Clean energy for EU islands: Strategic plan for the port of the island of Arousa

A Illa de Arousa, Spain

Clean energy for EU islands

Strategic plan for the port of the island of Arousa
A Illa de Arousa

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Summary

The present project has been developed for A Illa de Arousa (Spain) in order to support the island in the electrification of their port and main economic activity, mussel farming using the vessels known as bateerios. Therefore, several tasks have been performed

For the analysis of the wind potential, the terrain at the site has been modelled in detail, including elevation, roughness, and obstacles to the wind flow. A wind atlas has been created using the software WindPro at different, relevant heights above ground level (AGL). Subsequently, the most significant locations for the exploitation of wind energy have been traced. One configuration of a small-scale wind turbine has been modelled: The Vergnet MP-C at 55 m with nominal power of 275 kW. This study indicates this wind turbine could produce 744 MWh/year of electricity when located close to the port and 873 MWh/year when located at the optimal location over a project lifespan of 20 years, based on a P50 probability.

For the analysis of the solar potential, an assessment of the solar irradiance on the island was performed using the SolarGis Prospect tool. Subsequently, the average yearly irradiation was estimated and converted to PV output. One configuration was modelled: a ground-mounted PV system with a fixed axis towards the south and a tilt of 33°. This study indicates this PV installation could produce 1305 kWh/kW of electricity over a project lifespan of 25 years, based on a P50 probability.

The secretariat estimated the port's future energy consumption once the bateeiro electrification takes place. This was estimated to be 151.75 kWh per day based on an average working cycle from 06:00 to 13:00. Two charging profiles were created. One based on a three-phase AC charger of 11 kW that can defer load to optimise the renewable energy usage. The second based on a DC fast charger of 50 kW that is consecutively shared by multiple bateeiros.

For the third task, the energy system of the port was modelled using Homer Energy. This includes the port's future load profile (as investigated in the first task), the possibility of ground-mounted solar PV and small-scale wind turbines (as investigated in the second task), and the possible inclusion of a battery energy storage system. According to the obtained results, a combination of both solar PV and battery storage would be interesting from a financial point of view, leading to high renewable fractions of above 80%. While the exact capacity of installed solar PV and storage depends on how many bateerios are electrified and on the grid power purchase price, the optimum power system remains a combination of solar PV and storage. Small-scale wind turbines are not part of the optimal solution, mostly because they tend to be more expensive per amount of energy produced than solar PV or larger wind turbines. They do start making sense when the grid sellback price surpass a certain limit since the excess electricity can be sold at a reasonably high price.

Finally, three case studies were given regarding best practices on port clean energy transition and management. These case studies revolve around the electrification of port related activities, the fuel switch for maritime transport, and the development of smart grids.

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Glossary

AGL / ASL Above Ground Level / Above Sea Level

CAPEX Capital Expenditure

Corine Land Cover The Corine Land Cover database is an inventory of land cover in 44 classes. It was initiated in 1985 by the European Union and has been taken over by the EEA. 3E associates roughness information to each class in order to create roughness maps that are used in the wind flow models.

NPC Net Present Cost

PHEV Plug-in Hybrid Electric Vehicle

SSP Shore to Ship Power

WACC Weighted Average Cost of Capital

WAsP WAsP (Wind Atlas Analysis and Application Program) is a software package that simulates wind flows for predicting wind climates, wind resources, and power productions from wind turbines and wind farms. WAsP is developed and distributed by DTU Wind Energy, Denmark. It has become the wind power industry-standard PC-software for wind resource assessment.

WindPRO WindPRO is a software package for designing and planning wind farm projects. It uses WAsP to simulate wind flows. It is developed and distributed by the Danish energy consultant EMD International A/S. It is trusted by many investment banks to create wind energy assessments used to determine financing for proposed wind farms.

Introduction

A Illa de Arousa is a Spanish island located in Galicia in North-West of Spain, 30 km from Pontevedra (Figure 1). With an area of about 7 km^2, Arousa is the only island municipality in Galicia. It is connected to the mainland via a bridge built in 1985 and has a permanent population of around 6 500 inhabitants. The region as a whole (Ria de Arousa) is famous for its mussels and mussel farming is then the main economic activity on the island.

A Illa de Arousa is currently working on the BATEEIRO project supported by NESOI Island Facility. This project aims at decarbonising the main source of emissions and economic activity on the island: fishing. BATEEIRO is currently investigating how to hybridise mussel fishing boats by electrifying the machinery required for this activity and replacing the diesel-based propulsion system by either green hydrogen or electricity [1]. Along with the decarbonisation of boats, A Illa de Arousa would like to develop a strategy for its port, to ensure that the electricity supplied to the fishing machinery comes from renewable energy sources. To this end, the Islands secretariat, as part of its Technical Assistance to European islands, carried out the four main tasks outlined below, with the aim of providing enough material to the island to update the Use of Port Areas Plan (Plan de Usos). Special attention has been given throughout the project not to overlap with the areas and topics already covered by the NESOI project.

The Technical Assistance from the Islands secretariat (of which this report is the final deliverable) covers:

1. Island's renewable energy potential.
   The renewable energy resources of the island have been investigated, with a focus on solar and wind potential. This has led to the development of a wind resource and a solar resource map.
2. Estimation of the port's future energy baseline
   The secretariat has estimated the required electricity consumption by the port and the fishing boat fleet once the electrification of boats takes place. This includes the electrification of both the machinery as well as the propulsion of the boats. This analysis helps to understand the future needs of the port and therefore the required dimensioning of renewable energy in the third task.
3. Energy storage sizing
   The dimensioning of battery energy storage has been investigated in order to ensure that the generated renewable energy can be fed into the port even if there is a mismatch between energy production and demand. The dimensioning is based on both the renewable energy penetration and the system cost of the wind turbines, solar panels, and battery storage
4. Best practices on port clean energy transition and management
   Best practices have been laid out to provide an overview of how other islands with similar needs to Illa de Arousa are carrying out their ports' clean energy transition, as an inspiration for possible ways forward for the island.

Figure 1: Site location

Task 1: Island's renewable energy potential

This section focuses on quantifying the renewable energy potential of A Illa de Arousa, namely of wind and solar PV energy.

Wind potential

The wind potential in Arousa has been studied by elaborating a wind resource map suitable for wind turbines at three different relevant heights: 35.0 m, 55.0 m and 75.0 m. This map has been used to assess the wind potential across the island and to locate the most suitable locations for wind exploitation. The wind resource map covers the entire surface of the island of Arousa.

Methodology

At this preliminary stage of the project, in the absence of measurements on site, libraries from the Global Wind Atlas [2] were used as the wind resource. The wind flow model WAsP was used to extrapolate the wind regime vertically and horizontally. Terrain elevation is modelled within a radius of 15 km (in line with WAsP recommendations [3]) based on EU-DEM data (25 m gride). Height contour lines were then generated with an elevation difference of 5 m between two successive lines. Given that roughness length is closely related to land use, terrain roughness was modelled using a land-use database. The Corine Land Cover (2018) database was used and roughness length values specific to each land use were applied according to 3E's methodology [3]**Error! Reference source not found.**. Following WAsP recommendations, the terrain roughness has been modelled within a radius of 20 km.

Wind Resource Maps

For the whole island, a wind atlas has been created using the software WindPro[1]. The Wind Climate from the Global Wind Atlas **Error! Reference source not found.** has been used to calculate a wind resource map. Wind resource maps have been generated at three different heights above ground level: 35.0 m, 55.0 m and 75.0 m. These heights are in the range of potential hub heights for relevant wind turbine types which can be considered.

The wind on A Illa de Arousa predominantly blows from north-northeast (NNE) and east-northeast (ENE). The wind energy rose depicts that most of the energy production comes from sectors north-northeast (NNE) and south (S). (Figure 2).

[1] WindPRO is a software package for designing and planning wind farm projects. It uses WAsP to simulate wind flows. It is developed and distributed by the Danish energy consultant EMD International A/S. It is trusted by many investment banks to create wind energy assessments used to determine financing for proposed wind farms.

