifetime to 30 years, LCOE will fall to 18.5¢/kWh.

We must note however that given the prevailing low interest rates in Norway, a public investment program could sustainably finance such a project at substantially lower rates. In addition, Norwegian banks offer “green loans” with significantly lower rates to projects that contribute to reducing greenhouse emissions and/or locally polluting gases. If the project were financed at a 2% return rate, the LCOE over 30 years would fall to 15¢/kWh. This nearly matches the fuel cost of the business-as-usual scenario. Hence the combination of 1) investment by a public entity expecting low returns on its investment, and 2) the revenue from cruise ship operators paying the same price for shore power as they would for fuel, allows the PV project to break even over its lifetime.

Finally, the key challenge will be to deal with the mismatch between generation and consumption. This problem might be overcome by 1) further optimizing the system design, 2) interacting with the electricity grid to profit when selling excess energy back to grid, 3) inclusion of short-term battery storage, 4) modifying overall demand profiles by using excess solar energy for such purposes as charging electric vehicles or running heat pumps to store energy in long-term thermal storage facilities connecting to centralized heating systems. The full exploration of these possibilities will provide fertile ground for future research.

5. Conclusions

We have proposed a solution to utilize solar energy technologies to deal with a specific problem in Arctic tourist destinations. Namely, increased cruise ship tourism in the Arctic. To this end, the solar energy potential for Tromsø (Norway) has been evaluated by creating a high-resolution solar map in ArcGIS. We have also simulated the PV yield from a 6 MW$_P$ system by exploiting PVsyst. The total energy consumption from the CSs were estimated based on information about typical load combined with statistics about the number and the types of ships visiting Tromsø during the year. The aggregated monthly PV yield and CS load profiles were compared during the summer tourist season between April and September. Six case studies for specific chosen days were investigated to better capture fluctuations in PV energy yield and to investigate the possibilities for covering the CS load directly. Our results have shown that for the specific PV system in this study, the aggregated CS load could be fully covered in April, May and September. Unfortunately, it could not be entirely covered in June, July and August when the traffic is largest.

To fully utilize the proposed PV system in this study, we believe that a potential business model could consider both 1) local power production companies and governments and 2) the inhabitants to finance most of the system (each inhabitant could invest in a part of the system). The PV system would continuously interact with the existing distribution grid where excess energy can be sold- Investors would thus make a profit. In this way, PV generation would be always utilized. In addition, to create a drive force for an emerging market for renewables and shore power systems, governments could require the cruise ships to connect to the facility when visiting. If ships were not willing to connect (due to high costs)-or did not have the possibility to connect, they could be told to not dock in Tromsø harbor. A less aggressive potential solution would be to pay an additional price for releasing local pollution. This could be made significantly higher than using the shore power facility. Since Norwegians are mostly powered with renewable hydropower, a third solution for fully utilizing the PV system is to have a system design consisting of PV + Hydropower. Here, solar energy would be the main power source during summertime. Hydropower would be the main power source during the winter season.

In summary, we have used the location of Tromsø as a model system to discuss the main environmental, technical, social and economic aspects that should be taken into account when implementing renewables to cope with an increasing Arctic tourism. It is hoped that this work can provide both 1) a starting point for the further development of solar energy in the Arctic region and 2) plausible arguments for a widespread consideration of solar energy, independently of preconceived notions regarding its viability, by the rigorous consideration of the requirements, costs and opportunities of specific settings.

Credit author statement

Odin Foldvik Eikeland performed all analyzes and had the main responsibility for writing the manuscript. Harry Apostoleris performed the economic considerations and contributed by improving the English and the structure of the manuscript. Sergio Santos contributed to the inception of the study and supervised the draft and rebuttal writing. Karoline Ingebrigtsen and Tobias Boström provided valuable feedback and helped writing the manuscript. Matteo Chiesa assisted in the analysis and interpretation of the results and contributed to the inception of the manuscript. Odin Foldvik Eikeland, Harry Apostoleris, Sergio Santos and Matteo Chiesa wrote the manuscript with input from all authors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Funston BW. SDWG report on arctic energy. TerraGraphica, Anchorage, AK, USA: Arctic Council Sustainable Development Working Group; 2019.

[2] Apostoleris H, Sgouridis S, Stefancich M, Chiesa M. Evaluating the factors that led to low-priced solar electricity projects in the Middle East. Nature Energy 2018;3:1109–14. https://doi.org/10.1038/s41560-018-0256-3.

