European Commission

Clean energy for EU islands: Mitigating the impacts of ferry electrification on the distribution grids of Faial and São Jorge

Clean energy for EU islands

Mitigating the impacts of ferry electrification on the distribution grids of Faial and São Jorge

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Authors: Wout Deckers (3E), Riccardo Novo (3E)
Reviewers: Marie Angot (3E), Martina Cannata (3E)

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Summary

This report presents the results of the first year of technical assistance delivered from the Clean energy for EU islands secretariat to the Pico, Faial and São Jorge islands transition team. The work focuses on the expected impacts of the charging of two new electric ferries on the isolated distribution grids of Faial and São Jorge, also in consideration of the expected future evolution of electricity production.

First, from an *energy* perspective, the analysis verifies that the increase in electricity consumption related to the new electric ferries can be covered every year from the new Renewable Energy Sources (RES) generation capacity expected in 2027. The charging of the electric ferries will indeed represent approximately. 11% of the electricity consumption of Faial and 12% of the electricity consumption of São Jorge. **On both islands, the expected increase in RES generation will lead to RES penetration levels of ~35%, therefore large enough to cover the additional electrical demand introduced by the ferries.**

Second, from a *power* perspective, the electrification of ferries, although beneficial for reducing GHG emissions when coupled to an increase in RES generation, presents challenges in terms of peak power demand and grid stability. As a possible mitigation measure to this issue, and to reduce the negative impact of the ferry's intermittent load on the power grids of Faial and São Jorge, this report assesses the benefits deriving from the installation of stationary Battery Energy Storage Systems (BESS) at the ports. Additionally, with the growing share of renewable energy, BESS can help to mitigate the potential RES curtailment during periods of high-RES generation. The suitability of stationary BESS of different sizes to be installed at the ports is therefore assessed in relation to the connection capacity available at the same ports. This last parameter is considered an important decision variable, as it also represents the maximum increase of power load seen from the grid side and related to the ferry charging process.

The results obtained show that the system electric ferry-stationary BESS has the potential to decrease future RES curtailment from 21.7% to 14.2% in Faial and from 23.9% to 14.0% in São Jorge. In Faial, the introduction of a 2 MW / 2 MWh BESS can decrease the required connection capacity at the port from 2.75 MW to 1.50 MW. In São Jorge, the use of a 1 MW / 3 MWh storage can lower the needed connection capacity from 1.75 MW to 1.00 MW. The outcomes are presented as a set of feasible configurations, each given by the combination of storage power, storage capacity and connection capacity to the ports, and are intended to support the technical decisions for the deployment of the electric ferries and their charging facilities.

Notwithstanding the need to mitigate RES curtailment related to future wind and solar energy installations through the deployment of additional storage systems, the results of this report show that **the system electric ferry-stationary BESS has the potential to significantly improve renewable energy exploitation in future energy systems configurations.**

1. Introduction

The Pico, Faial and São Jorge islands transition team, composed of the Regional Directorate for Energy, EDA - Electricidade dos Açores, the Chamber of Commerce of São Jorge island and the University of the Azores, has been selected in late 2023 to receive technical assistance from the Clean energy for EU islands (CE4EUI) secretariat under the program “30 for 2030”. The team has been asked to focus the technical assistance on the electrification of the ferries connecting the island of Pico with the island of São Jorge, and the island of Pico with the island of Faial. The ferries are expected to be recharged on São Jorge and Faial only.

This report presents the results of the first year of technical assistance, focused on the expected impacts of the charging of the electric ferries on the distribution grids of Faial and São Jorge, which are built and operated as insular power systems. In this regard, two main topics are discussed in this report.

First, from an *energy* perspective, the electrification of ferries will require an additional amount of electricity to be generated on the islands. If no renewable capacity addition is introduced and the additional electricity required to power the ferries is generated only by means of the existing diesel power plants, the environmental benefit of the electrification might be very limited or, even, there could be an overall increase in greenhouse gas (GHG) emissions related to the ferry lines.

Second, from a *power* perspective, the charging of ferries in Faial and São Jorge at daytime, in between journeys, will require a high-power demand for a short duration of time. The characteristics of such additional power demand are to be accurately assessed, as their peak values may be high when compared to the island baseloads. The island networks may therefore not be able to withstand the unbalances related to such load variation.

Both the above perspectives are discussed and analysed in this report, firstly assessing the expected impacts and secondly analysing possible solutions. Particular attention is devoted to the possible energy storage solutions, which could contribute on the one hand to facilitating the management of ferry charging, and on the other hand to enabling higher penetration of RES in the island power systems.

The report is structured as follows:

- Section 2 discusses the expected future evolutions of electricity production and consumption on Faial and São Jorge, both from an *energy* and *power perspective*, as a consequence of ferries' electrification and the development of new renewable power plants.
- Section 3 proposes some future scenario analysis to analyse the role and benefit of storage facilities under different hypotheses.
- Section 4 provides conclusions and recommendations for the further development of the project.

2. Future evolutions of electricity production and consumption on Faial and São Jorge

In this section, the short- to medium-term evolutions of electricity production and consumption on Faial and São Jorge are analysed.

Section 2.1 describes the current situation of the electricity systems of the two islands; Section 2.2 discusses the new expected electricity demand and load deriving from ferry charging; Section 2.3 discusses the expected generation from the new planned renewable energy plants on the islands; Section 2.4 gives an overall picture of the resulting electricity consumption and production in consideration of the increased demand and generation; Section 2.5 analyses the future electric load; Section 2.6 presents the expected challenges in the operation and management of the future energy systems, and introduces the installation of stationary storage systems as a possible mitigation strategy.

Expected electrification of ferry routes connecting Pico, Faial, and São Jorge is set to introduce new peak load demands. The rise in renewable energy production may lead to increased curtailment during periods of high generation.

2.1. Current situation

At present, on both islands, the majority of electricity production comes from diesel generators. A smaller portion of the electricity production comes from wind turbines. The load profiles were determined based on the output of the various production units.

2.1.1. Faial electricity system

The Faial electricity system is characterised by the following key characteristics:

- Total yearly electricity generation equal to 48,384 MWh/year (EDA data from 2023).
- 6 diesel generators (G3-G8) with a nominal power between 2.00 and 3.74MW. In relation to the total energy production, this accounts for ~89%.
- Wind farm of five wind turbines, each with a capacity of 850 kW. In relation to the total energy production, this accounts for 11%.
- Hydro plant with a turbine with a capacity of 320 kW. In relation to the total energy production, this accounts for 0.2%. Due to its small share, this production unit is not included in the further calculations.
- The baseload of the island grid is ~3.7 MW, and the peak load is ~9.5 MW.

2.1.2. São Jorge electricity system

The São Jorge electricity system is characterised by the following key characteristics:

- Total yearly electricity generation equal to 29,070 MWh/year (EDA data from 2023).
- 7 generators (G6-G12) with a nominal power between 1.00 and 1.54 MW. In relation to the total energy production, this accounts for ~92%.
- Wind farm of six wind turbines with a capacity of 300 kW each. In relation to the total electricity production, this accounts for ~8%.
- The baseload of the island is ~2.3 MW, and the peak load is ~5.3 MW.

2.2. Ferries electrification

The ferry connections between the islands of Faial and São Jorge to the island of Pico are managed and operated by Atlânticoline [1]. The company has provided a technical report presenting the key characteristics of the new electric ferries, as well as the length and schedule of the relevant routes [2]. This information is presented as follows and used as an input for the estimation of the loads related to the recharging of the electric ferries in Faial and São Jorge.

2.2.1. Routes schedule and characteristics of the electric ferries

The key characteristics of the two routes identified by Atlânticoline, and of the ferries respectively operating them, are the following:

- Linha AZUL:
    - Route: Horta (Faial) – Madalena (Pico).
    - Length: 6 nmi.
    - Duration: 30 minutes.
    - Scheduled trips per day: 4 roundtrips every day of the week.
    - Capacity of the ferry's onboard battery: 6,735 kWh.
    - Charging port and night mooring port: Horta (Faial).
    - Charging time and frequency: 3 x at least 1 hour and 45 minutes at daytime (every roundtrip, duration depends on the time of the day), 1 x 13 hours at night.
- Linha LARANJA:
    - Route: Velas (São Jorge) – São Roque (Pico).
    - Length: 11 nmi.
    - Duration: 60 minutes.
    - Scheduled trips per day: 2 roundtrips on Monday, Tuesday, Friday, Saturday and Sunday, with specific timing depending on the day of the week.
    - Capacity of the ferry's onboard battery: 11,225 kWh.
    - Charging port and night mooring port: Velas (São Jorge).
    - Charging time: 1 x at least 5 hours at daytime (in-between two consecutive roundtrips, duration depends on the day of the week), 1 x at least 9 hours and 15 minutes at night (duration depends on the day of the week).