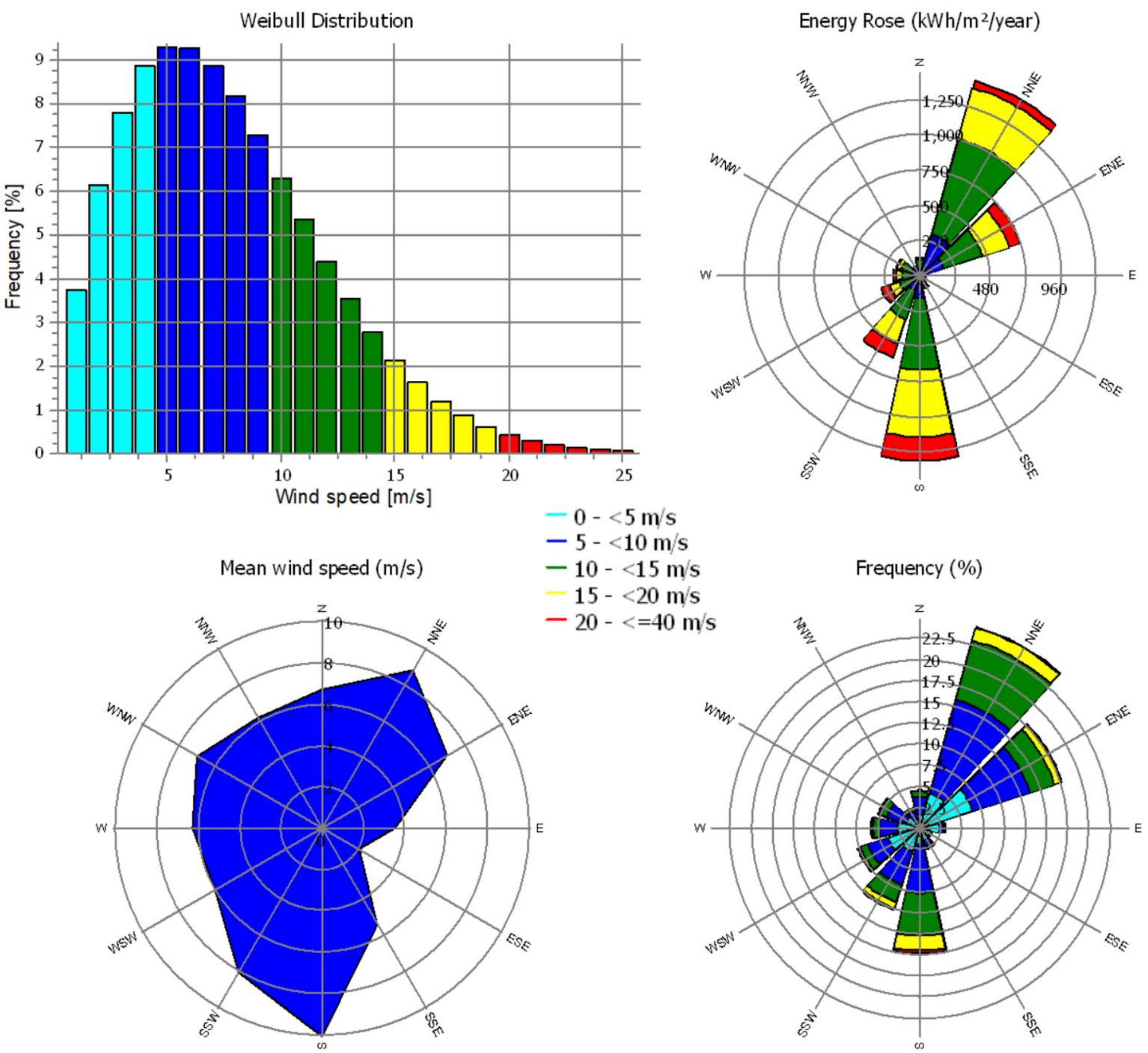

Figure 2: Wind distribution on the most wind-efficient location of the Island at 55 m of height. (Exact location: 42.57N and 8.86E)

The different wind resource maps are presented in the figures below The mean wind speed on site ranges between 5.9 m/s and 7.3 m/s at 35.0 m, between 6.5 m/s and 7.6 m/s at 55.0 m and between 7.0 m/s and 7.9 m/s at 75 m depending on the location on the island, as shown in the resource maps from Figure 3 to Figure 5.

The highest wind speeds can be found in a specific location in the north-west sector of the island, mainly in correspondence with the highest altitudes (around 50 m). As a general observation, the coast at the easter part of the island typically has higher wind speeds with respect to the western coast and central locations. This is especially true for the wind resource map at 35 m. A similar wind speed pattern is however observed for all the heights considered in this study.