[3] Rosenberg E, Lind A, Aamodt Espegren K. Electricity end-use consumption focusing ong lighting in Norwegian households. In: Institute for energy technology; 2012. Kjeller, Norway.

[4] Heide D, Greiner M, Bremen Lv, Hoffmann C. Reduced storage and balancing needs in a fully renewable European power system with excess wind and solar power generation. Renew Energy 2011;36:2515–23.

[5] Creutzig F, Agoston P, Goldschmidt JC, Luderer G, Nemet G, Pietzcker RC. The underestimated potential of solar energy to mitigate climate change. Nature Energy 2017;2.

[6] Vieira FM, Moura PS, de Almeida AT. Energy storage system for self-consumption of photovoltaic energy in residential zero energy buildings. Renew Energy 2017;103:308–20.

[7] Olauson J, Nasir Ayob M, Bergkvist M, Carpman N, Castellucci V, Goude A, Lingfors D, Waters R, Widèn J. Net load variability in Nordic countries with a highly or fully renewable power system. Nature Energy 2016;1. https://doi.org/10.1038/nenergy.2016.175.

[8] Ringkjøb H-K, Haugan PM, Nybø A. Transitioning remote Arctic settlements to renewable energy systems-A modelling study of Longyearbyen, Svalbard. Appl Energy 2019;258:1–13.

[9] Good C, Shepero M, Munkhammar J, Boström T. Scenario-based modelling of the potential for solar energy charing of electric vehicles in two scandinavian cities. Energy 2018:110–25.

[10] Ghenai C, Bettayeb M, Brdjanin B, Kadir Hamid A. Hybrid solar PV/PEM fuel Cell/Diesel Generator power system for cruise ship: a case study in Stockholm, Sweden. Case Studies in Thermal Engineering 2019;14.

[11] Lee K-J, Shin D, Yoo D-W, Choi H-K, Kim H-J. Hybrid photovoltaic/diesel green ship operating in standalone and grid-connected mode-Experimental investigation. Energy 2013;49:475–83.

[12] Skinner T. Is Norway's tromso the new reykjavik? Financ Times 5 September 2018 [Online]. Available: https://www.ft.com/content/a4fa6e78-ac3d-11e8-8253-48106866cd8a. [Accessed 5 September 2019].

[13] Palma D, Varnajot A, Dalen K, Basaran IK, Brunette C, Bystrowska M, Korablina AD, Nowicki RC, Ronge TA. Cruising the marginal ice zone: climate change and Arctic tourism. Polar Geogr 2019;42(4):215–35.

[14] D'Aprile A. Arctic tourism: how the great north is becoming the new exotic. Future Earth 21 August 2018 [Online]. Available: https://www.climateforesight.eu/future-hearth/arctic-tourism-how-the-great-north-is-becoming-the-new-exotic/. [Accessed 29 October 2019].

[15] Cruise Industry News. Shorepower an ongoing debate. October 2019. p. 15 [Online]. Available: https://www.cruiseindustrynews.com/cruise-news/19744-shorepower-an-ongoing-debate.html. [Accessed 30 September 2019].

[16] Abbasov F, Earl T, Jeanne N, Hemmings B, Gilliam L, Calvo Ambel C. One corporation to pollute them all. Brussels: European Federation for Transport and Environment AISBL; 2019.

[17] International Hydropower association. Norway," iha-International hydropower association. May 2017 [Online]. Available: https://www.hydropower.org/country-profiles/norway. [Accessed 28 October 2019].

[18] Gielen D, Boshell F, Saygin D, Bazlian MD, Wagner N, Gorini R. The role of renewable energy in the global energy transformation. Energy Strategy Reviews 2019;24:38–50.

[19] W H, Harbor MMaT. Interviewee, questions about cruise ship traffic in Tromsø harbor. 6 May 2019 [Interview].

[20] Havn Tromsø. Statistikk. 2019 [Online]. Available: https://www.tromso.havn.no/om-oss/om-oss/statistikk/. [Accessed 5 September 2019].

[21] Prospects GE. Special focus 1. With the benefit of hindsight: the impact of the 2014-16 oil price collapse. World Bank Group; 2018.

[22] Graw R, Faure A. Air pollution emission inventory, for 2008 tourism season, klondike gold rush national heritage park. Alaska: Alaska Department of Environmental Conservation; 2010.

[23] Simonsen M. Cruise ship tourism - a LCA analysis. Western Norway Research Institution; 2014.

[24] Sikveland T, Wangen E. Interviewees, *project Manager and electrical Manager at Port of Kristiansand*. 30 September 2019 [Interview].