The details of the new schedules developed by Atlânticoline are provided in Figure 1. A representation of the two routes on a geographical map is also provided in Figure 2.

Linha AZUL	Travessia 6 milhas nauticas		
Tempo de viagem max.	00:30:00		
			% Bateria
1ª Viagem	Horta/Madalena	07:30:00	100%
	Madalena (chegada)	08:00:00	66%
	Tempo de paragem (Madalena)	00:15:00	Não Carrega
2ª Viagem	Madalena/Horta	08:15:00	66%
	Horta (chegada)	08:45:00	33%
	Tempo de paragem (Horta)	02:00:00	Carregamento a 100%
3ª Viagem	Horta/Madalena	10:45:00	100%
	Madalena (chegada)	11:15:00	66%
	Tempo de paragem (Madalena)	00:15:00	Não Carrega
4ª Viagem	Madalena/Horta	11:30:00	66%
	Horta (chegada)	12:00:00	33%
	Tempo de paragem (Horta)	02:15:00	Carregamento a 100%
5ª Viagem	Horta/Madalena	14:15:00	100%
	Madalena (chegada)	14:45:00	66%
	Tempo de paragem (Madalena)	00:15:00	Não Carrega
6ª Viagem	Madalena/Horta	15:00:00	66%
	Horta (chegada)	15:30:00	33%
	Tempo de paragem (Horta)	01:45:00	Carregamento a 100%
7ª Viagem	Horta/Madalena	17:15:00	100%
	Madalena (chegada)	17:45:00	66%
	Tempo de paragem (Madalena)	00:15:00	Não Carrega
8ª Viagem	Madalena/Horta	18:00:00	66%
	Horta (chegada)	18:30:00	33%
	Tempo de paragem	13:00:00	Carregamento a 100%

	Linha LARANJA	Travessia 11 milhas nauticas		
	Tempo de Viagem máx.	01:00:00		
				% Bateria
Segunda e Sexta	1ª Viagem	Velas/São Roque	07:45:00	100%
		São Roque (Chegada)	08:45:00	66%
		Tempo de Paragem (São Roque)	00:15:00	Não Carrega
	2ª Viagem	São Roque / Velas	09:00:00	66%
		Velas (Chegada)	10:00:00	33%
		Tempo de Paragem (Velas)	05:00:00	Carregamento a 100%
	3ª Viagem	Velas/São Roque	15:00:00	100%
		São Roque (Chegada)	16:00:00	66%
		Tempo de Paragem (São Roque)	00:15:00	Não Carrega
	4ª Viagem	São Roque / Velas	16:15:00	66%
		Velas (Chegada)	17:15:00	33%
		Tempo de Paragem (Velas)	14:30:00	Carregamento a 100%
Terça e Sábado	1ª Viagem	Velas/São Roque	07:45:00	100%
		São Roque (Chegada)	08:45:00	66%
		Tempo de Paragem (São Roque)	00:15:00	Não Carrega
	2ª Viagem	São Roque / Velas	09:00:00	66%
		Velas (Chegada)	10:00:00	33%
		Tempo de Paragem (Velas)	10:15:00	Carregamento a 100%
	3ª Viagem	Velas/São Roque	20:15:00	100%
		São Roque (Chegada)	21:15:00	66%
		Tempo de Paragem (São Roque)	00:15:00	Não Carrega
	4ª Viagem	São Roque / Velas	21:30:00	66%
		Velas (Chegada)	22:30:00	33%
		Tempo de Paragem (Velas)	12:30:00	Carregamento a 100%
Domingo	1ª Viagem	Velas/São Roque	10:00:00	100%
		São Roque (Chegada)	11:00:00	66%
		Tempo de Paragem (São Roque)	00:15:00	Não Carrega
	2ª Viagem	São Roque / Velas	11:15:00	66%
		Velas (Chegada)	12:15:00	33%
		Tempo de Paragem (Velas)	08:00:00	Carregamento a 100%
	3ª Viagem	Velas/São Roque	20:15:00	100%
		São Roque (Chegada)	21:15:00	66%
		Tempo de Paragem (São Roque)	00:15:00	Não Carrega
	4ª Viagem	São Roque / Velas	21:30:00	66%
		Velas (Chegada)	22:30:00	33%
		Tempo de Paragem (Velas)	09:15:00	Carregamento a 100%

Figure 1: Journey schedules for the Linha AZUL (Horta (Faial) – Madalena (Pico)) and the Linha LARANJA (Velas (São Jorge) – São Roque (Pico)). Images from [2].

Figure 2: Routes of the new Linha AZUL (Horta (Faial) – Madalena (Pico)) and Linha LARANJA (Velas (São Jorge) – São Roque (Pico)), to be served via electric ferries.

As observed in the description above, the ferries will have limited docking times during the day. For this reason, they will need to be equipped for a fast-charging process that will also result in an intermittent peak load on the grid, with potential for unbalancing the island's distribution grids. Overnight charging will instead be spread out over the entire duration of staying at the ports.

2.2.2. Expected electricity demand and load related to the Linha AZUL ferry charging in Faial

The yearly power consumption and the specific power load, on a quarter-hourly basis, deriving from the ferry charging in Faial have been estimated from the schedule of the Linha AZUL presented in

Figure 1 and the size of the ferry's onboard battery (6,735 kWh). The estimation is done under the assumption that the whole ferry docking time is exploited for charging.

The ferry of the Linha AZUL is estimated to consume 6,555 MWh/year. The daily load from its charging process, which is expected to be the same on each day of the year, is presented in Figure 3. The key characteristics of the resulting load are:

- Every weekday
  - From 18:30 to 07:30: 350 kW.
  - From 08:45 to 10:45: 2,250 kW.
  - From 12:00 to 14:15: 2,000 kW.
  - From 15:30 to 17:15: 2,570 kW.

The maximum load requested by the ferry is therefore expected to be 2,570 kW.

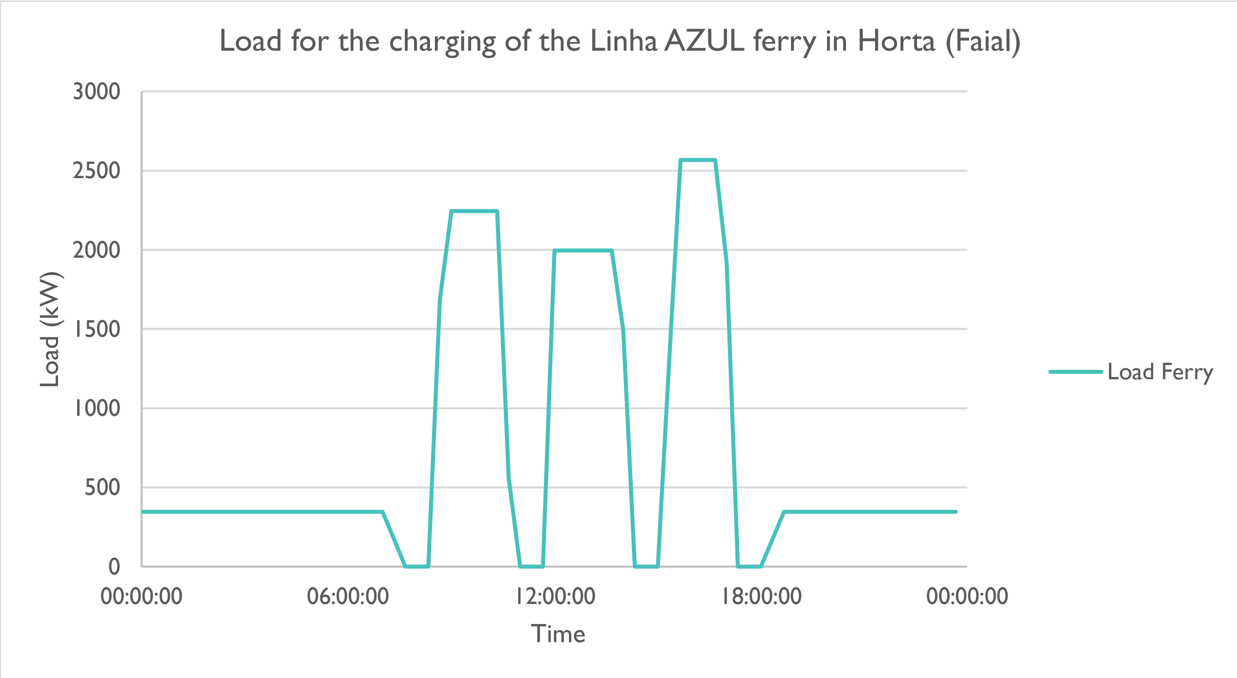

Figure 3: Daily load for the charging of the Linha AZUL ferry in Horta (Faial).

