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SMILE

Smart Island Energy Systems

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Report on market acceptance and replicability (final version)

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1 Introduction

1.1 Scope and Objectives

The overall scope of the SMILE project is to demonstrate, in real-life operational conditions, a set of both technological and non-technological solutions meant to enable demand response schemes, smart grid functionalities, storage and energy system integration, with the final objective of paving the way for their introduction in the market. To this end, three large-scale demonstrators have been implemented on three European islands having similar topographic characteristics but different policies, regulations, and energy markets: Orkneys (UK), Samsø (DK), and Madeira (PT).

The present document presents the outcomes of an assessment conducted to investigate opportunities for replicating the Madeira demonstrator within the national and international markets. Although Replicability Analysis (RA) is commonly combined with Scalability Analysis (SA) and often complemented by a Cost-Benefit Analysis (CBA), here the focus is only on the replicability potential of the Madeira demonstrator. Therefore, both SA and CBA are to be considered out of the scope of this report.

In the present document, replicability is understood as "the property of a system that allows it to be duplicated at another location or time" [1] and depends on a set of pre-conditions - i.e., the boundary conditions characterizing a given context - pertaining the (i) technical, (ii) regulatory, and (iii) socio-economic domains. In particular, and according to [2], the socio-economic domain is here considered as the one that determines the market acceptance potential of smart grid technologies. Therefore, market acceptance is here regarded as one of the drivers for replicability.

For the purpose of this RA, six European islands, one for each of the countries members of the SMILE consortium (i.e., Portugal, Scotland, Denmark, Italy, Greece, and the Netherlands), were selected as possible replication sites. A qualitative assessment of the technical, regulatory, and socio-economic boundary conditions of the selected sites, will determine whether such boundary conditions represent barriers, drivers or enablers for replicating the Madeira demonstrator on those islands. Based on the review of relevant literature, it was decided to adopt a qualitative approach to RA instead of conducting a quantitative simulation-based evaluation. This choice is further motivated by the complexity of collecting all the necessary input data on the selected sites. Ultimately, this approach allows taking into account all those influencing aspects that are difficult to quantify – e.g., aspects related to the specific policies, regulations, energy markets, and socio-economic characteristics of the selected sites.

1.2 Structure

The present document is structured as follows: Section 2 provides a detailed description of the solutions demonstrated in Madeira. The methodology adopted for the purpose of this RA, which is introduced by a summary of relevant literature, is described in section 3. The outcomes of the RA are presented in section 4, followed by a discussion of the results (section 5). Finally, the document ends with conclusions and a list of references.

1.3 Relationship with other deliverables

A draft version of the present report (Deliverable D4.10) was submitted in M36 [3]. Hence, the present document includes part of the content from D4.10 - i.e., chapter 2 "Description of the proposed solutions" and chapter 3 "Methodology" - and is extended by the outcomes of the RA.

This report relates to the following tasks defined for WP4:

- Task 4.5 “Evaluation of storage and DSM, aimed at assessing the results of the DSM pilot in Madeira”.
- Task 4.8 “Evaluation of EV smart charging, aimed at assessing the results of the EVs smart-charging pilot in Madeira”.

It receives inputs from D4.11 “Installation report of the DSM demo” [4], D4.12 “Installation report of the EV smart charging demo” [5], and D4.13 “Report on customer acceptance and satisfaction”[1] [6]. Regarding the other SMILE work packages, it also receives inputs from WP9 and WP6, particularly D9.5 Replication plans for all individual technologies [7] and D6.1 Report on selected evaluation indicators [8].

[1] Deliverable D4.13 “Report on customer acceptance and satisfaction” is classified as confidential and, therefore, it will not be publicly available for consultation.

2 Description of the proposed solutions

Due to its remote location, the power grid of Madeira is completely isolated – i.e., the island is not electrically connected to the mainland. In such a scenario, increasing the penetration of RES to achieve the desired 50% quota of renewables in the mix while maintaining grid stability is very challenging. The local demonstrator consists of the following three main solutions and has been designed to tackle such a challenge:

- "*DSM and BESS for optimizing self-consumption*": focus of this solution is the optimization of self-consumption of the so-called UPACs – i.e., small PV generation units that operate in self-consumption regime only, without the possibility to inject excess production into the grid.
- "*Voltage control and peak-shaving*": this solution aims to provide load-levelling and voltage control services at the distribution network level.
- "*Smart charging of EVs*": it consists of a set of cheap and non-intrusive smart charging solutions suitable for different typologies of electric vehicles.