[25] havn Tromsø, Havn Om Tromsø [Online]. Available: https://www.tromso.havn.no/om-oss/. [Accessed 20 April 2019].

[26] Lingfors D. Solar variability assessment in the built environment: model development and application to grid integration. Uppsala: Uppsala University, Disciplinary Domain of Science and Technology, Technology, Department of Engineering Sciences, Solid State Physics; 2017.

[27] Babar B. Solar resource assessment at high latitude regions. Tromsø: UiT The Arctic University of Norway; 2019.

[28] Kartverket, Høydedata. Kartverket. 2019 [Online]. Available: https://hoydedata.no/LaserInnsyn/. [Accessed 12 September 2019].

[29] Foldvik Eikeland O. Investigation of photovoltaic energy yield on tromsøya by mapping solar potential in ArcGIS. 13 June 2019 [Online]. Available: https://hdl.handle.net/10037/16580. [Accessed 4 November 2019].

[30] Andersen R. Interviewee, *Access to server computer from IT staff in digital research services at UiT*. 1 March 2019 [Interview].

[31] PVsyst. PVSyst Photovoltaic software. PVSyst; 2019 [Online]. Available: https://www.pvsyst.com/. [Accessed 12 September 2019].

[32] PVsyst- Meteonorm. Meteonorm data and program [Online]. Available: https://www.pvsyst.com/help/meteo_source_meteonorm.htm. [Accessed 12 September 2019].

[33] EU Science hub. Photovoltaic geographical information system (PVGIS). 30 July 2019 [Online]. Available: https://ec.europa.eu/jrc/en/pvgis. [Accessed 12 September 2019].

[34] Torsøe M. Leter etter smarte løsninger for fornybar energy. Forskning 24 June 2017 [Online]. Available: https://forskning.no/partner-alternativ-energi-uit-norges-arktiske-universitet/leter-etter-smarte-losninger-for-fornybar-energi/338223. [Accessed 30 October 2019].

[35] Munkhammar J, Grahn P, Widen J. Quantifying self-consumption of on-site photovoltaic power generation in households with electrich vehicle home charging. Sol Energy 2013:208–16.

[36] Luthander R, Widen J, Nilsson Danial PJ. Photovoltaic self-consumption in buildings: a review. Appl Energy 15 March 2015;142:80–94.

[37] Kartverket- Geodata AS. Matrikkeldata. Kartverket, geovekst og kommuner - Geodata AS 2019 [Online]. Available: https://geodataonline.maps.arcgis.com/apps/Embed/index.html?webmap=384b4cac7e4b4c41980f90dc0f30fb12&extent=11.0427,59.955,11.0472,59.9566&zoom=true&scale=true&disable_scroll=false&theme=light. [Accessed 11 September 2019].

[38] yr. Klimastatistikk for Tromsø målestasjon. 2019 [Online]. Available: https://www.yr.no/sted/Norge/Troms/Tromsø/Tromsø_(Vervarslinga)_målestasjon/klima.html. [Accessed 5 September 2019].

[39] Nord Pool AS. Day-ahead prices. Nord Pool, 03 07 2020. [Online]. Available: https://www.nordpoolgroup.com/Market-data1/Dayahead/Area-Prices/NO/Monthly/?view=table. [Accessed 3 July 2020].

[40] International Maritime Organization (IMO). Shipping in polar waters- international code for ships operating in polar waters (polar code). 2019 [Online]. Available: http://www.imo.org/en/MediaCentre/HotTopics/polar/Pages/default.aspx. [Accessed 16 November 2019].

[41] Oiltanking. Important terms from A to Z. 2019 [Online]. Available: https://www.oiltanking.com/en/news-info/glossary/details/term/marine-fuels.html. [Accessed 16 November 2019].

[42] SHIP & BUNKER. Rotterdam bunker prices. Ship & Bunker; 2019 [Online]. Available: https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam#MGO. [Accessed 16 November 2019].

[43] Hundertmark J. Electrification of the hurtigruten fleet. HAMM: HAMM-LIPPSTADT, University of Applied Sciences; 2019.

[44] International Renewable Energy Agency (IRENA). Renewable power generation costs in 2017," IRENA 2018. 2018. Abu Dhabi, UAE.

[45] Fu R, Feldman D, Margolis R. U.S. Solar photovoltaic system cost BenchMarck: Q1 2018. National Renewable Energy Laboratory, U.S Department of Energy; 2018.

[46] Apostoleris H, Chiesa M. The role of financing in achieving ultra-low solar electricity prices in the Middle East. In: IEEE photovoltaic specialists conference. vol. 46; 2019.