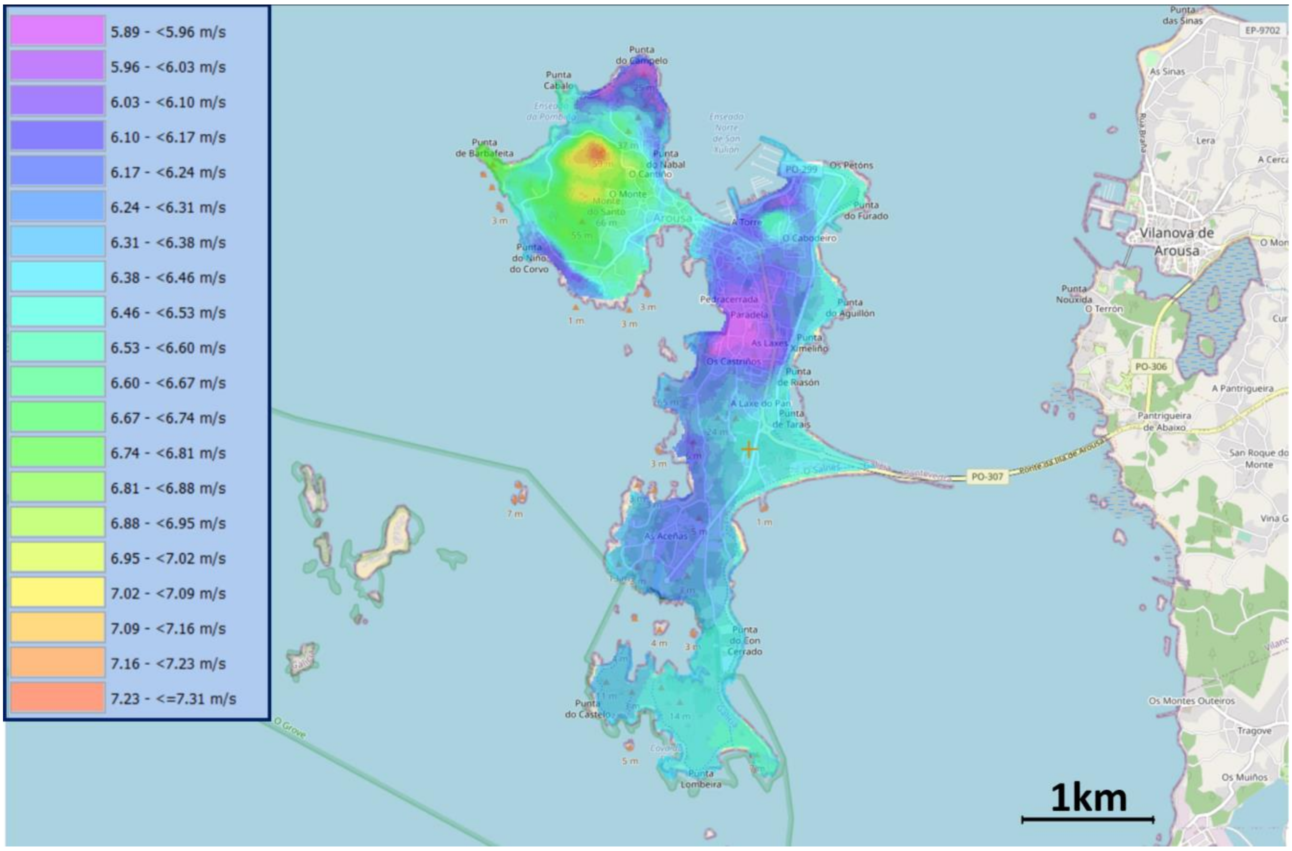

Figure 3: Mean wind speed at 35.0m AGL

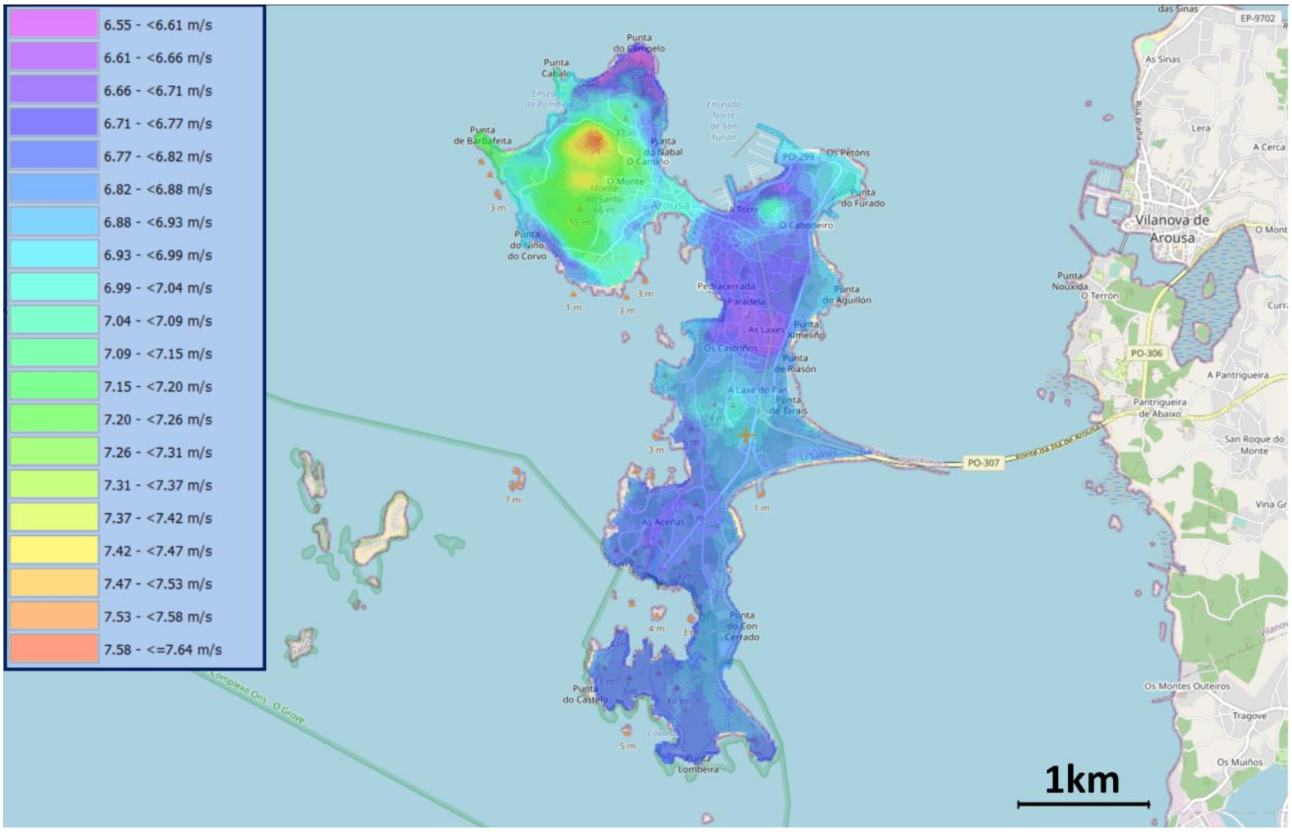

Figure 4: Mean wind speed at 55.0m AGL

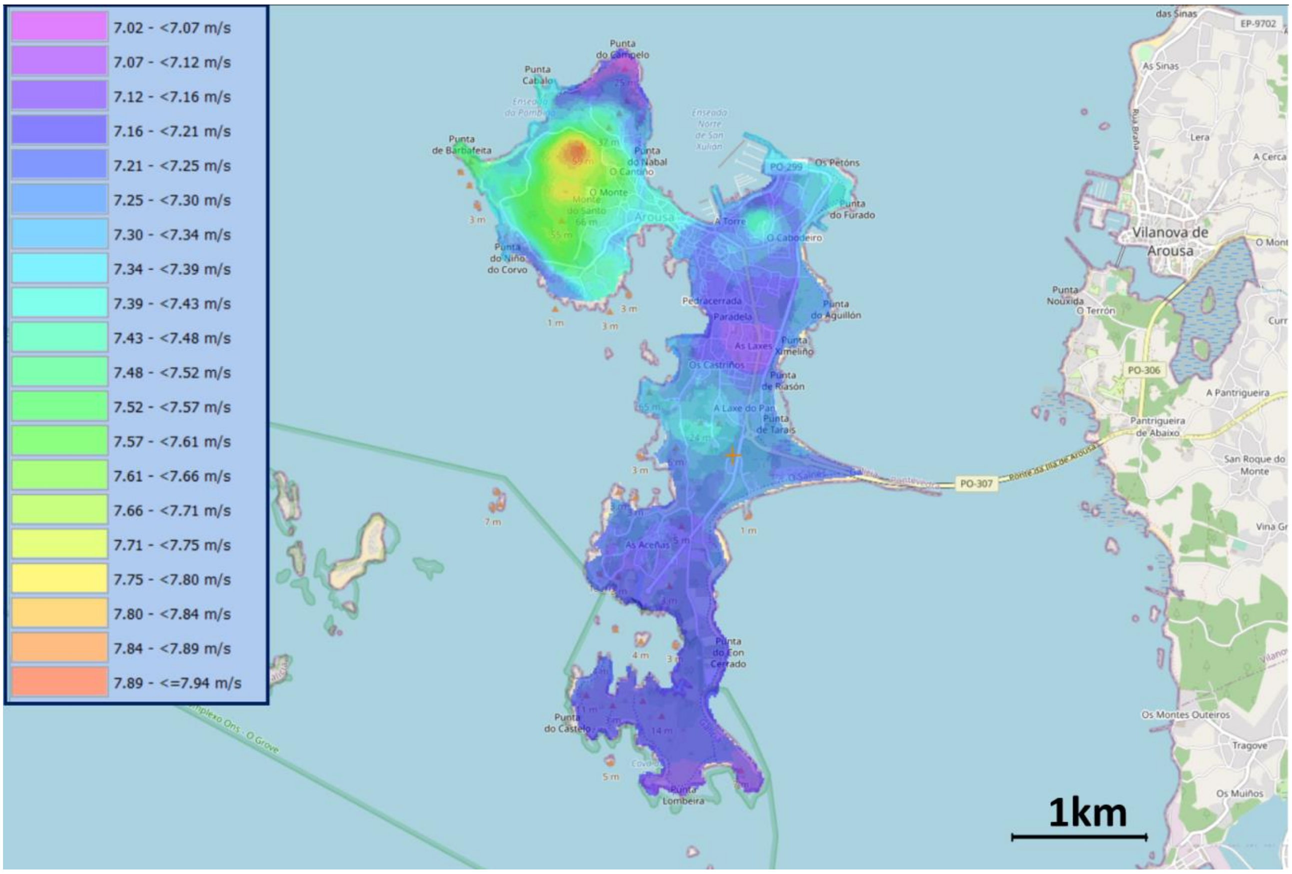

Figure 5: Mean wind speed at 75.0m AGL

A wind resource map in terms of annual production MWh/year has been generated at 35.0 m, 55.0m and 75.0 m above ground level based the wind turbine Vergnet GEV MP R with nominal power of 275 kW. This model has been selected as an indicative choice based on the size and energy needs of the island, the turbine's relatively small dimensions, and its higher energy production compared to similarly sized vertical axis wind turbines.

The results show that the average wind potential on the island at 35.0 m ranges between 570 MWh/year and 846 MWh/year for the Vergnet GEV MP R with nominal power of 275 kW. (Figure 6). At 55.0 m it ranges between 698 MWh/year and 911 MWh/year (Figure 7) and, finally, at 75.0 m it ranges between 793 MWh/year and 971 MWh/year (Figure 8). Higher values are typically found at higher altitudes.

Before suggesting feasible areas for wind energy exploitation, additional criteria should be investigated such as how accessible the site is (in terms of roads, elevation), constraints related to the presence of protected areas/nature reserves, and the distance from the main grid. Based on these considerations, two layouts with one wind turbine each are proposed in the following sections.

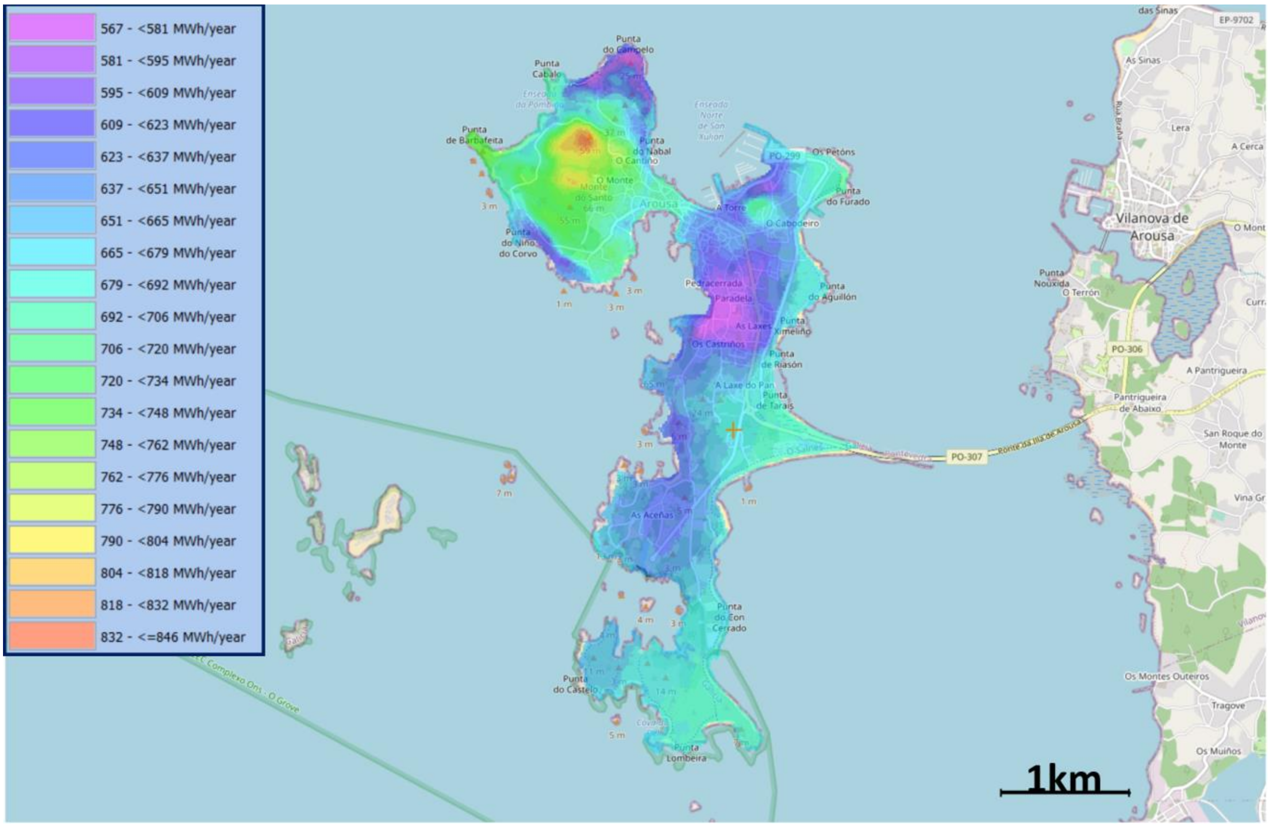

Figure 6: Annual wind production at 35.0m AGL based on the Vergnet GEV MP R 275kW wind turbine [MWh/an]