Although the proposed solutions can be replicated in other markets and geographic contexts individually, in the scope of the Madeira demonstrator, they have been deployed jointly and are regarded as the components of a high-level solution aimed at improving the overall grid performance. For this purpose, the systems are integrated into and managed by the Energy Management System (EMS) developed by PRSMA.

In the following sections, a description of the PRSMA EMS, as well as an overview of each solution and respective technical boundary conditions (i.e., minimum requirements) for its replication in another market is provided.

2.1 PRSMA Energy Management System

PRSMA Energy Management System (EMS) is the backbone of the Madeira demonstrator. It provides a hardware agnostic software solution for storing, accessing, and processing energy-related data collected from the pilot sites where each of the three above-mentioned solutions is being deployed.
Initially deployed to handle all the data collected, the EMS evolved into a more advanced system that provides:

- data access, query, and storage mechanisms.
- data processing functionalities e.g., it allows to calculate energy flows and different pricing options.
- a set of widgets that can be used to develop dashboards (Figure 2.1 and Figure 2.2) to visualize the stored - and processed - data (e.g., real-time and historical visualization of the UPACs' energy consumption and production patterns), as well as to handle data acquisition.
- remote, real-time control of the energy storage devices deployed at the pilot sites (solutions 1 and 2) - via third-party integration.
- remote control of EV charging infrastructures via third-party integration (solution 3).

The EMS was designed to be highly compatible with different third-party systems and technologies (e.g., BESS or energy monitoring systems), and easily upgraded with new features and data sources. In fact, additional web-services (e.g., for data processing) can be developed upon request.

Figure 2.1: Combination of UI widgets to provide a dashboard for UPACs comparing production and consumption data from two different weeks.

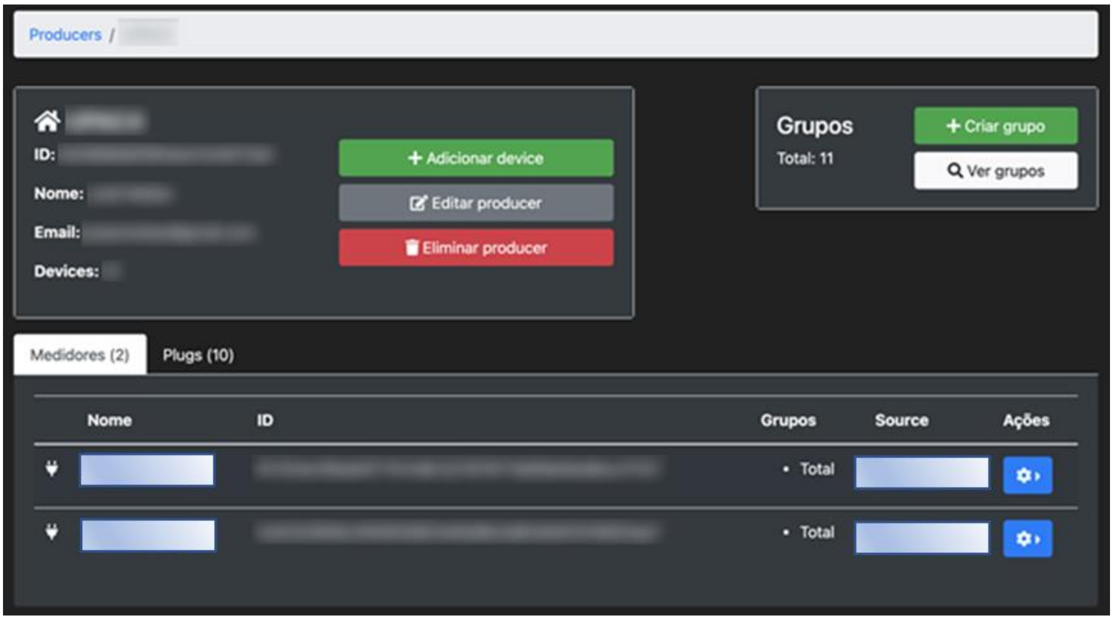

Figure 2.2: Data storage user interface for system administrators.