2.2.3. Expected electricity demand and load related to the Linha LARANJA ferry charging in São Jorge

The yearly power consumption and the specific power load, on a quarter-hourly basis, deriving from the ferry charging in São Jorge, have been estimated from the schedule of the Linha LARANJA presented in Figure 1 and the size of the ferry's onboard battery (11,225 kWh). The estimation is done under the assumption that the whole ferry docking time is exploited for charging.

The ferry of the Linha LARANJA is estimated to consume 3,930 MWh/year. The daily load from its charging process, which is variable depending on the day of the week, is presented in Figure 4 for Mondays and Fridays. The key characteristics of the resulting load are:

- Monday and Friday
  - From 17:15 to 07:45: 520 kW.
  - From 10:00 to 15:00: 1,510 kW.
- Tuesday and Saturday
  - From 22:30 to 07:45: 820 kW.

- From 10:00 to 20:15: 740kW.
- Sunday
    - From 22:30 to 07:45: 820 kW
    - From 12:15 to 20:15: 940 kW
- Wednesday and Thursday
    - There is no ferry service.

The maximum instantaneous power requested by the ferry is therefore expected to be 1,510 kW.

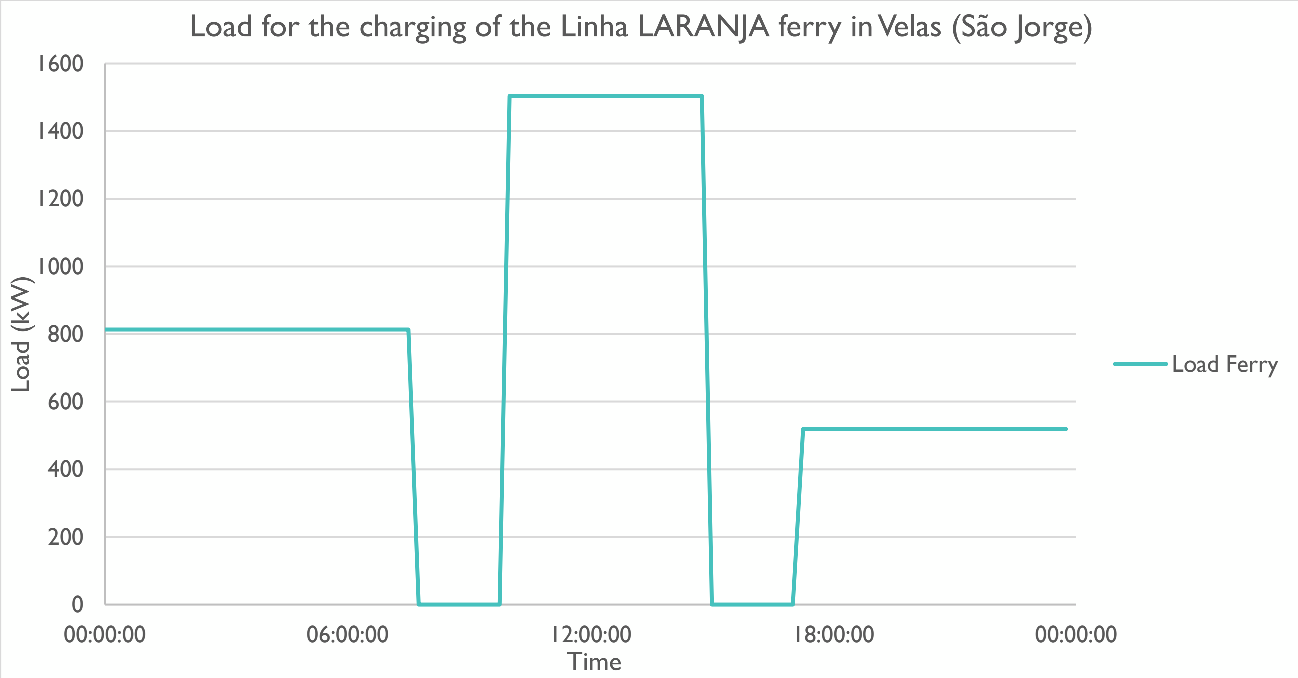

Figure 4: Example of daily load (Mondays and Fridays) for the charging of the Linha LARANJA ferry in Velas (São Jorge).

2.3. Increase in generation from Renewable Energy Sources

There are several private initiatives for the realisation of new wind turbines and photovoltaic plants on the islands of Faial and São Jorge. These have been communicated by EDA and are presented as follows:

- Island of Faial:
    - New PV Plant: 1,5 MW in 2025.
    - Expansion of the existing wind farm (5 x 850 kW) with an additional wind turbine of 2,3 MW in 2027.
    - New PV Plant: 8 MW. The plant will be built by a private investor; the date is uncertain, but considered to be active in 2027. To limit curtailment, the plant is also expected to be equipped with a BESS.
- Island of São Jorge:
    - Revamping of the existing wind turbines (6 x 300 kW) with new machines in 2025 (5 x 900 kW).
    - New PV Plant: 1 MW in 2026.
    - New PV Plant: 4 MW. The plant will be built by a private investor; the date is uncertain, but considered to be active in 2027. To limit curtailment, the plant is also expected to be equipped with a BESS.

It is to be noted that, on both islands, the newly expected capacity is comparable to the peak load demand and significantly higher than the baseload.

For the productivity of the wind farms, an expected capacity factor (CF) was suggested by EDA, in consideration of about 2,700 gross equivalent hours and an availability factor of 95%, resulting in an expected CF=29.3%. The PV potential was instead analysed via simulations performed in PV-Syst software, which generated projections for future solar energy production based on the geographical and meteorological data of the islands, with a resulting CF=14.8%.

In summary, the reference capacity factors used in the analysis amount to:

- Island of Faial:
  - PV plants: CF 14.8%.
  - Wind farms: CF 29.3%.
- Island of São Jorge:
  - PV plants: CF 14.8%.
  - Wind farms: CF 29.3%.

In the absence of further details on the characteristics of the future plants, the same generation profiles as for the existing plants in each island, communicated by EDA and referring to the year 2023, have also been used for the new plants. These figures might be conservative from an energy perspective, especially for wind turbines that can greatly benefit from higher hub heights.

2.4. Future electricity consumption and production

The following two sections analyse the future expected electricity consumption and production on Faial and São Jorge, based on the assumptions described in the previous sections.

2.4.1. Electricity consumption and production in Faial now and in 2027

The key figures for the comparison of the actual (2023) and future (2027) electricity mix and electricity production in Faial are presented in Figure 5. The main elements are listed as follows:

- The Linha AZUL electric ferry will introduce a new electricity consumption of 6,555 MWh/year[1], that will increase the total electricity consumption to approximately. 59,000 MWh/year. The new ferry will therefore be responsible for 11% of the new electricity demand in Faial.
- The expansion of the existing wind farm will lead to a total potential annual wind generation of 16,812 MWh/year.
- The new PV plants will have a potential annual production of approximately. 12,300 MWh/year.

Currently, about 11% of the island's electricity production comes from renewable sources, primarily wind energy. In future, this percentage is expected to increase due to the installation of new wind turbines and the construction of new PV plants. This could lead to an increase in renewable electricity up to 49% of the total energy production, and to a consequent decrease in the diesel-based generation. However, this projection assumes that there would be no curtailment of electricity generation from renewables. During peak periods of solar and wind generation, it may be necessary

[1] The values of electric ferry electricity consumption include the losses related to the ferry onboard electricity storage systems. They do not include losses in the eventual stationary storage systems which are discussed in Section 3.

to curtail some of the renewable generation, as diesel generators are also used to maintain grid stability and cannot simply be turned off. This topic, and particularly the potential for storage systems to mitigate the need for curtailment, is further discussed in Section 3.