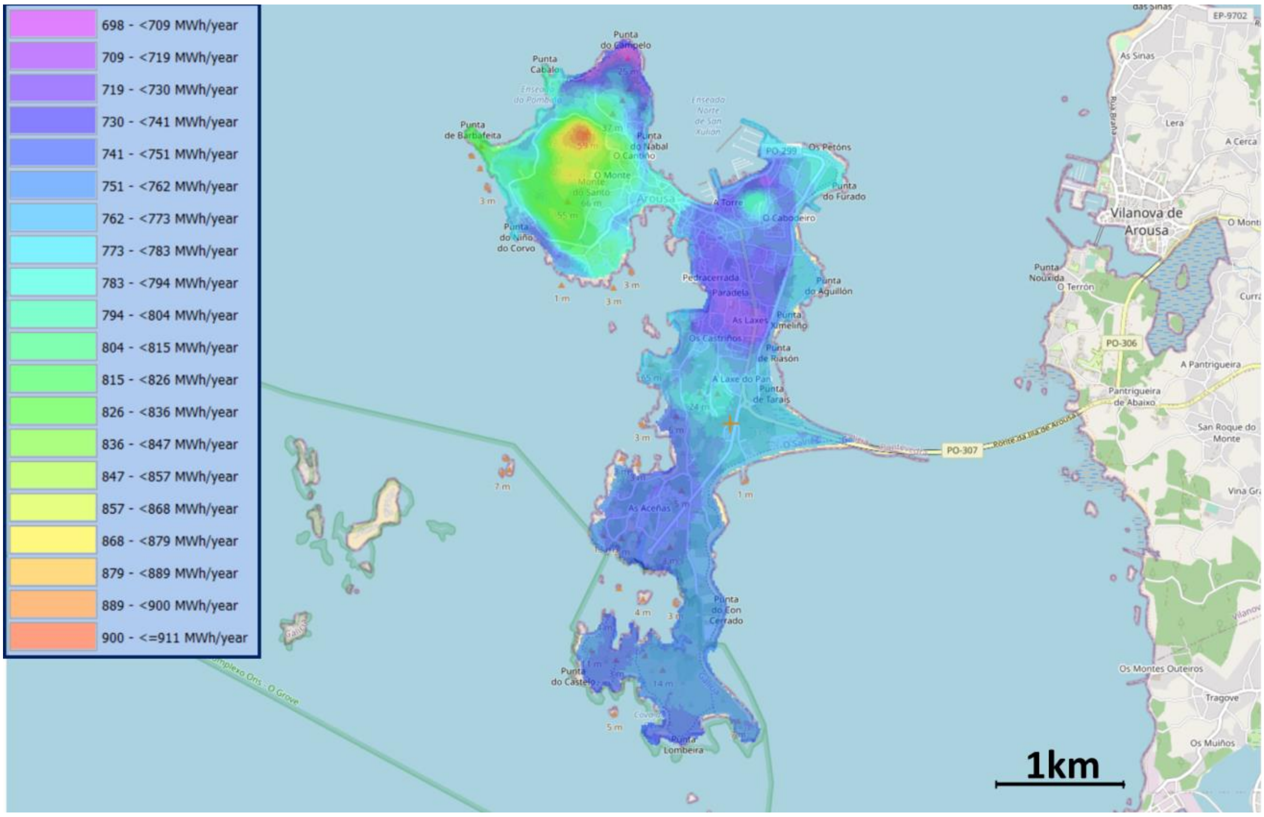

Figure 7: Annual wind production at 55.0m AGL based on the Vergnet GEV MP R 275kW wind turbine [MWh/an]

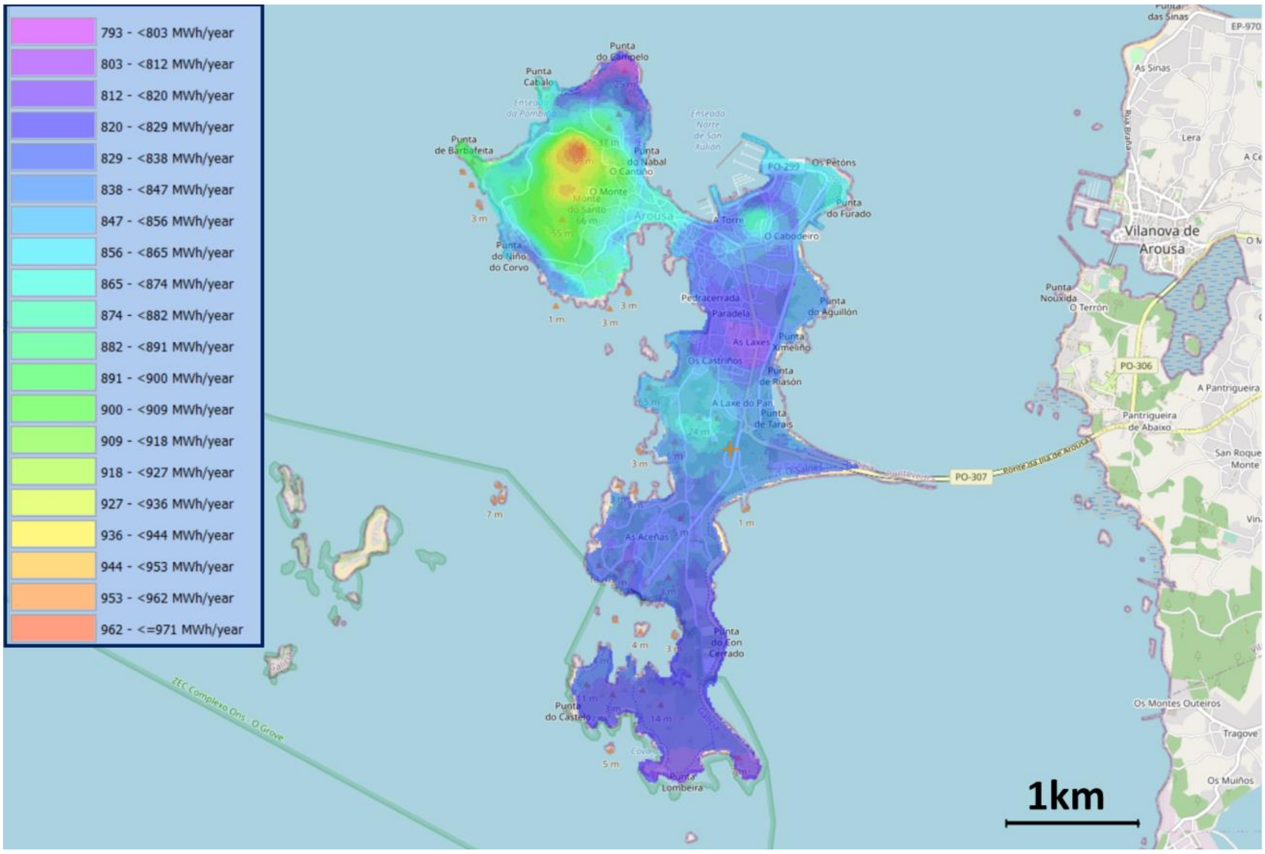

Figure 8: Annual wind production at 32.0m AGL based on the Vergnet GEV MP R 275kW wind turbine [MWh/an]

Net energy production of the two proposed sites

Two layouts are indicatively proposed for the wind turbine Vergnet GEV MP R 275 kW with 55 m of hub height: one in the vicinity of the port and one in the most wind-efficient position. The first layout aims at maximising the feasibility of the turbine in terms of transportation, being located in the proximity of the port, close to road arteries and with a fair distance from the first residential area. The second one maximises the production of the wind turbine and is indicative of the energy potential on the island. These layouts are displayed in Figure 9. Their coordinates in Geo [deg]-WGS84 are -8.862 E and 42.568 N for the turbine located in the port and -8.881 E and 42.562 N for the turbine located in the most wind-efficient position.

The expected annual energy production and other energy production figures are presented in Table 1. These results are preliminary, as it must be specified that they do not include additional losses related to curtailments and that some of the proposed locations might be subject to restriction (e.g., nature reserves, access to grid and grid limitation).

Table 1: Expected wind farm energy production figures

Configuration	**Vergnet MP R 0.275MW @55m**	
Scenario	Close to the port	Most wind-efficient location
Mean wind speed [m/s]	6.9	7.6
Gross energy production [MWh/y]	791	928
Annual net energy production [MWh/y]	744	873

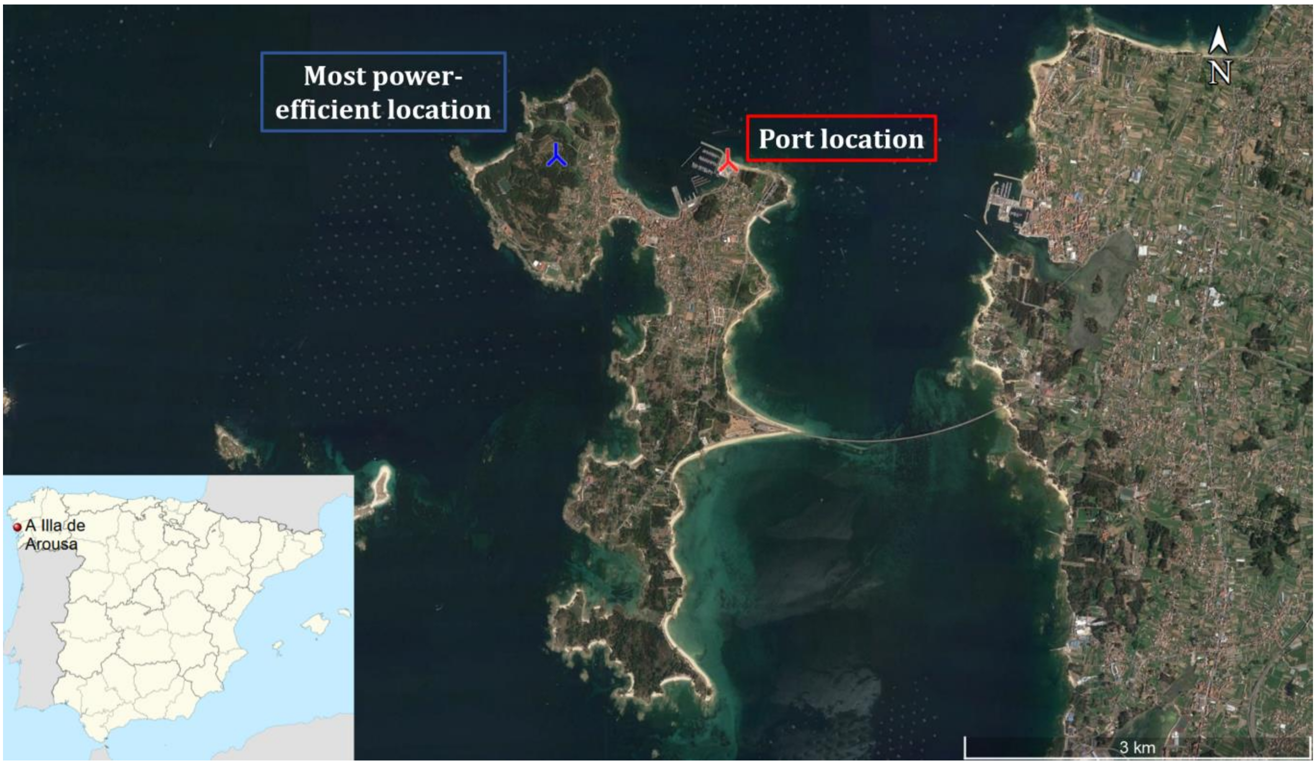

Figure 9: Location of the two proposed layouts: in the vicinity of the port (in red) and most power-efficient location (in blue)

Conclusions on wind potential

Regarding the wind potential on Arousa, the mean wind speed ranges between 5.9 m/s and 7.3 m/s at 35.0 m, between 6.5 m/s and 7.6 m/s at 55.0 m and between 7.0 m/s and 7.9 m/s at 75 m which represent favourable conditions for wind exploitation. The proposed horizontal axis wind turbine Vergnet GEV MP R 275 kW should be considered as an indicative model used for the purposes of this study. Other models of wind turbines with the same size and the same/higher power class can be considered for this specific site. The two Vergnet GEV MP R 275 kW wind turbines in the proposed locations lead, indicatively, to the following annual productions: 740 MWh/y for the location in the vicinity of the port and 870 MWh/y for the most wind-efficient location. These results together with the relatively high wind speeds (already) at low altitudes underline that this site is suitable for wind exploitation. The annual production will be used in Task 3 regarding the power system modelling.