As mentioned above, the EMS can be considered as a key element of a high-level solution aimed at improving the overall grid performance, which integrates the three 'self-standing' solutions tested in Madeira:

- DSM and BESS for optimizing self-consumption;
- Voltage control and peak-shaving;
- Smart charging of EVs.

2.2 DSM and BESS for optimizing self-consumption

2.2.1 Value proposition and main functionalities

Goal of this solution is to optimize self-consumption from solar PV generation by providing real-time cloud-based control of Battery Energy Storage Systems (BESSs). Based on the user's production and consumption data, an algorithm running on the EMS manages charge and discharge of a BESS according to a set of control strategies. In the scope of the Madeira demonstrator, two control strategies have been developed:

- The greedy control algorithm: a standard operation strategy in self-consumption scenarios, which basically UPACs to store excess production for later use, thus maximizing self-consumption. As reported in [4], this strategy is particularly effective for households that have an over-sized PV installation and flat-rate energy tariff.
- The greedy control with pre-charge algorithm: this strategy aims at maximizing monetary savings rather than self-consumption and is meant for end users with Time-of-Use (ToU) tariffs. The standard greedy control is used only during peak hours while, during off-peak periods, the algorithm charges the battery from the grid - when the electricity price is lower. This second control strategy is particularly advantageous for commercial UPACs (that could use the electricity stored overnight to cover early morning loads) as well as under-sized domestic installations.

The main advantages of the solution are:

- compatibility with different monitoring and energy storage systems.
- the possibility of implementing several control strategies.
- it provides users with detailed energy feedback on production, consumption, and battery status, which can be accessed via a user-friendly web interface.

2.2.2 Target

This solution targets:

- commercial and domestic prosumers (whether they are UPACs allowed to inject energy surplus into the grid or UPACs restricted to self-consumption);
- local energy communities.

2.2.3 Components

- EMS;
- BESS control algorithms;

2.2.4 Requirements and limitations

The minimum requirements for implementing this solution are:

- internet connection;
- energy monitoring system (collecting consumption and, in case of a prosumer, also production data);
- communication gateway (in case the energy monitoring system do not provide access to consumption and production data);

- battery energy storage system.

Despite the EMS being highly compatible with several systems, the HW used should comply with the following requirements.

Monitoring equipment:

- Support communication through the ModBus protocol;
- Support documentation for the implementation of the ModBus protocol.

Communication gateway:

- allow the use of Modbus protocol.

BESS:

- Provide access to an interface (e.g., web APIs) for monitoring the BESS;
- Provide access to an interface (e.g., web APIs) for controlling the BESS.

2.3 Voltage control and peak-shaving

2.3.1 Value proposition and main functionalities

This solution aims to provide grid stability services, namely voltage support (particularly relevant for isolated power systems with high penetration of renewables from Distributed Energy Resources) and peak-shaving functionalities. This output is achieved by deploying a BESS at the low-voltage distribution network level, which is operated by control algorithms running on the EMS. The algorithms trigger real-time events based on the grid status when selected metrics are outside predefined (and configurable) thresholds.

In Madeira, the solution is being deployed at Fazendiha, a LV distribution sub-station that has a considerable amount of UPPs (i.e., generation units that, unlike UPACs, inject all the energy produced into the grid) connected to it.

The battery is there used as a highly responsive storage backup: (i) it is used to store excess production from UPPs so as to minimize the chance of voltage fluctuations due to the intermittency of renewable production, and (ii) in the case of an unexpected increase in the demand, it is discharged to flatten the load curve.

2.3.2 Target

The main target groups for this solution are:

- Network operators such as Distribution System Operators (DSOs) and Transmission System Operators (TSOs).
- Companies providing flexibility services to DSOs and TSOs.

In Madeira, the system is owned by Empresa de Eletricidade da Madeira (EEM), the local DSO. In this regard, it is important to point out that, with the 2019 Electricity Directive [9], network operators are not allowed to own and/or manage storage facilities since energy storage in the electricity system is considered a commercial activity. Nevertheless, as described in deliverable D7.1 [10], the new EU legal framework also provides some regimes of exception to this general rule. Madeira, for example, being an 'outermost region', on the basis of article 66 benefits from such a derogatory regime. Therefore, the best approach for replicating this solution should be verified case by case, depending on the local energy market and how the EU regulatory framework is applied.

2.3.3 Components

- EMS;
- BESS control algorithm.