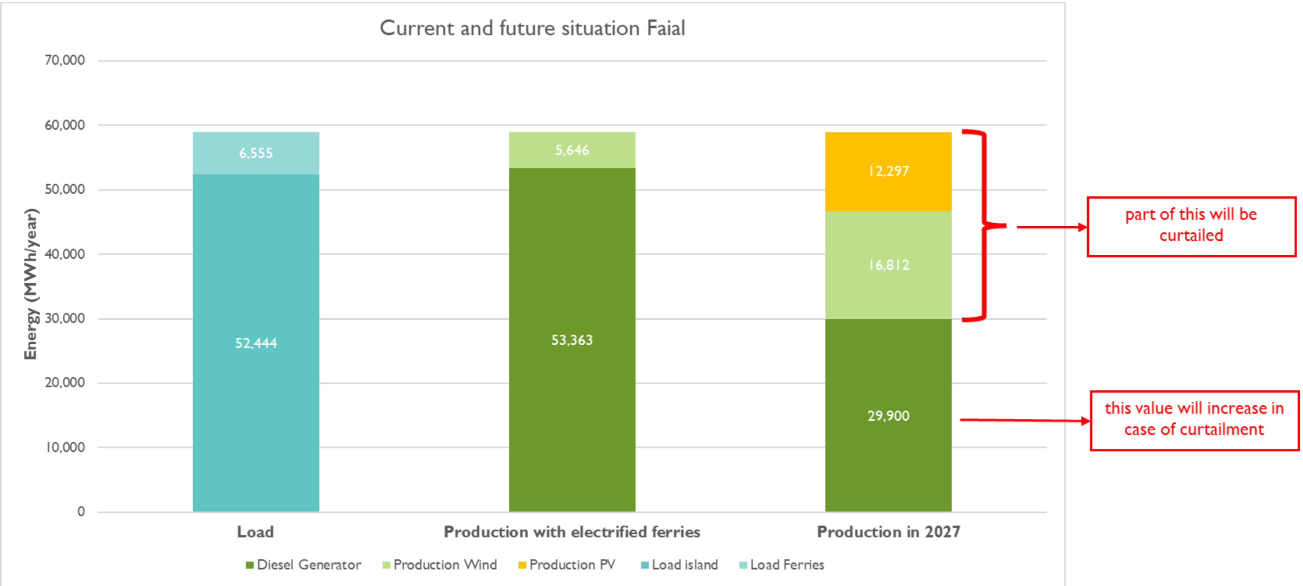

Figure 5: Comparison of the current and future electricity production and consumption in Faial.

2.4.2. Electricity consumption and production in São Jorge now and in 2027

The key figures for the comparison of the actual (2023) and future (2027) electricity mix and electricity production in São Jorge are presented in Figure 5. The main elements are listed as follows:

- The Linha LARANJA electric ferry will introduce a new electricity consumption of 3,930[1] MWh/year, which will increase the total electricity consumption to approximately. 33,885 MWh/year. The new ferry will therefore be responsible for approximately. 12% of the new electricity demand in São Jorge.
- The revamping of the existing wind farm will lead to a potential annual wind generation production of 11,550 MWh/year.
- The new PV plants will have a potential annual production of approximately. 6,470 MWh/year.

Currently, about 8% of the island's energy comes from renewable sources, primarily wind energy. In future, this percentage is expected to increase due to the repowering of the existing wind turbines and the construction of new PV plants. This could lead to an increase in renewable electricity up to ~53% of the total energy production, and to a consequent decrease in the diesel-based generation. However, this projection assumes that there will be no curtailment of electricity generation from renewables. As for Faial, the eventual curtailment of renewable energy generation and the role of storage systems to mitigate it needs to be discussed.

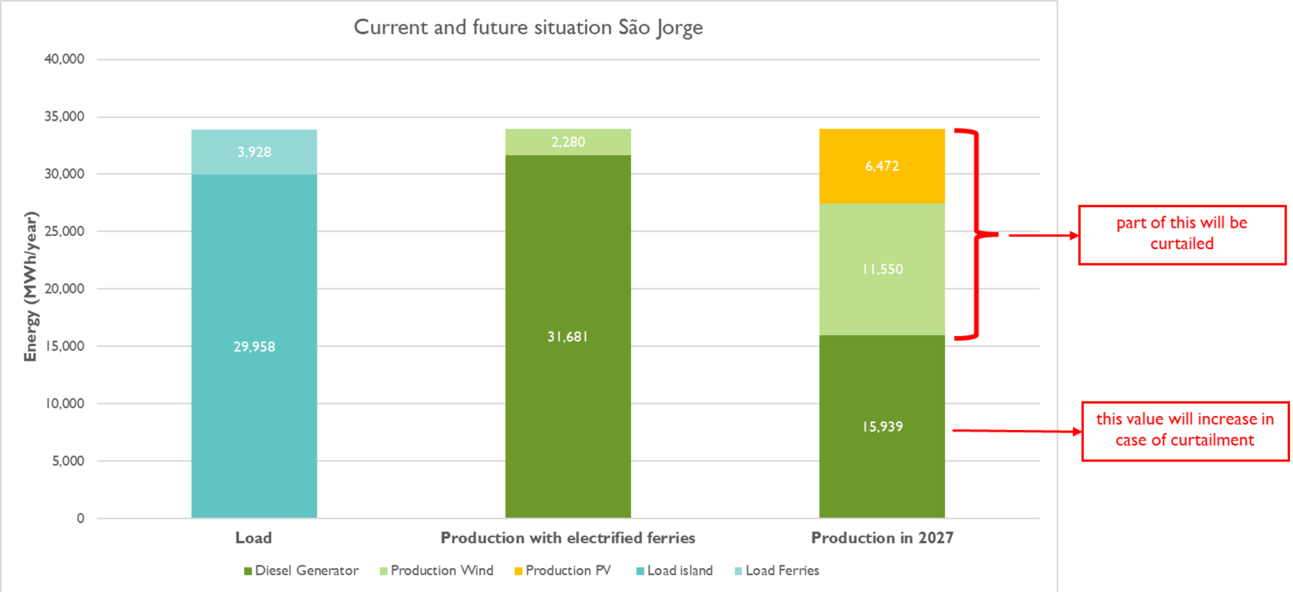

Figure 6: Comparison of the current and future electricity production and consumption in São Jorge.

2.5. Future electrical load

The following two sections analyse the future electrical load on Faial and São Jorge, based on the assumptions previously described.

2.5.1. Expected electrical load in Faial

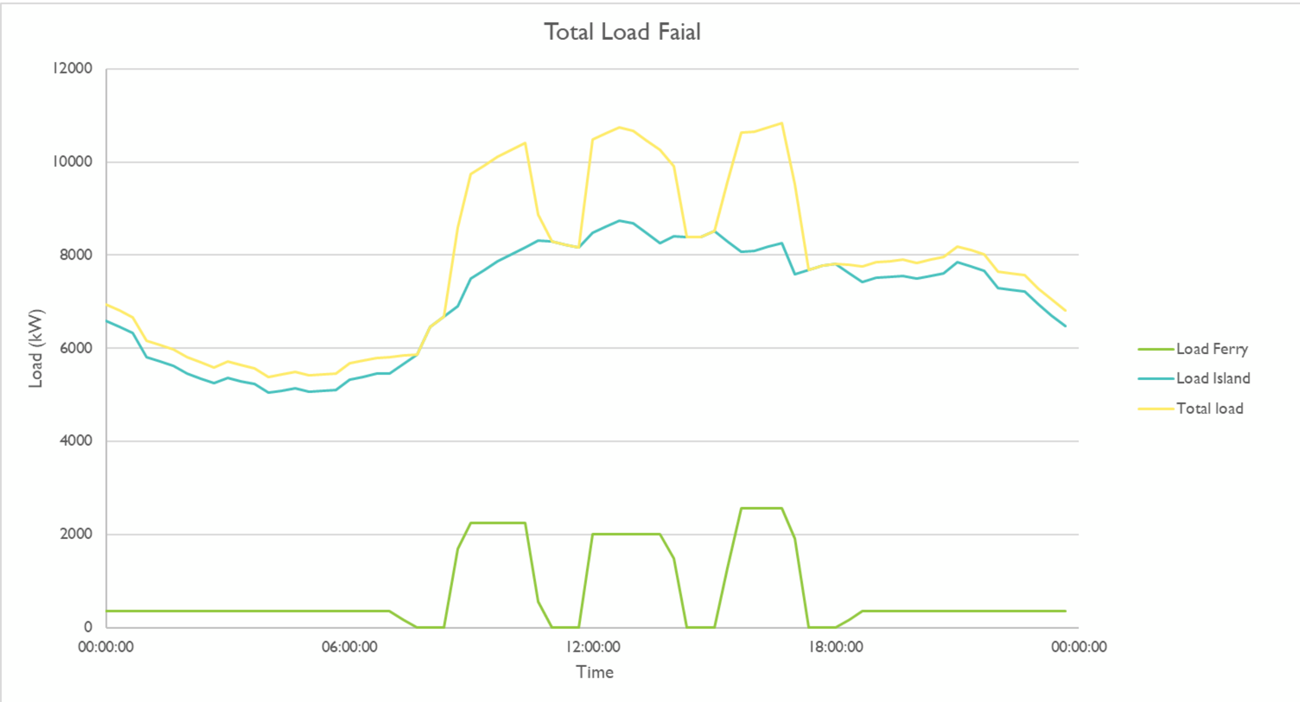

Figure 7, where it oscillates between 5.4 MW and 10.8 MW. The nighttime baseload presents an increase of some hundred kW with respect to the pre-intervention situation. Also, the results show a sudden and steep increase (and consecutive decrease) in electricity demand three times a day, in correspondence with the ferry charging, up to 2.6 MW in addition to the existing load.