Solar potential

Methodology

At this preliminary stage of the project, in the absence of onsite measurements, a first assessment of the solar irradiance on A Illa de Arousa was performed using the SolarGis Prospect tool. As opposed to wind, solar irradiance remains quite consistent on the entire island. Hence, instead of developing a solar resource map, the average solar irradiance on A Illa de Arousa has been calculated.

The average solar irradiance has also been converted into solar PV power output using the same tool. While solar PV power is highly dependent on the presence of possible obstacles and their shading, this effect was not included as the exact location of the PV installation is not yet known. The modelled PV system is assumed to have an optimal configuration with minimal shading: a grounded-mounted system with a fixed axis towards the south and a tilt of 33°[2].

Net energy production

The average yearly irradiation equals 1 463 kWh/m², which makes A Illa Arousa an interesting location for solar PV in Europe. The yearly specific PV production then equals 1 305 kWh/kW of electricity over a project lifespan of 25 years, based on a P50 probability. The monthly production is shown in Figure 10 and shows that while the production increases in Summer due to increased irradiation, the performance ratio slightly drops due to the increased temperature. As mentioned before, while solar irradiance does not significantly differ on Illa Arousa, the exact PV output will change depending on the specific location because effects like shading (due to hills, obstacles, etc.). The entire solar report can be found in ANNEX A: Solar report.

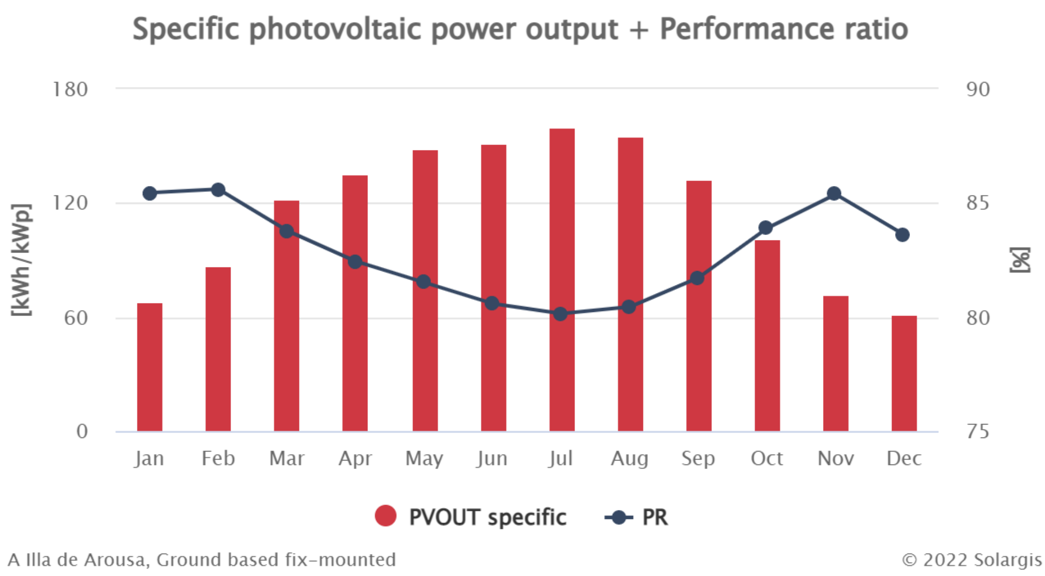

Figure 10: Specific PV production on Illa de Arousa (source: Solargis Prospect tool)

[2] Other model parameters include: inverter efficiency=97.8%, monthly soiling losses up to 3.5%, monthly snow losses up to 3.5%, DC cabling losses=2%, DC mismatch losses=0.3%, AC cabling losses=0.5%, system availability=0.5%

Task 2: Estimation of the port's future energy baseline

With the hybridisation of the bateeiros on the horizon, it is important to ensure that the port undergoes the necessary structural changes in order to meet the increased electricity demand. This section will detail how the port's future energy baseline has been calculated This task was based on deliverable 1 of the NESOI BATEEIRO project [1] as well as on personal communication with the report authors. The bateeiro's operation and energy consumption was estimated as part of the BATEEIRO study. A standard boat work cycle operation in this aquaculture application leaves the port at 6:00 and returns at 11:00. This work cycle could be structured as:

- 20 to 30 minutes: The boat sails to the bateas (the wooden platforms located in the sea for mussel farming) with an average consumption of 40 kWh.
- 2 h to 2.5 h: Mussel harvesting within the farm with an average consumption of 8.5 kWh.
- 1 h to 1.30 h: Running the hydraulic crane with an average consumption of 27 kWh.
- 20 to 30 minutes: The boat returns to port with an average consumption of 40 kWh.

The above work cycle requires between 70.6 kWh and 101.75 kWh, which corresponds to a 4 h operation. Depending on the mussel market needs, the boats can do up to 2 work cycles per day. It is assumed that the average boat will do 1.5 cycles per day from 6:00 to 13:00, equalling 151.75 kWh per day. The charging profile is assumed to be constant throughout the year, with no significant effects due to seasonality. However, during the weekend, it is assumed that only a third of the bateeiros will be out, leading to a third of the regular charging need. As the average work cycle runs between 6:00 and 13:00, there remain 17 h within a day to fully charge the boats before the next morning.

Currently, there are about 100 bateeiros active on the island, but considering the new generation of bigger and electrified bateeiros, this number is expected to decrease. The number of bateeiros that will be operational is estimated to be between 50 and 100. Therefore, a reference of 75 bateeiros is used in thus study. Additionally, a sensitivity study will be performed in Task 4 to estimate the impact of the eventual number of bateeiros on the energy system.

Two separate charging strategies have been considered:

1. Slow chargers: All bateeiros charge at the same time, using a three-phase AC charger of 11 kW (AC 3x 230 V x 16 A). At maximum capacity, each boat needs to charge for 14 h. However, there is a 17 h window, so some load can be deferred to optimise the use of renewable energy. In total, this leads to 75 chargers.
2. Fast chargers: The bateeiros use a DC fast charger of 50 kW (DC 400 V x 125 A). The bateeiros can be charged in 3 h shifts, allowing six consequent shifts to charge the entire fleet. Load cannot be deferred during the week, as the chargers need to be utilised at maximum capacity to charge the bateeiros in time. However, during the weekend when only a third of boats need to be charged, load can be deferred in this scenario as well. In this case, 13 chargers need to be purchased, but each charger is more expensive.

Both charging strategies will be modelled in Task 3 to determine what the effect is on the optimal battery size, as well as on the installed capacity of both solar PV and wind turbines.

Task 3: Energy storage sizing

The introduction of the electrified bateeiros will have a significant impact on the electricity consumption of the port. This might require additional power generation capacity such as solar PV or wind turbines. Furthermore, battery energy storage might be needed to ensure that the generated renewable energy can be fed into the port even if there is a mismatch between energy production and demand. The storage system can thus be used for energy load shifting in order to use intermittent renewable energy production at times when there is no or insufficient production. This section will show the most cost-efficient energy system for the port of A Illa de Arousa, taking into account the two bateeiro charging strategies from Task 2, the potential production from both solar PV and wind turbines from Task 1, and a possible battery energy storage system.

Methodology

This study has been carried out using HOMER Pro, a software that allows finding the optimal power system configuration based on user input and requirements. It can integrate multiple types of renewables – such as solar PV, wind, and hydro – as well as energy storage, fossil fuel generators and the mainland electricity grid itself. This section first explains the various renewable technology components included in the model. Thereafter the general assumptions of the model are explained.

Components

The electrical components that are included in the model are:

Wind turbines: The MP-C 275 kW, with a hub height of 55 m, is the wind turbine used in Task 1 for the resource maps. It has a lower environmental impact due to its smaller size and therefore poses less visual obstruction. Both locations for the wind turbine (port location and best location) and their subsequent annual energy production are modelled. The capital cost was given by a MP sales representative and equals €800 000 for the turbine itself, the installation, and the additional civil and electrical works, while the O&M costs are about €15 000 per year. The expected lifetime of the wind turbine is 20 years

Solar PV: The solar plant is modelled based on the SolarGis data (Task 1). The system is oriented towards the south with a tilt of 33°. The PV panels are of the crystalline silicon type and the total losses equal 17.7%, including aging, wiring, connection losses, dust, etc. The price of this component is estimated at €920 /kW, which includes all investment costs (hardware, Balance of Plant, installation, insurance, etc.). The generated solar power is assumed to be used to charge the bateeiros, while all excess production is sold directly to the grid.