2.3.4 Requirements and limitations

To be implemented, this solution requires:

- internet connection;
- monitoring equipment (power quality and energy analyzer);
- communication gateway (to communicate with the power quality and energy analyzer);
- battery energy storage system;
- a set of grid quality or general heuristics provided by the TSO, which serve as an input to control the charge/discharge of the BESS.

Despite our EMS being highly compatible with several systems, the HW used should comply with the following requirements.

Monitoring equipment:

- allow for real-time (1 Hz) data measuring and communication;
- allow for high-frequency data storage (kHz) when a pre-configured event is detected;
- allow for instant actuation (few milliseconds) on the Direct Current (DC) output relay signal when a certain pre-configured event is triggered;
- capability to handle the nominal current and voltage requirements of the secondary winding of the substation transformer;
- capability to measure the following data:
- Voltage (in volts);
- Current (in Amps);
- Real power (in Watts);
- Reactive Power (in Var);
- Apparent Power (in VA);
- Power factor (value from 0 to 1);
- Frequency (in Hz).

Communication gateway:

- allow the use of TCP/IP Modbus protocol.

BESS:

- Provide access to an interface (e.g., web APIs) for monitoring the BESS;
- Provide access to an interface (e.g., web APIs) for controlling the BESS.

2.4 Smart charging of EVs

2.4.1 Value proposition and main functionalities

The third solution aims to provide smart charging mechanisms through non-intrusive and cheap systems that allow to take control of the ON/OFF status of the charge. In particular, it:

- allows to implement different charging strategies (e.g., based on pricing, electricity demand, renewable availability, or aggregated energy consumption in the building) and manage the charging of multiple vehicles at the same time.
- provides feedback on energy consumption (via a web app) [11] and vehicle(s) charging status (via web-app and a mobile application) [11-12].
- is highly compatible with different off-the-shelf chargers and plugs - thus, it can be used to retrofit existing installations.
- allows end-users to manually control and schedule the charging via a user-friendly web interface (through the EMS).
- allows to manage the charging so as to provide demand response service to the grid.

In Madeira, the solution has been deployed in two different pilot sites, to manage the charging of full-fledged and small electric vehicles respectively. From the HW standpoint, the system used to provide smart charging for small electric vehicles (e.g., electric scooter) is entirely based on off-the-shelf hardware components. On the contrary, the system used for full-fledged EVs relies on custom-made hardware solutions (here referred to as the adaptor).

2.4.2 Target

- Businesses or public entities owning a fleet of full-fledged or small EVs;
- EVs owners;
- EVs charging stations operators.

2.4.3 Components

SW side:
- EMS.
- charging algorithms;

HW side:
- adaptor/actuator (which varies depending on the type of charger).

2.4.4 Requirements and limitations

To be implemented, the solution requires:
- internet connection;
- monitoring equipment;
- communication gateway.

Despite our EMS being highly compatible with several systems, the communication gateway should allow the use of Modbus protocol.

3 Methodology

This section describes the methodology adopted for the RA. The following sections address respectively:

- background research;
- description of the framework and the methodology used to conduct the analysis;
- selection criteria used to identify the sites for the RA.

3.1 Background research

In order to identify a framework for assessing the replication potential of the proposed solutions within the national and international markets, a review of existing projects and relevant scientific literature was performed with the goal of getting a better understanding of the methodology commonly used for replicability analysis smart grid projects. In particular, the focus was on four contributions (two scientific articles [1-2] and two EU research projects: InteGrid [13] and Grid4EU [14-17]) whose approaches to RA are briefly explained below.

Sigrist and colleagues [1] stress the importance of concepts like scalability and replicability to prevent smart grid project demonstrators from remaining local experimental exercises. For this reason, the authors identified a set of factors that may influence scalability and replicability of such projects. These factors have been first identified through an extensive literature review and ultimately assessed by means of a set of questionnaires submitted to coordinators and leaders of smart grid project demonstrators. Specifically, the authors have found that the degree of replicability of a smart grid project - "the property of a system that allows it to be duplicated at another location or time" - depends on factors belonging to four main domains: technical, economic, regulatory and stakeholder acceptance. According to their framework:

- Technical factors determine whether the solution developed in a particular setting is inherently replicable (e.g., standard-compliant and interoperable with the existing infrastructure) in another area.
- Economic factors determine whether it is economically viable to replicate the solution proposed in another setting.
- Regulatory factors describe the extent to which the regulations in force in the new setting allow a given solution to be replicated.
- Stakeholders' acceptance factors define the extent to which the local stakeholders are willing to adopt a given solution.