Extending the analysis to the whole year:

- The new baseload (achieved at nighttime between 6 pm and 6 am) is estimated at 4 MW. The nighttime baseload will increase by 340 kW because of the charging of the ferries.
- The new peak demand (achieved at 01/08/2023) is estimated at 12 MW, with an increase of 2.6 MW with respect to the current situation.

Figure 7: Expected future total electricity load in Faial on a typical summer day based on the introduction of the new Linha AZURA electric ferry.

2.5.2. Expected electrical load in São Jorge

The future electrical load of São Jorge on a typical summer day is presented in Figure 8, where it oscillates between 3.0 MW and 6.3 MW. The nighttime baseload presents an increase which depends on the day of the week, due to the schedule of the ferries varying across the week. Most importantly, the results show a sudden and steep increase (and consecutive decrease) in electricity demand for one time in the day, in correspondence with the ferry charging, of 1.5 MW in addition to the existing load.

Extending the analysis to the whole year:

- The new baseload (achieved at nighttime between 6 pm and 6 am) is estimated at 2.4 MW. The nighttime load will increase from 130 kW to 800 kW (depending on the day of the week), because of the charging of the ferries.
- The new peak demand (achieved on 20/07/2023) is estimated at 6.4 MW, with an increase of 1.5 MW with respect to the current situation.

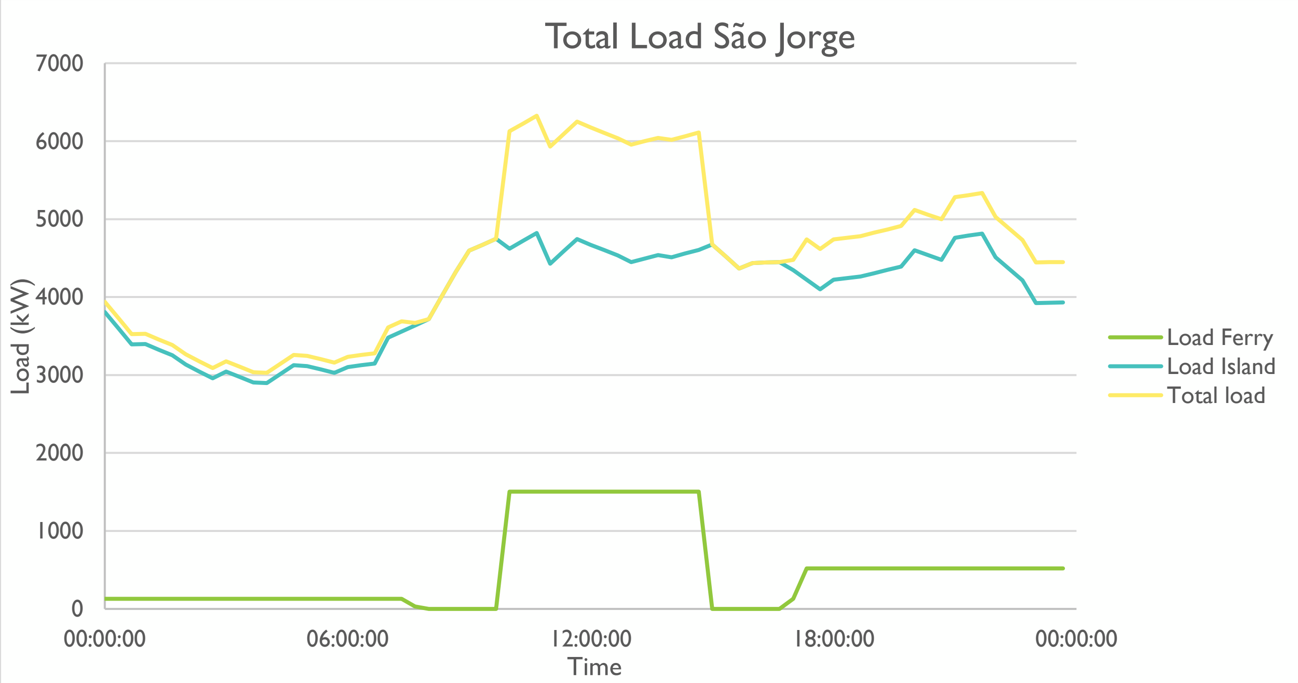

Figure 8: Expected future total electricity load in São Jorge on a typical summer day based on the introduction of the new Linha LARANJA electric ferry (the presented profile is valid for Thursdays).

2.6. Expected challenges in the operation and management of the future energy systems

2.6.1. Key challenges

Based on the developed analysis and on the projections described in Sections 2.4 and 2.5, two key considerations are made at this stage on the challenges for the operation and management of the future energy systems:

- First, to meet the new demand instantaneously, additional diesel generators may need to be activated quickly. In practice, this will be hardly implementable, because diesel generators will need a certain ramp-up time and are characterised by a minimum runtime. The ferry charging will potentially have a large impact on Faial's electricity peak demand and, therefore, on its grid stability.
- Second, with the expected increased share of renewables and the intermittent nature of wind and solar, it will be essential to implement technologies and processes to maintain grid stability. At certain times, power demand could potentially be met solely by renewable sources, but this would not ensure a stable grid due to fluctuations in grid frequency. To maintain stability, at least one generator must always operate, together with a utility battery system managed by the DSO.

In the following paragraphs, the potential contribution of energy storage systems to the two challenges is presented on a qualitative basis, laying the basis for the analysis proposed in Section 3.

2.6.2. Mitigating the impacts on power grids with storage systems

Energy storage can reduce the impact of demand peaks and generation peaks and lead to an increase of the share of renewable energy through *peak shifting* services.

A Battery Energy Storage System (BESS) is a technology designed to store electrical energy for later use, typically using rechargeable cell stacks. BESS allows for greater flexibility in energy management, as it stores energy during periods of low demand and releases it when demand is higher. This system is gaining increasing importance in modern power grids, especially with the growing share of intermittent renewable energy sources such as wind and solar.

One of the primary applications of BESS is peak shifting, which involves storing energy during low-demand hours and discharging it during peak-demand periods. By doing so, BESS helps reduce the strain on the electrical grid during high-demand times, thereby lowering the need for additional power generation capacity. This can lead to cost savings and improved grid efficiency.

The authors consider that, in view of the expected evolutions of the electricity systems of Faial and São Jorge, both grids would require the planning and deployment of stationary storage systems of adequate capacity. This represents an essential element to ensure that the new electricity from RES is hosted without negatively impacting the network's stability, and that the demand deriving from the future electric ferries is met without leading to an increase in diesel-based generation. It is to be mentioned that the existing thermal units (gensets) were sized to guarantee supply for all island consumption. With a significant increase in consumption and no investment in stationary BESS, it could become necessary to increase the number of thermal units on each island (which is undesirable, since both islands are on their way towards a decarbonised power mix). The sizing of the new storage facilities should then consider the expected evolutions in both demand and generation, to valorise load aggregation and provide a holistic management of the electricity flows.

A relevant topic in this regard is also the location for the new stationary storage. Installing stationary storage directly at the harbours of Horta (Faial) and Velas (São Jorge), where the electric ferries are charged, would offer some key advantages. Charging the electric ferries will indeed require significant power, especially during short docking periods at daytime, potentially placing sudden strains on the local grid. Despite the main issue being represented by the supply of electricity to the ferry in fast-charging mode rather than the grid infrastructure, the installation of BESS directly at the harbour would reduce the required upgrading of the grid infrastructure from the key nodes of the medium voltage network to the port.

In the following section, the benefits deriving from the installation of storage facilities of different sizes and durations at the harbours of Horta (Faial) and Velas (São Jorge) are assessed as a function of the connection capacity to the island power grid, which in turn affects both the electric grid infrastructure and the electricity supply system.

It should be noted that the following analysis is limited to studying the mitigation of the impacts of ferry charging, which is the key scope of this report. The future electricity systems of Faial and São Jorge will likely require storage systems to support the new foreseen RES power plants.