The cable to the mainland: In this modelling exercise, the cable transporting electricity to the mainland is assumed to have sufficient capacity to carry any load. At the time of writing, electricity prices in Europe have exploded with the wholesale price having quintupled over the last 12 months. This disruption is not expected to last although the new energy price equilibrium will be higher than before. The electricity price is therefore assumed to come at a cost of €0.15 /kWh, considering that a large offtaker such as the port will pay considerably less in transmission tariffs and distribution charges. Excess electricity from local production is assumed to be sold at an injection price of €0.03 /kWh, considering profile costs for injection at intermittent periods. Both of these prices are still uncertain; hence, a sensitivity analysis has been carried out to study whether variations on these prices have a significant impact on the results.

The battery: A 4 h Lithium-ion battery in modules of 1 MW and 4 MWh was used to model the energy system. Li-ion batteries have the advantage of excellent round-trip efficiency, a relatively long lifetime, and a low self-discharge rate. They are the most used battery type nowadays, making up about 90% of the battery market and also rapidly decreasing in cost due to its widespread use and industrial fabrication. The capital cost was based on the IRENA "Electricity storage and renewables report [4]." and equals €1 000 000 for a 1 MW/4 MWh battery while the O&M cost are about €7 500 per year The battery module has a roundtrip efficiency of 90%, a lifetime throughput of 21 000 MWh, and an expected lifetime of 15 years.

The boat chargers: Two types of chargers are modelled

- Slow charger: Three-phase AC charger of 11 kW (AC 3x 230 V x 16 A) at an installation cost of €2500 per charger
- Fast chargers: DC fast charger of 50 kW (DC 400 V x 125 A) at an installation cost of €25 000 per charger.

General assumptions

Several assumptions were made in order to run the simulations. These assumptions are drawn from experience in similar projects as well as international best practices. The input parameters for the HOMER model have been estimated as:

- Project lifespan: The systems are assumed to have a 20-year lifespan, which is the value used by most global renewable energy independent programmes.
- Discount rate: The nominal discount rate is 6%, based on the average after-tax weighted average cost of capital (WACC) for solar PV projects in Spain between 2014 and 2019.
- Inflation: While the current inflation has surpassed 10% in Spain, this is not expected to last long-term. Therefore, the average inflation rate of the last 20 years is taken, which equals 2.5%.
- Cost reflectivity: There are no recoverable costs at the end of the lifespan of the system.

Results and discussion

Two charging strategies were tested as explained in Task 2:

1. Slow chargers: 75 AC chargers of 11 kW, equalling one charger per bateeiro allowing to defer load
2. Fast chargers: 13 DC fast chargers of 50 kW, equalling one charger per six bateeiros with minimal deferral of load

Modelling both charging strategies shows that the lowest cost energy solution for the port of Arousa for both cases is to rely on solar PV and battery storage, supplemented with grid power, as can be seen in Table 2. However, the difference between both strategies is that the DC charging strategy requires more solar PV and battery storage. This is the case since less load can be deferred to the day, as is shown in Figure 11. The economic optimal solution for the fast charger strategy also achieves a high renewable penetration of 96.0% compared to 80.3% for the slow charger strategy. Both are high however, which leads to a significant amount of electricity being injected onto the grid.

Table 2: Comparison of both charging strategies

Description	Slow chargers	Fast chargers
Power system		
PV capacity [kW]	2022	2637
Battery capacity	1 MW/4 MWh	2 MW/8 MWh
Chargers	75 AC 11-kW chargers	13 DC 50-kW chargers
Annual Energy balance		
Total electricity production [MWh]	5 093	5 535
PV energy production [MWh]	4 155	5 419
Grid purchase [MWh]	938	116
Total electricity consumption [MWh]	5 093	5 535
Electricity demand [MWh]	3 438	3 438
Grid sales [MWh]	1 314	1 603
Electricity lost in conversion (converter/storage) [MWh]	342	494
Environment		
Renewable fraction [%]	80.3%	96.0%
Finances[3]		
Net present cost	€5.75M	€6.03M
Total initial investment	€3.01M	€4.76M
Initial investment solar PV	€1.86M	€2.43 M
Initial investment battery storage	€1.00M	€2.00 M
Initial investment charging equipment	€0.15M	€0.33M
Operating cost	€165k	€77k
Discounted payback time	8.89 years	10.87 years
Net present worth compared to status quo	€2.98M	€2.88M

While the same amount of electricity needs to be charged in both scenarios, they differ in the amount of load that can be deferred to more suitable times. The slow charger has 17 h to charge all boats but only needs 14 h, whereas the fast charger needs to work non-stop at full power in order to charge all six bateeiros in one group before the next shift. The fast charger thus provides more flexibility with regards to deferable load but makes it impossible to quickly charge a bateeiro.

The load profiles for both charging strategies are given in Figure 11. No charging occurs between 6:00 and 13:00 when the boats are out of the harbour. The difference between week and weekend days is also obvious, as only a third of bateeiros are assumed to be working on weekends. Charging takes place throughout the night until the next morning so all bateeiros can start with a fully charged battery. The two load profiles clearly differ in the deferrable load. The slow AC 11 kW charger

[3] Calculated using the parameters described in **Error! Reference source not found.**

scenario (top of Figure 11) shows that once the bateeiros return to the harbour, charging occurs at maximum power of 825 kW[4] as long as the sun is shining (until around 17:00 in summer and 19:00 in winter) in order to optimally use solar energy. On the other hand, the fast DC 50 kW charger scenario illustrates that the bateeiros work at maximum power of 650 kW[5] on weekdays from 13:00 until 6:00 (charging the boats in groups of six) to ensure that all bateeiros are fully charged before they need to leave the port for fishing in the morning. During the weekends though, the smaller number of bateeiros (a third compared to weekdays) are charged during daylight hours to maximise renewable energy consumption.

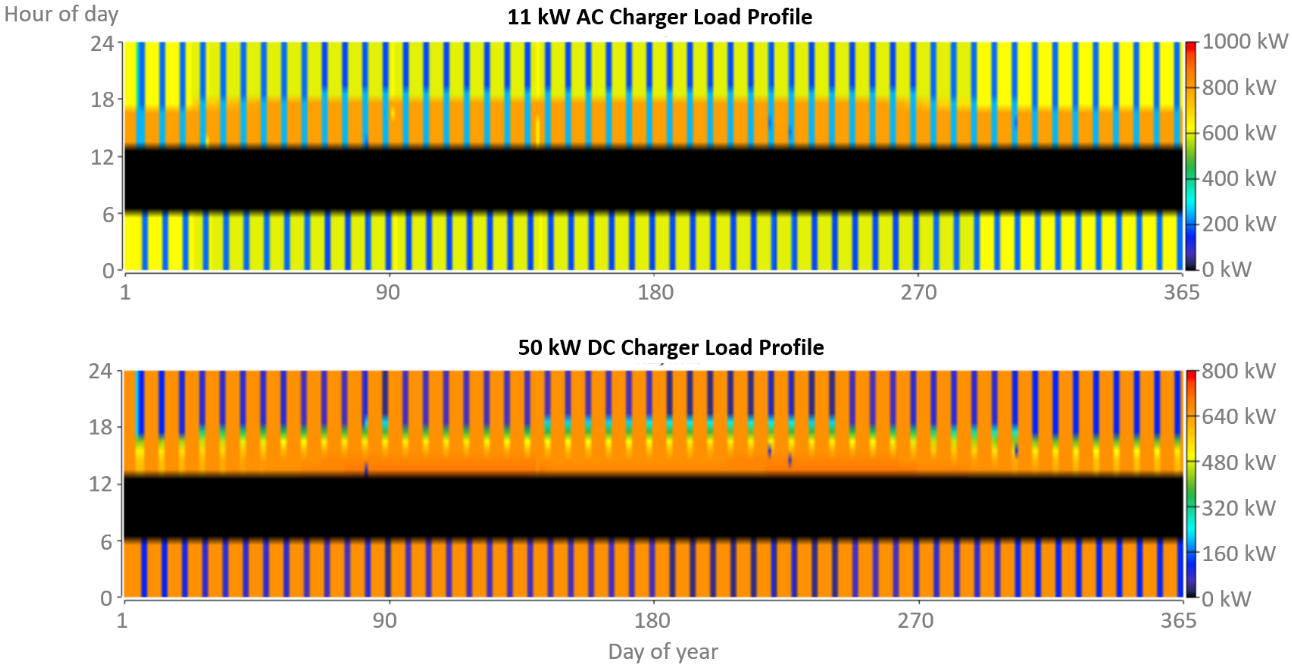

Figure 11: Load profile of charging strategies. AC 11 kW charger (top), DC 50 kW charger (bottom)

The interaction with the grid can be seen Figure 12. The figure illustrates in the case of the slow charger strategy that the solar and storage combination can provide electricity up until around midnight, but afterwards still relies on grid power at an assumed €0.15 /kWh. The fast charger strategy on the other hand can meet almost the entire charging demand. Due to the large size of solar PV, not all solar energy can be stored by the battery and needs to be sold to the grid at an assumed €0.03 /kWh. This is even more so the case in the fast charger scenario. It’s important to emphasise that further research needs to verify whether the local grid can handle such injections.