The framework proposed by Sigrist et al. aims at providing a flexible tool to quantify the degree of scalability and replicability of on-going and new projects and is summarized in Figure 3.1.
Furthermore, the results of their study (i.e., the feedback collected via questionnaires) suggest that regulatory and stakeholder acceptance factors are the most important aspects to consider when it comes to replicating a solution in a new setting.

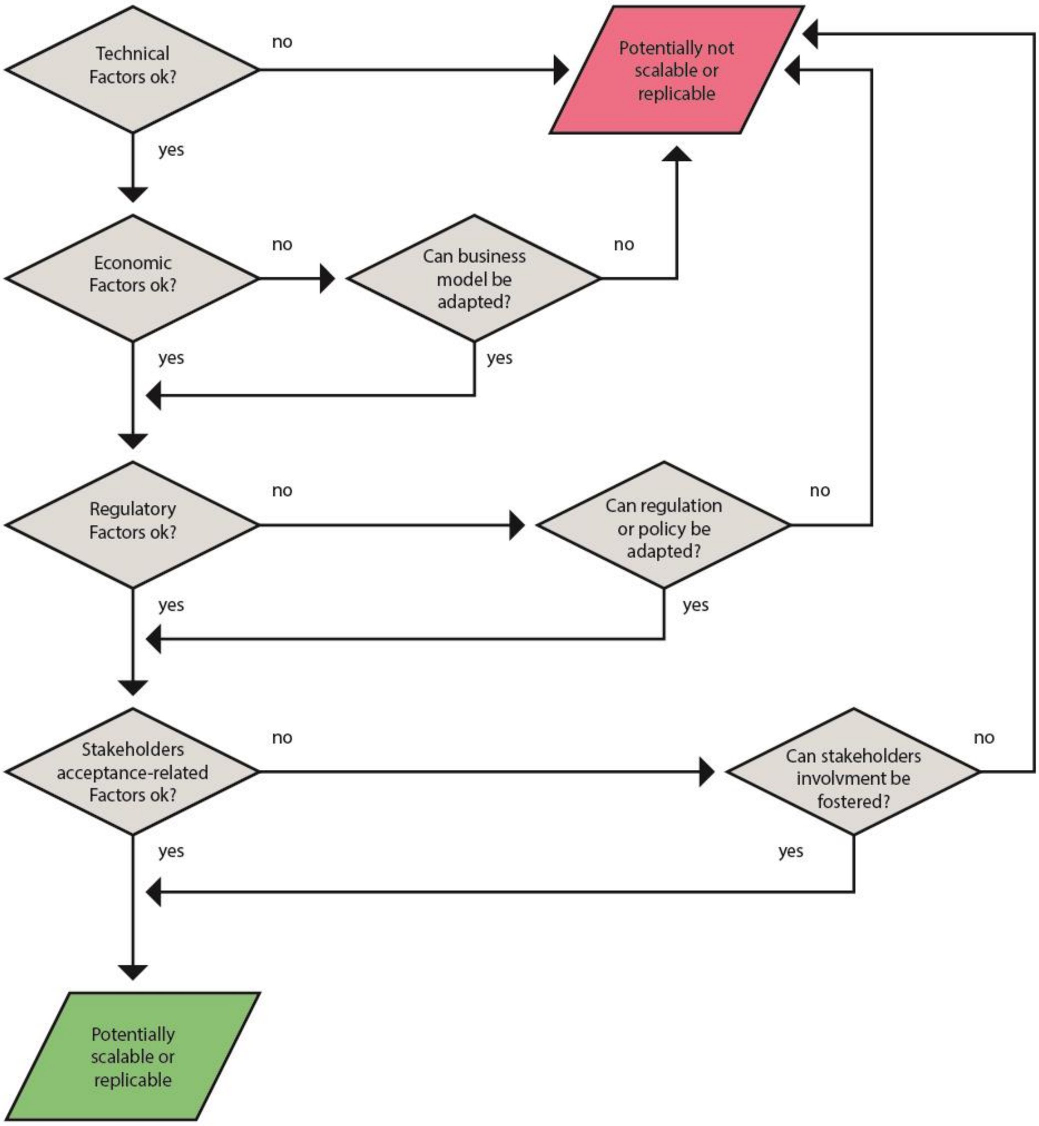

Figure 3.1: Overview of the methodology for assessing the factors

The importance of considering social acceptance to ensure the successful implementation of smart grid solutions is also highlighted by Curtius et al. [2]. This work aims to define a set of customer value-based market segments and business models for smart grid products and services. Despite not being explicitly focused on replicability analysis, the study provides very useful insights on the aspects that influence market acceptance and, ultimately, the adoption of smart grid solutions. In fact, the authors identify three important drivers for smart grid development and implementation:

- technological drivers;
- political drivers; and
- market drivers.

Market drivers are key elements of their business models and are defined by a two-axis framework that distinguishes two sub-dimensions:

- social acceptance (i.e., degree of involvement with sustainability issues); and
- economic viability of smart grid products.

The InteGrid project's [13] approach to Scalability and Replicability Analysis (SRA) is very similar to those described above (and heavily based on the methodology developed by the Grid4EU consortium). The InteGrid framework covers the following domains:

- technical, divided into
    - functional (related to the expected performance of a given solution); and
    - ICT (related to the barriers and constraints which could preclude scalability or/and replicability of the ICT-architecture needed to deploy a given solution);
- economic; and
- regulatory.

The methodology used by InteGrid for the SRA consists of the following steps:

- Pre-evaluation: including (i) analysis of the project's use cases/solutions to identify the most promising ones for the SRA, (ii) selection of the sites for the analysis (in addition to the three demo countries), and (iii) definition of the most important factors that would influence scalability / replicability of the project's use cases. As part of this step, for each domain, they have been identified both input factors (qualitative) to be considered for the SRA, and expected outputs of the analysis - either qualitative or quantitative (i.e., KPIs) depending on the domain.
- Definition of simulation scenarios to be used for the functionality-oriented and economic-oriented SRA.
- SRA (technical-, economic-, and regulatory-oriented analysis) for each of the proposed solutions.

The SRA methodology adopted by the InteGrid project aims at providing as many quantitative results as possible. For what concerns the Replicability Analysis (RA), the expected outputs, for each domain, are the following:

- Technical Functionality-oriented RA: outputs of the functionality-oriented RA will be quantitative KPIs produced by means of simulations for each of the simulation scenarios created.
- Technical ICT-oriented RA: The goal of the ICT-oriented RA is to identify and highlight barriers and constraints which could preclude the replicability of the proposed solutions. It consists in the qualitative-based assessment of the interoperability and interchangeability of the system architecture.
- Economic-oriented RA: it consists of an investment analysis performed for each of the simulation scenarios created. Specifically, it calculates standard economic KPIs such as Net-Present Value (NPV) and Internal Rate of Return (IRR). Despite the analysis being inherently quantitative, it is pointed out that (due to lack of data) the conclusions shall be considered as a qualitative evaluation of the potential for replicability of the proposed solutions.
- Regulatory-oriented RA: as for the ICT-oriented RA, the regulatory-oriented RA is a qualitative-based assessment. The goal of this analysis is to identify barriers and drivers embedded in the regulation that might hamper, enable, or promote the replication of the project's solutions.

Finally, the Grid4EU project studies international and intranational scalability and replicability under the main focus of technical and non-technical (regulatory, economic, and acceptance related) barriers and drivers [14-15].
The goal of this analysis was twofold [16]:

- assessing the technical impacts on distribution networks of the smart grid solutions proposed. This assessment results from quantitative simulation-based analysis and is measured through a set of KPIs.
- assessing the effect of non-technical boundary conditions on such a technical impact. This assessment, on the contrary, consists of a qualitative evaluation of a list of non-technical aspects conducted to understand (i) whether they represent barriers, enablers and drivers for

the scalability and replicability of the proposed solutions, and consequently (ii) to what extent they could affect the KPIs values resulting from the above-mentioned simulation-based analysis.

A slightly different approach was adopted for the analysis of Grid4EU replicability in non-EU contexts [17]. Results of this analysis are derived from a qualitative assessment of the technical and non-technical boundary conditions of the selected sites (California in the U.S.A. and Brazil) and are based on the lessons learned from the SRA at the EU level. This work relies on the relevant information publicly available and, despite not producing any quantifiable results, provides a clear and holistic picture of the replication potential of the Grid4Eu demonstrators in very diverse contexts.