3. Sizing BESS to reduce the impact of ferry charging

In this section, a set of simulations of the electricity systems of Faial and São Jorge is proposed to evaluate the suitability of stationary BESS of different sizes installed at the ports of Horta (Faial) and Velas (São Jorge) to support the charging of the two ferries. Section 3.1 provides the key elements of the methodology applied, whereas Section 3.2 presents the results of the analysis.

3.1. Methodology

The methodology used to model the energy systems of the islands of Faial and São Jorge incorporates a comprehensive analysis of energy consumption, production, and storage integration, and the development of future scenarios under different levels of future renewable energy generation.

3.1.1. Assumptions on demand load and generation

As discussed in Section 2.1, power consumption was retrieved from the data made available by EDA for the year 2023. This data includes the total production of electricity by both conventional generators (diesel-based) and renewable energy sources, specifically wind turbines. The load estimated for the charging of the electric ferries, discussed in Section 2.2, was then added to the current one, leading to the future load presented in Section 2.5.

On the generation side, the current electricity supply was again retrieved from data communicated by EDA and is presented in Section 2.1. The electricity production and load profiles of the newly added renewable energy sources were modelled as described in Section 2.3. Therefore, the production and load profiles were modified to account for the new renewable plants and electric ferries, respectively. The new BESS, foreseen to be installed with the large PV plants on the two islands, are here conservatively not modelled.

3.1.2. Assumptions on connection capacity to the port

A first key parameter that was used in the simulations of the electricity systems consists of the capacity of the power connection from the key nodes of the distribution grids to the charging systems at the ports, including the BESS facilities. This not only represents the capacity of the cable and power transformers that should deliver power to the charging facilities, but especially the maximum instantaneous increase of power demand related to the functioning of the ferries that can be observed from the grid side.

The following intervals have been considered:

- Faial (Linha AZUL, expected peak power demand: 2,570 kW): from 500 kW to 2,750 kW, with steps of 250 kW.
- São Jorge (Linha LARANJA, expected peak power demand: 1,510 kW): from 250 kW to 1,750 kW, with steps of 250 kW.

The maximum values of connection capacities are deliberately higher than the expected peak power demand, to consider for eventual slight modifications in the travel schedules or delays, e.g. due to unfavourable meteomarine conditions.

3.1.3. Assumptions on BESS

The impact of stationary BESS integration at the ports was studied through a series of simulations designed to evaluate different storage sizes. These scenarios were developed specifically to analyse the effects of storage on reducing the peak loads from ferry charging.

The selected BESS technology to be included in the electricity system simulations was Li-ion batteries – more specifically, lithium-iron-phosphate (LFP) batteries. Li-ion batteries present the best option for the service analysed in this work as they offer:

- A possibility to fully charge the battery in shorter times: a large charging power, very close to or even equivalent to the discharging power.
- Excellent lifetime calendar and cycling.
- High round-trip efficiency.

The following parameters were used:

- C-rate:
    - A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity. A 1C rate means that the discharge current will discharge the entire battery in 1 hour; for a battery with a capacity of 100 Ah, the discharge current is 100 A.
    - Different C-rates (between C/8 and 4C) are used for different scenarios, resulting in different sizes of storage.
- State of Charge (SOC) [%]:
    - This is the level of charge of an electric battery relative to its capacity. The units of SoC are percentage points (0% = empty; 100% = full). Different battery technologies may be characterised by different values of min. SOC and max. SOC, limiting the available capacity during operation. Using a storage system until 0% or 100% State of Charge (SoC) can significantly accelerate battery degradation.
    - For the sake of simplicity, the state of charge (SoC) is here assumed to range between 0-100%. Results are therefore in terms of exploitable storage capacity.
- State of Health (SOH) [%]:
    - This is a figure of merit of the condition of a battery (or a cell, or a battery pack), compared to its ideal conditions. The units of SOH are percentage points (100% = the battery's conditions match the battery's specifications). SOH at the end of life is assumed to be between 60-80% of the initial capacity, as with a typical 2-3% degradation per year.
    - Battery degradation is not used in the simulations. Ultimately, the battery will need to be oversized to account for this phenomenon and mitigate its impact over time.
- Roundtrip efficiency:
    - Battery efficiency considering both charging and discharging losses. The round-trip efficiency defines the amount of energy recoverable from a storage device relative to the amount initially absorbed.
    - A roundtrip efficiency of 90% is used, from AC input to AC output.

The following key parameters have been used on both islands for sizing storage facilities in different scenarios:

- Storage power: no storage, 1 MW, 2 MW, 3 MW, 4 MW.
- Storage duration: 0.5 h, 1 h, 1.5 h, 2 h, 3 h, 4 h, up to a maximum of 8 MWh storage capacity.

3.1.4. Assumptions on grid stability requirements

With the expected increase in the share of renewables (overall 30% in Faial and 34% in São Jorge), it will be essential to maintain grid stability. Grid stability should be carefully assessed with an adequate dynamic modelling, including battery converters, eventually modelled in grid-forming mode, and considering the possible contribution of EDA utility battery, the battery from the PV plant and the port battery.

The following thermal power, equal to the technical minimum of one machine at each diesel power plant, was also assumed to be continuously operational:

- Faial: at least 1,900 kW.
- São Jorge: at least 900 kW.

3.1.5. Simulation tool and strategy

HomerPro [3] was used for developing the simulation of the electricity systems of Faial and São Jorge. HomerPro is a power system simulation tool used to model microgrids, allowing for the analysis of off-grid scenarios. For simulating the energy system of the islands, HomerPro integrates various components, such as renewable energy sources (wind, solar, etc.), diesel generators, and BESS, and analyses their interactions. The software enables to simulation of the impact of different energy mixes, including renewable energy, and evaluates system performance under varying load demands. HomerPro examines all possible combinations of system types in a single run and then sorts the systems according to the optimisation variable of choice.

The simulations were conducted following a controlling algorithm where the batteries are primarily charged, making use of renewable electricity, characterised by a null marginal cost. The batteries are exclusively used to charge the ferry and therefore do not return electricity to the grid. Scenarios characterised by any level of capacity shortage, i.e. not capable of fully ensuring the supply of the demand and, therefore, the charging of the electric ferries, were marked as unfeasible.

3.1.6. Future scenarios

To anticipate the changes in energy demand and supply due to ongoing developments such as the electrification of ferries and the expansion of RES, the electricity system simulations are focused on the situation expected by 2027. On one side, the introduction of electric ferries will significantly increase power consumption and, especially, power load during charging times. On the other hand, the growing share of renewable energy will introduce more significant fluctuations in production.

Future energy scenarios for the islands of Faial and São Jorge in 2027 have been analysed with the following key characteristics:

- Island of Faial:
  - New PV Plants with a total capacity of 9.5 MW.
  - Expansion of the existing wind farm (5 x 850 kW) with an additional wind turbine of 2.3 MW (overall a capacity factor of 29.3%, before eventual curtailment).
  - Generation capacity of 1,900 kW continuously operational (with the support of EDA utility battery).
- Island of São Jorge:
  - New PV Plants with a total capacity of 5 MW.
  - Revamping of the existing wind turbines (6 x 300 kW) with new machines (5 x 900 kW), with a capacity factor of 29.3% (before eventual curtailment).

    - Generation capacity of 900 kW continuously operational (with the support of EDA utility battery).

The key perspective of analysis is on ferry charging and stationary BESS at the ports, based on the following key parameters:

- Connection capacity to the port:
    - Faial: from 500 kW to 2,750 kW, with steps of 250 kW.
    - São Jorge: from 250 kW to 1,750 kW, with steps of 250 kW.
- BESS size:
    - Storage power: no storage, 1 MW, 2 MW, 3 MW, 4 MW.
    - Storage duration: 0.5 h, 1 h, 1.5 h, 2 h, 3 h, 4 h, up to a maximum of 8 MWh storage capacity.

Scenarios are obtained as a combination of the above parameters, for a total of 200 scenarios for Faial and 140 scenarios for São Jorge. By simulating these scenarios, an assessment of how battery storage systems can be utilised to manage the ferry peak loads and reduce the impact of ferry charging on the islands' electricity systems is performed. The expected level of RES curtailment is calculated, and if the new system ferry + BESS, can lead to its decrease with respect to the case with no ferry charging system.

The results present which of the simulated scenarios are considered feasible and identify the most suitable combinations in terms of minimum requirements for the three key parameters discussed above.