[4] 75 bateeiros each charging at 11 kW equals 825 kW

[5] 13 chargers each charging at 50 kW equals 650 kW

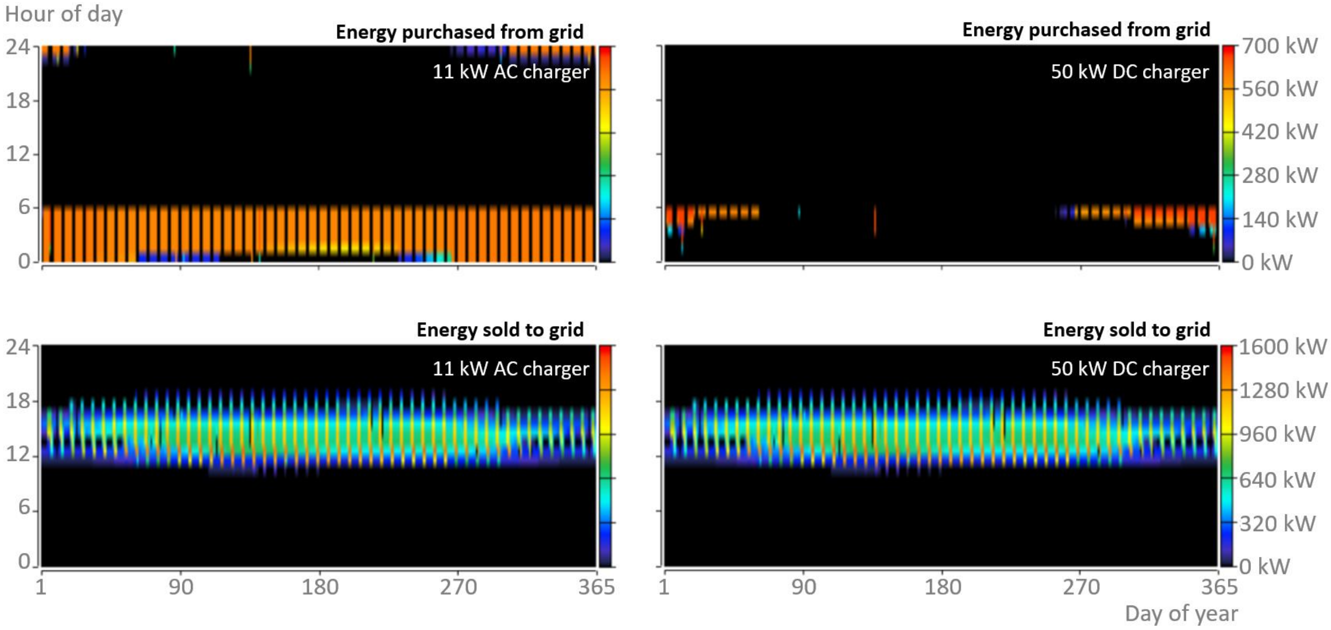

Figure 12 Grid purchases (top) and grid sales (bottom) for the 11-kW charger (left) and the 50-kW charger (right) strategy

In reality, a mix of both charging strategies might be used, implying that both slow and fast chargers will be introduced in the port. In this case, the optimal power system will still be combination of solar PV and storage and the installed capacities will lie somewhere in between both presented results. Furthermore, it could be interesting to install more DC chargers than strictly necessary so that each charger can make better use of solar power. In other words, it might be more economical to buy more DC chargers that charge throughout the day and invest less in batteries to charge throughout the night. This was not further studied in this report but could prove interesting for future research.

Sensitivity analysis

As indicated in the previous section three variables are uncertain or volatile:

- The electricity purchase price from the grid and electricity sell-back price to the grid
- The eventual number of bateeiros that need to be charged

Variations in these variables have been assessed to confirm whether they have a meaningful impact on the results. As a reference, the slow AC charger strategy is used.

The electricity purchase and sell-back price

The optimal solution was to install both solar and storage. This was based on an electricity price of €0.15 /kWh and a selling price of excess electricity of €0.03 /kWh, as indicated in the methodology section. This optimum can change somewhat depending on the eventual prices but remains quite consistent, as shown in Figure 13. When the sellback price increases above €0.05 /kWh, adding a wind turbine in the "best" location to the mix becomes interesting as excess electricity from wind can be sold to the grid at a sufficiently high price. Important to note is that no change in power system type occurs when increasing the electricity purchase price, illustrating that solar and PV remain the best solution. When decreasing the electricity purchase price, the necessity for battery storage decreases since the grid starts acting as a cheap battery.

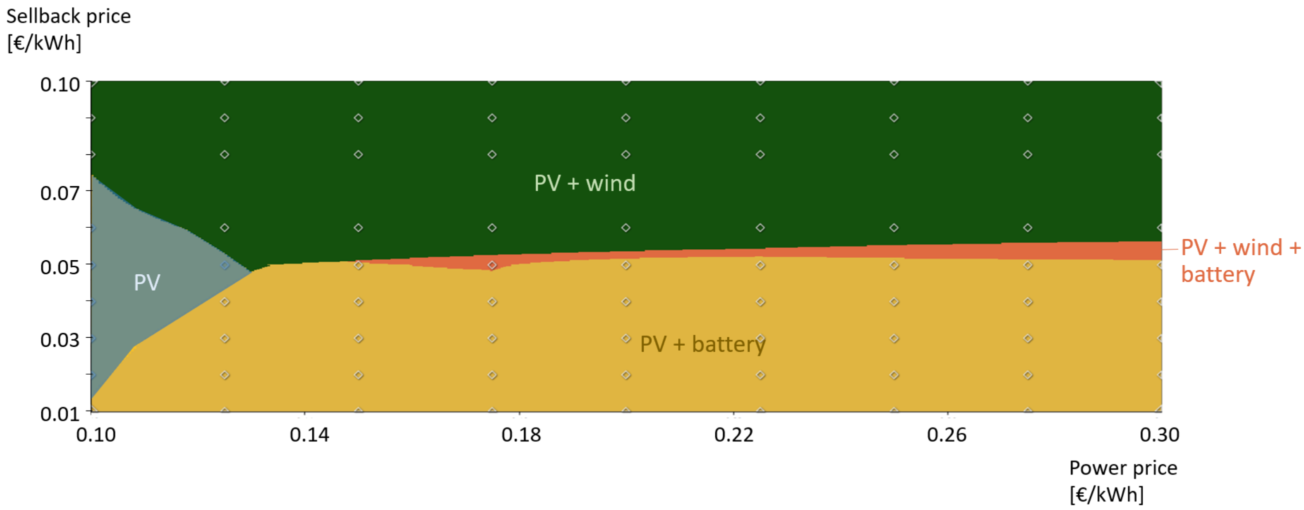

Figure 13: Impact of grid injection and consumption price on the optimum power solution

The number of bateeiros to be charged

As mentioned in Task 2, there currently are about 100 bateeiros active on the island. However, this number is expected to decrease and is estimated to be between 50 and 100. This study assumed that an average of 75 bateeiros will need to be charged daily, but Figure 14 shows what the impact would be if this would change. If more bateeiros need to be electrified, there is a sudden jump in the amount of solar PV that is installed as it becomes more economical to rely on two battery modules that need additional solar PV to be charged. If less bateeiros are electrified, the optimal solution sticks to one battery module with a decreasing amount of solar PV installed. Important to note here as well is that there is no change in the optimal power system when changing the number of bateeiros to be electrified.

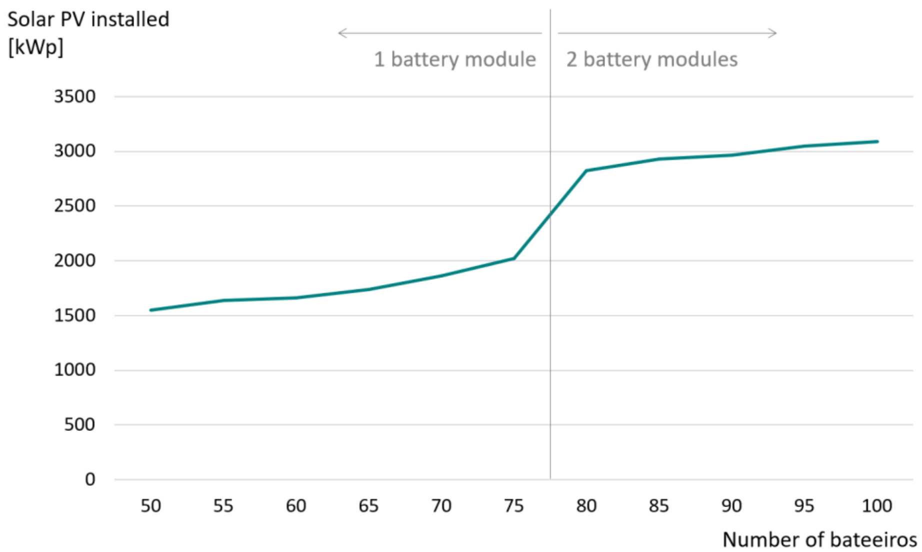

Figure 14: Impact of the number of electrified bateeiros on the optimum power solution

Conclusions on system modelling

In this section, a power system model of the port on Illa de Arousa is developed in HOMER Pro. The model is used to determine the viability of different energy mixes to meet the charging requirements of the electrified bateeiros. The results show that the optimal solution is to install a combination of solar and storage, both when installing slow AC chargers and fast DC chargers. In both cases, very high renewable fractions of above 80% are reached. Both cases also produce a significant amount of excess renewable energy that cannot be used to charge the bateeiros and is instead sold back to the grid.

While the exact capacity of installed solar PV and storage depends on how many bateerios are electrified and on the grid power purchase price, the optimum power system remains a combination of solar PV and storage. Small-scale wind turbines are not part of the optimal solution, mostly because they tend to be more expensive per amount of energy produced than solar PV or larger wind turbines. They do start making sense when the grid sellback price increases above €0.05 /kWh since the excess electricity can be sold at a reasonably high price.

Important to note is that this exercise did not take into account constraints related to permitting, space, and so forth. Hence, while the optimal solution for the reference case is to install 2 MWp of solar PV, this might not be feasible due to lack of space or other constraints on the island. In this case, a small-scale wind turbine could replace part of the solar PV installation at only a slightly higher cost of electricity.

Task 4: Best practices on port clean energy transition and management

Ports can play a pivotal role in the world's energy transition if port authorities and industry sectors join forces in order to create strategies and explore their decarbonisation potential. A recent report by DNV GL and Eurelectric [5] outlines ten Green Transitions that are key to decarbonising ports.