3.2 Framework and proposed methodology

The existing literature proposes several frameworks to assess the replication potential of smart grid project demonstrators. All the proposed frameworks are intended to be general schemes that must be adapted to the specific characteristics of each project. Despite some obvious differences in the approaches adopted by different authors, there seems to be a certain degree of agreement in performing replicability analysis under four main domains: technical, regulatory, social, and economic. Our approach to the RA is based on such categorization. Specifically, our framework (summarized in Figure 3.2) defines a set of influencing factors that belong to three main domains:

- technical - i.e., the technical parameters associated with the distribution networks as well as the network users that may affect the replicability of the use cases under consideration;
- regulatory - i.e., the regulatory framework in force in the selected sites; and
- socio-economic - i.e., energy market model and socio-economic status of the target population. In line with [2], the socio-economic domain is here considered as the one that determines the (potential) stakeholder acceptance and, together with the technical and regulatory boundary conditions, ultimately define a set of qualitative indicators of the replication potential of our solutions in the target sites.

Technical Factors +
Regulatory Factors +
MARKET ACCEPTANCE (Social + Economic Factors) =

REPLICABILITY

Figure 3.2: The framework adopted for the analysis.

The output of our RA will be quite similar to the one reported in deliverable D3.8 of the Grid4Eu project [17], which analyzes the replicability of the project solutions in non-EU contexts. Indeed, instead of attempting a quantitative simulation-based analysis, we opted for a qualitative assessment of the replication potential of our solutions under the three main domains identified. This choice was made because collecting the information and data needed for a quantitative analysis would have been a very complex task, and chances were that, due to the lack of data, results from such a quantitative assessment should have anyway been considered as a qualitative evaluation. Therefore, this report aims at providing a holistic overview of the main barriers, enablers, and drivers for replicating Madeira solutions in the selected sites, and is based on the publicly available information on technical, socio-economic and regulatory boundary conditions specific to each site.
The methodology for the proposed RA has several overlaps with the InteGrid [13] project and consists of the following consecutive steps:

- Pre-evaluation: this initial step lies the basis for the RA and consists in the definition of the solutions to be replicated, including value propositions, target groups, requirements, and limitations (see section 2);
- Definition of the framework for the analysis: this second step has been informed by the results from both review of relevant literature and pre-evaluation of the proposed solutions, and resulted in a list of the main influencing factors belonging to each domain (see section 3.2.1). As part of this step, we have defined the selection criteria used to identify the target sites for the RA (see section 3.3).
- Data collection and analysis (results from the analysis are reported in chapter 4 and discussed in chapter 5).

3.2.1 The framework: influencing factors for each domain

As mentioned above, a set of factors (for each domain) that may influence the replicability potential of the proposed solutions in other contexts have been identified. These factors, whose definition has been kept intentionally general so as to adapt to the specificities (whether they are technical, regulatory, or socio-economic) of the target sites, are reported and explained in the sections below.

3.2.1.1 Technical dimension

Factors included in the technical domain relate to the technical parameters associated with the distribution networks as well as the network users that may affect the replicability of the use cases under consideration.

- **Distribution network configuration and operation**: this factor relates to the characteristics of the distribution network such as network design and physical constraints, generation mix, performance indicators (e.g., network losses, continuity of the supply, voltage variations, etc.), smart metering status, and users characteristics (e.g., consumption mix, load profiles, share of DER and degree of self-supply, etc.);
- **Electric mobility infrastructure and penetration**: information describing the state-of-the-art in terms of electric mobility (e.g., number and characteristics of public charging stations, charging patterns, EVs penetration, etc.).
- **Standardization and interoperability**: to what extent our solutions integrate into the existing infrastructure.

3.2.1.2 Regulatory dimension

This domain relates to the (national and/or local) regulatory framework in force in the selected sites and describes the extent to which such a framework allows a given solution to be replicated. The factors included in this domain address the following topics:

- **distribution regulation**: for example, local grid balancing legal framework, micro-grids legal framework, quality of service policies and regulations, policies for reduction of CO_2 emissions, etc.
- **smart meter deployment**: for example, smart meter deployment policies, local deployment strategies, common metering technical functionalities or individual requirements, as well as regulations related to data monitoring and ownership.
- **RES promotion policies and incentives for smart grid demonstration projects**;
- **electric mobility regulation**: including incentives and policies for promoting electric mobility, and V2G legislation.