3.2. Results

3.2.1. Faial

The key results from the simulation of the Faial electricity system in 2027 show that future scenarios with electric ferries are characterised by a RES penetration between 42.1% and 42.8%, with a RES curtailment level oscillating between 12.8% and 14.2%. This last value depends on the size of the BESS and connection capacity, and the highest curtailment is achieved when no stationary BESS is introduced. As a reference, the same electricity system without a ferry and a stationary BESS would have a RES penetration of around 40.8%, with a RES curtailment level of about 21.7%. Therefore, the introduction of the system electric ferries (+ BESS) can lead to a significant improvement in the exploitation of the available renewable energy sources.

The set of feasible scenarios for Faial among those studied is presented in Figure 9. The two axes represent the two expected key decision-making drivers for the design of the future ferry charging system at the port of Horta (Faial):

(i) the x-axis represents the connection capacity at the port;
(ii) the y-axis represents the storage capacity at the port.

The circles represent the suitable combinations of connection capacity and storage capacity; their colour represents the minimum storage power to ensure the feasibility of that specific option. The green dashed line crossing the circles represents the feasibility line, dividing the red unfeasible area (i.e., scenarios that do not ensure the full supply of electricity to the ferries) from the blue suboptimal area (i.e., scenarios characterised by higher characteristics than the minimum requirements to ensure feasibility).

The analysis performed shows that a 1.5 MW connection capacity (-1.25 MW wrt. the baseline) would require a stationary BESS at the port of at least 2 MW / 2 MWh. Further decreases in connection capacity would lead to higher required storage capacity, up to 4 MWh for the 1.25 MW connection and 6 MWh for the 1 MW connection.

These results can be explained by the high intermittency of the load from the Linha AZUL ferry and the terminal's proximity to the charging phases (2 intervals of 1 hour and 15 minutes only during the day). Because of that, significantly reducing the available connection capacity requires a steep increase in the storage capacity.

It is to be remarked that storage facilities with a larger power sizing than the connection capacity can only fully exploit their power when charging the ferry and not when being charged themselves.

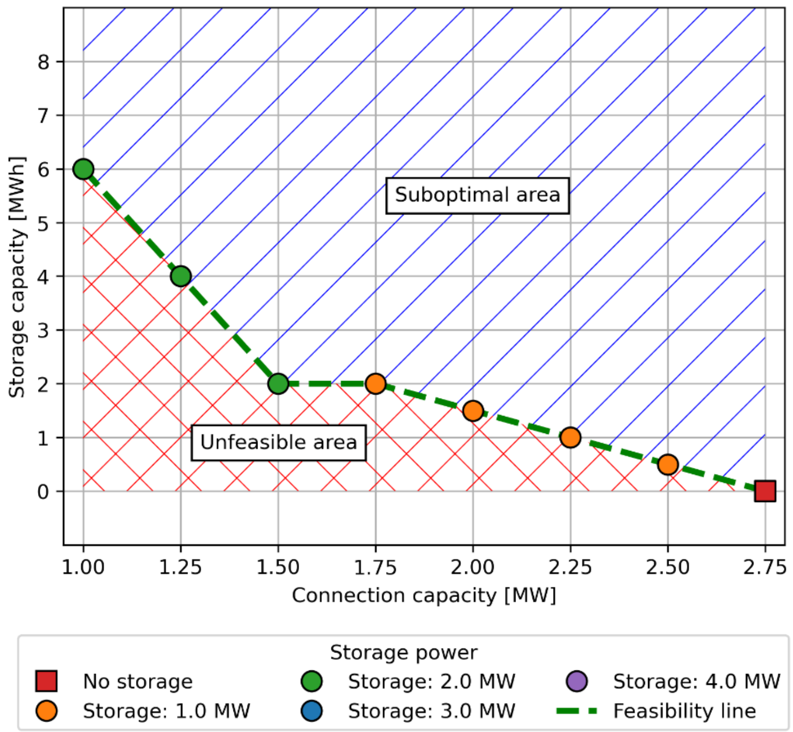

Figure 9: Feasible scenarios for Faial, deriving from the combination of connection capacity at the port, and the storage capacity and storage power of the BESS installed at the port. The colored circles on the feasibility line (green dashed line) represent, for each combination of connection capacity and storage capacity, the minimum required storage power.

The generation profiles and electrical load on a typical day, namely the 17/08 of the simulated year, for the scenario 1.5 MW connection capacity and 2 MW / 2 MWh BESS, are proposed in Figure 10. The chart shows a generally sunny day, also characterised by consistent wind power generation from mid-morning. This leads the diesel power plant to operate for several hours at its minimum power. It is observed that the storage gets discharged in the hours when the ferry is connected for recharging, limiting to 1.5 MW the increase/decrease in total required generation related to the ferry charging. The battery then gets recharged immediately after the ferry has left, in between the different ferry runs. During the long break at nighttime, the ferry gets charged at low power demand, not requiring the battery to enter operation.

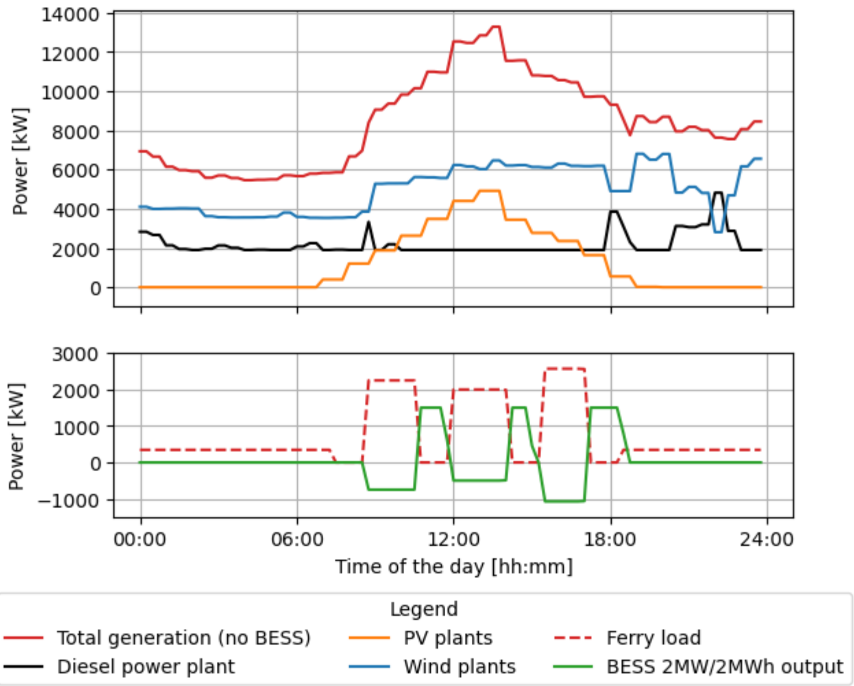

Figure 10: Time series of load, production and stationary BESS on a typical summer day in Faial for the scenario with 2 MW / 2 MWh BESS and 1.5 MW connection capacity.

3.2.2. São Jorge

The key results from the simulation of the São Jorge electricity system in 2027 show that future scenarios with electric ferries are characterised by a RES penetration of around 45%, with a RES curtailment level between 14.3% and 14.6%. As a reference, the same electricity system without a ferry and a stationary BESS would have a RES penetration of around 43.4%, with a RES curtailment level of 23.9%. Therefore, in São Jorge, the introduction of the system of electric ferries + BESS can lead to a significant improvement in the exploitation of available renewable energy sources.

The set of feasible scenarios for São Jorge among those studied is presented in Figure 11. The chart structure is the same as the one presented in the previous section for Faial.

The analysis performed shows that a 1 MW connection capacity (-0.75 MW wrt. the baseline) would require a stationary BESS at the port of at least 1 MW / 3 MWh. A further decrease in connection capacity to 0.75 MW would lead to a higher storage size, in the order of 3 MW / 4.5 MWh.

Because of the Linha LARANJA charging profile, a stationary BESS at the port of Velas (São Jorge) can provide even higher advantages than the ones expected in Horta (Faial). Again, it is also to be remarked that storage facilities with a larger power sizing than the connection capacity can only fully exploit their power when charging the ferry and not when being charged themselves.