1. Electrification of port related activities
2. Fuel switch for maritime transport
3. Electrification of industry
4. Integration of offshore wind
5. Energy system integration
6. Hydrogen as a feedstock and energy vector
7. Phase-out of fossil-fuelled power plants
8. Carbon capture and storage
9. New regulations
10. A circular and bio-based economy

While most of these transitions relate to larger ports, some are also relevant for a smaller port like A Illa de Arousa. These transitions are the electrification of port related activities, and the fuel switch for maritime transport. These two transitions will also have a big impact on the electricity infrastructure, which will need to be able to facilitate large swings in load and require special control and coordination. This leads to the development of smart grids. Below, several examples of (island) ports that have undergone the mentioned transitions are discussed.

Transition 1: Electrification of port related activities

Electrifying port related activities has the benefit of reducing carbon emissions, but also brings other benefits, such as fewer local emissions, higher reliability, efficiency, and lower maintenance costs when using electromotors instead of internal combustion engines. Examples include bunkering, freight handling with cranes and logistical vehicles; service vessels such as tugboats, offices, and buildings.

A specific topic for ports is cold ironing, also called shore to ship power (SSP). The term cold ironing means that a ship docked at the port is supplied with electricity from shore and thus can avoid running its engines or diesel generators to power on board activities. The Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure[6], or 'Directive on Alternative Fuels Infrastructure (DAFI)' was adopted by the European Parliament and the Council on 29 September 2014. The Directive requires all ports to have cold ironing provision by the end of 2025:

Cold ironing projects are being implemented in some European Island Ports, like in La Palma (Mallorca). The ferries that dock at the Paraires quay or the Commercial quays at the port of Palma

[6] Available here: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32014L0094

will be connected to the onshore power grid while they are moored[7]. The port authorities of the Balearic Islands and Barcelona have jointly applied for European CEF-Transport aid, which will finance 40% of this investment. More examples of cold ironing projects are available on the report for Thira Technical Assistance.

Transition 2: Fuel switch for maritime transport

Fuel switch is the transition from conventional maritime fuels to carbon neutral fuels. The easiest way is to blend in low carbon drop in fuels, e.g., in the form of biogas and small amounts of hydrogen for LNG powered vessels. Other fuels, like ammonia or electricity, will require more extensive modifications in the vessels themselves and in the shore side fuel infrastructure. A hybrid option, where ships switch to full electric mode in and near ports or other emission sensitive locations could become a feasible option. This section aims to give a deeper insight into fully electric ships powered by batteries.

Batteries provide the ability to directly store electrical energy for propulsion, opening many other opportunities to optimise the power system. Recent advancements in battery technology and falling costs thanks to the growing worldwide demand for batteries have made this technology more attractive to shipping, especially for ships running on short distances since the weight of batteries is too high for longer distances due to their lower energy density.

This has resulted in ships running on electricity becoming more common, as illustrated in Figure 15. In 2022, 494 battery-powered ships were in operation and an additional 157 are under construction to be completed by 2026. Not all battery-powered ships are fully electric though, the majority (51%) are a mild hybrid, while 22% and 23% are plugin-hybrid and pure electric ships respectively[8] [6]. On a full-electric ship, all the power—for both propulsion and auxiliaries—comes from batteries. A plug-in hybrid ship, similar to a plug-in hybrid car (PHEV), is able to charge its batteries using shore power and has a conventional engine in addition. The ship can operate on batteries alone on specific parts of the route, when manoeuvring in port, during stand-by operations. A hybrid ship uses batteries to increase its engine performance and does not use shore power to charge its batteries [7].

[7] https://www.portsdebalears.com/en/en/noticia/apb-will-invest-123-million-euros-implementation-cold-ironing-systems-ports-palma-alc%C3%BAdia

[8] The remaining 4% are unknown

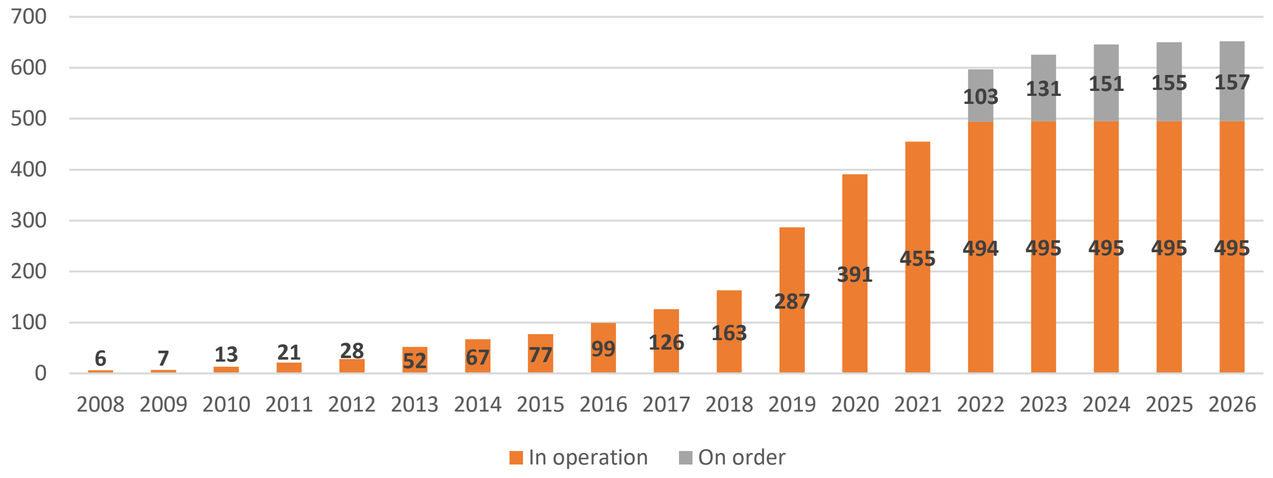

Figure 15: Growth of battery-powered ship fleet (source: Alternative Fuel Insights [6])

When looking only at fishing vessels, about 20 electric ones are in operation today. The first commercial hybrid fishing vessel first started operating in 2015 and was designed and built by Selfa Arctic AS. The vessel is 11 metres long and has a 195 kWh ESS, and a small 50 kW diesel auxiliary generator with a 500 l tank [8]. The vessel runs on diesel to and from the fishing grounds, but switches to electricity for fishing, loading and unloading. It runs electric-only for almost three hours every day, and the batteries are fully recharged in port overnight. This allows to achieve staggering fuel savings of about 70%, and also leads to reduced noise and exhaust from the diesel engine, thus improved working conditions for the fisherman [9].

In 2019, Selfa Arctic started working on their second hybrid-electric fishing boat "Sundsbøen" (12 m), which will be operated by LofotFishing. The combination of diesel-electric engines and batteries (charged with onshore power supply) is expected to reduce the fossil fuel consumption by 50% and the number of engine operating hours with up to 80% [10].

In general, small, motorised fishing boats number more than 2.5 million globally, according to the UN Food and Agriculture Organisation. Small boats particularly dominate in inland fisheries, where they account for as much as 91% of all motorised vessels. With increased electrification across all sectors of society, the market for hybrid fishing boats is thus potentially massive [9].

Transition 3: Smart grids

Smart grids are electrical grids which include a variety of operation and energy measures, such as smart meters, smart appliances, renewable energy sources, and monitoring devices. As the system is undergoing a major change and complexity and interaction are increasing, the effect on grid reliability is uncertain. The risks and consequences of these changes could be mitigated by ensuring a smart design of the whole system and intelligent operation and control.

An example from the Danish Island Samsø is given from. This island recently participated in The Smart Islands Energy System (SMILE) project which aimed to help island communities with limited power grids to increase the use of sustainable energy by testing smart grid technologies [11]. As part of this project, the Ballen Marina was energy-optimised by storing and managing energy from solar power cells.

The project consists of a solar PV installation (60 kW), a battery energy storage system (240 kWh/50 kW), and software to manage the energy flows, effectively making it a smart grid. The marina's smart grid enables monitoring load on the grid, which in turn enables the harbour to manage energy flow distribution. For example, the harbour master can decide to turn off or on the sauna, the sanitary pump, the circulating pump and so forth if this benefits the grid. In this way, the marina is much less vulnerable to power shortage, and can utilise the fluctuations in power production that are a natural consequence of using solar power.

Furthermore, the marina has increased the number of power stations on the jetties, and new sockets have been installed. In addition, all sockets are now equipped with their own power meter. This allows to accurately measure how much power each boat consumes and to identify a pattern to the visiting yachtsmen's power consumption. This provides a lot of best-practice experience on how the marina can plan and predict power consumption. Additionally, the smart grid can facilitate financial arrangements as well. Visiting yachtsmen can pay harbour fees and their electricity consumption through an app. On top of this, the price for electricity consumption could be made variable, dependent on the actual usage or even dependent on the time of day to better reflect the power supply at any given time.

Detailed information on the project, the deliverables, dissemination material, and contact information can all be found on the SMILE project website [12].

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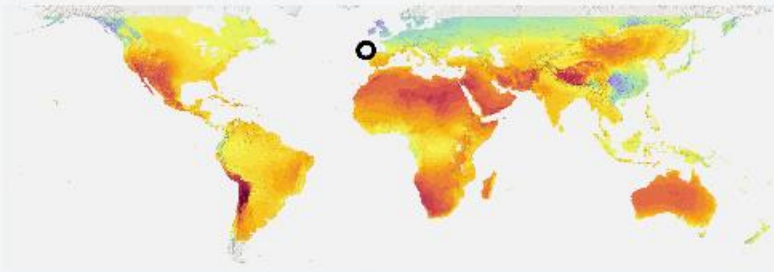
ANNEX

ANNEX A: Solar report

SOLARGIS **PROSPECT**



Preliminary assessment of the photovoltaic electricity production

Project: A Illa de Arousa (Spain)

Geographical coordinates	42.549732°, -008.86734° (42°32'59", -008°52'02")
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