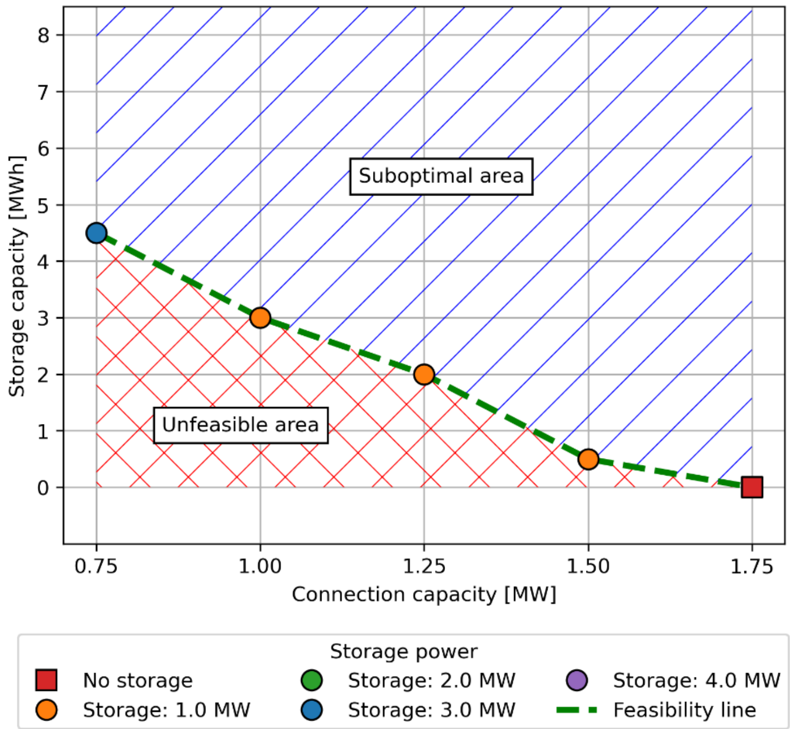

Figure 11: Feasible scenarios for São Jorge, deriving from the combination of connection capacity at the port, and the storage capacity and storage power of the BESS installed at the port. The colored circles on the feasibility line (green dashed line) represent, for each combination of connection capacity and storage capacity, the minimum required storage power.

The generation profiles and electrical load on a typical day, namely the 17/08 of the simulated year, for the scenario 1 MW connection capacity and 1 MW / 3 MWh BESS, are proposed in Figure 12. The chart shows a generally sunny day, also characterised by medium wind power generation. It is observed that the storage gets discharged in the hours when the ferry is connected for recharging, thus limiting the increase in peak power and then is recharged immediately after. Notably, the battery power is not fully exploited in discharge, because of the longer duration of the charging process wrt. the case in Faial, and because of the large dimensions of the onboard battery. For this reason, BESS technologies else than Li-ion and with longer duration (e.g., NaS) could also be considered in the case of São Jorge.

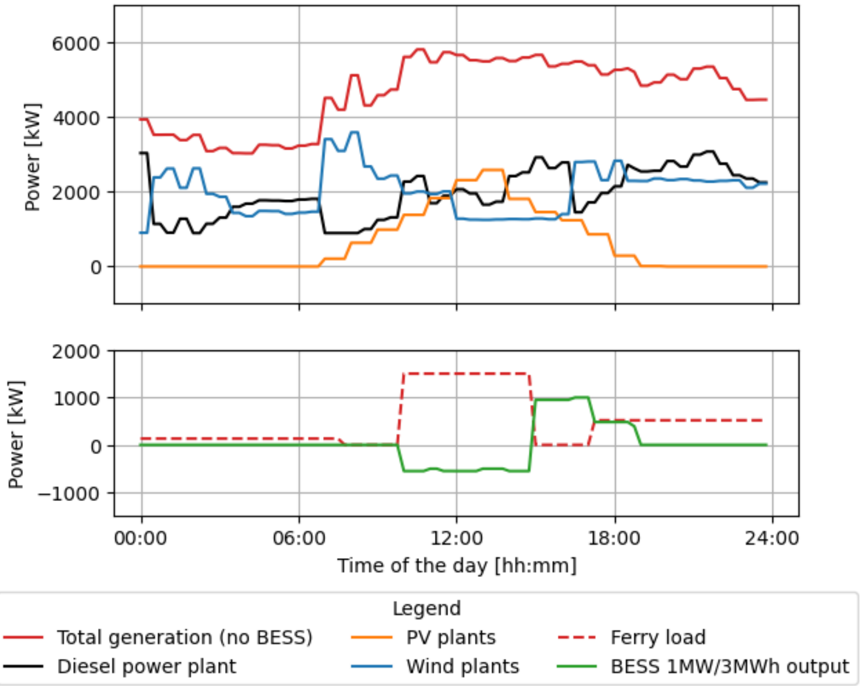

Figure 12: Time series of load, production and stationary BESS on a typical summer day in São Jorge, for the scenario with 1 MW / 3 MWh BESS and 1 MW connection capacity.

4. Conclusion and recommendations

4.1. Conclusion

This report examined the foreseen impact of the future evolution of electricity production and consumption on the islands of Faial and São Jorge, whose grids are constructed and operated as isolated electricity systems. From the consumption point of view, the work considered the expected increase in electricity demand related to the introduction of two new electric ferries to be charged, respectively, at the ports of Horta (Faial) and Velas (São Jorge). Concerning electricity production, the work considered the expected increases in the RES generation capacity in 2027 on both islands.

First, from an *energy* perspective, the analysis verified that the increase in electricity consumption related to the new electric ferries can be covered every year from the newly expected RES generation capacity. The charging of the electric ferries will indeed represent approximately. 11% of the electricity consumption in Faial and 12% of the electricity consumption in São Jorge. On both islands, **the expected increase in RES generation would be able to cover the additional electrical demand introduced by the ferries**.

Second, from a *power* perspective, the electrification of ferries, although beneficial for reducing GHG emissions when coupled to an increase in RES generation, presents challenges in terms of peak power demand and grid stability. As a possible mitigation measure to this issue, and to reduce the negative impact of the ferry's intermittent load on the power grids of Faial and São Jorge, this report assessed the benefits deriving from the installation of a stationary BESS at the ports. Additionally, with the growing share of renewable energy, BESS can help mitigate the potential RES curtailment during periods of high renewable generation. The suitability of stationary BESS of different sizes to be installed at the ports was therefore assessed in relation to the connection capacity available (grid and production system). This last parameter is considered an important decision variable, as it also represents the maximum increase of power load seen from the grid side and related to the ferry charging process.

Simulations of the electricity systems of the two islands were developed through HomerPro software. Results revealed the possibility of reducing future RES curtailment in Faial from 21.7% to at least 14.2%, and on São Jorge from 23.9% to at least 14.0%. In Faial, the introduction of a 2 MW / 2 MWh BESS can decrease the required connection capacity (grid and production system) from 2.75 MW to 1.50 MW. In São Jorge, the use of a 1 MW / 3 MWh storage can lower the needed connection capacity (grid and production system) from 1.75 MW to 1.00 MW. The outcomes were presented as a set of feasible configurations, each given by the combination of storage power, storage capacity and connection capacity, and are intended to support the technical decisions for the deployment of the electric ferries and their charging facilities.

In conclusion, notwithstanding the need to mitigate RES curtailment related to future wind and solar energy installations through the deployment of additional storage systems, the results of this report show that **the system electric ferry-stationary BESS has the potential to significantly improve renewable energy exploitation in future energy systems configurations.**

4.2. Recommendations

The following key recommendations and suggestions for the electric ferry project continuation and implementation are given based on the outcomes of this report:

- It is recommended that stationary BESS are deployed at the ports of both Horta (Faial) and Velas (São Jorge). This will allow for effective peak-shifting of the ferry charging, reducing the related negative impacts on the islands' grids, and could contribute to the ramp-up / ramp-down of the demand from the ferry itself. Moreover, the BESS will enable better integration of renewable energy sources, minimise curtailment and make use of surplus energy during peak wind and solar production periods. It is also recommended that the size of the future BESS suggested in this report is further discussed with the relevant actors, first and foremost the DSO (EDA), as a function of the connection capacity that can be reasonably made available at the two ports and in consideration of the specificities of the distribution grids.
- As neither the future battery degradation nor the permissible SoC is accounted for in the simulations proposed in this report, it is recommended to size the battery systems with an additional margin to account for degradation over time, ensuring the long-term suitability of the proposed solution, and for the non-exploitable storage capacity. It is suggested that this topic be discussed with the BESS manufacturers/providers, who can provide details on the expected degradation rates.
- Grid stability should be carefully assessed with adequate modelling, including battery converters from the different storage facilities expected (including the DSO utility battery and the BESS associated with the PV plants). It is also recommended that the ramp-up related to the loads of the future BESS and ferry charging systems be assessed from a grid stability point of view on each island, to consider the suitable requirements for a safe and reliable operation of the charging process.
- From a financial point of view, it is recommended that the work proceed through the estimation of the CAPEX and OPEX figures related to one or more options, and that the relevant stakeholders are engaged in the identification of suitable financing mechanisms.

5. References

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