- **treatment of DG units**: this includes self-consumption regulation, connection of DG units to the distribution grid, renewable energy targets at retail and self-generation level, placements and sizing of DG units, grid code specifications, incentives and regulations about energy storage (storage application/location - such as transmission, distribution, and customer storage -, requirements and installed capacity allowed), and additional rules/policies related to the landscape impact of DG assets.

3.2.1.3 Socio-economic dimension

The socio-economic domain includes a set of factors describing both the energy market model and the socio-economic status of the population of the target sites. These factors are:

- **Macro-economy**: describing the potential impact that the proposed solutions might have on the island economy (e.g., new job creation, sustainable tourism market development) and, more in general, to their economic viability/profitability (e.g., in terms of reduction of power and/or fossil fuel that has to be purchased from the mainland for transportation and power generation).
- **Micro-economy**: this factor relates to the individual financial attributes that are likely to impact people's willingness to invest in EVs and/or DG: e.g., employment rate, average salary and purchasing power of the target population, cost of energy, cost of fuel, profitability of the investment, etc.
- **Market design**: bundling vs. unbundling, market players and how they interact, bidding strategies and tariff structure (e.g., cost of energy, whether there are feed-in tariffs, taxes, or subsidy schemes), incentives/penalties to improve network performance and/or quality of the supply, etc.
- **Community engagement and sustainability education**: this factor defines the degree of involvement of relevant stakeholders (e.g., citizens, cooperatives, municipalities, etc.) in sustainability projects and/or initiatives to foster energy efficiency and/or improve sustainability education.
- **People's attitude towards sustainability and energy efficiency**: acceptance and adoption rates of AMI, EVs, DG (particularly photovoltaic), DR, and BESS. In assessing this factor, we will also consider any reported concerns regarding, for instance, the landscape impact of DG assets (e.g., solar PV) or AMI and data privacy protection.

3.3 Sites selection

As previously mentioned, to assess the replication possibilities of SMILE Madeira solutions within the national and international markets, it was decided to carry out this analysis focusing on one island for each of the countries members of the SMILE consortium (Portugal, Scotland, Denmark, Italy, Greece, and the Netherlands). This choice is due to the need for covering very diverse contexts while keeping the task of information gathering manageable. The differences in terms of policies, regulations, energy markets, as well as socio-economic characteristics of these countries make the sample diverse enough to represent the heterogeneity of the European context. Below, we briefly describe the main and secondary criteria used for selecting the target sites.

3.3.1 Main selection criteria

- **Energy self-sufficient islands**: given the isolated nature of its electric grid, most of the solutions tested in Madeira are particularly suited to address the issues characterizing those islands that are not connected to mainland energy distribution grids (e.g., the phenomenon of voltage

increase which is commonly associated with the increase of DER). Therefore, in order to fully explore the replication possibilities of the proposed solutions, and particularly the 'voltage control and peak shaving' pilot, it was decided to select islands that are disconnected (completely or partially - i.e., with a very limited connection to the mainland energy system) or aiming at becoming 100% energy self-sufficient despite being grid-connected.
- **Information availability**: another fundamental selection criterion was the amount of relevant and reliable information (published, for example, by regulators and institutions) publicly available.

3.3.2 Additional selection criteria

In case a country has more than one island that meets the main selection criteria, the following aspects were taken into consideration for selecting the target site:
- **Solar PV penetration**: since two out of three solutions focus on solar PV generation, we opted for islands with the highest penetration, either actual or potential, of solar PV generation.
- **Market dimension and demand for smart grid solutions**: when selecting the sites for this analysis we opted, when possible, for those islands with bigger market potential - i.e., with more population and/or involved in other projects or initiatives aimed at fostering the introduction of smart grid technologies and increase consumption from renewable energy sources.
- **EVs penetration**: since one of our solutions aims at achieving smart charging of EVs, we opted for islands with the highest penetration of EVs and/or involved in initiatives aimed at fostering electric mobility.

4 Results

The application of the criteria described in section 3.3 led to the selection of the following replication sites:

- Santa Maria island - Azores archipelago, Portugal
- Pantelleria island – Italy
- Astypalea island – Greece
- Ærø island – Denmark
- Texel island - The Netherlands
- The Shetland islands – Scotland

The technical, regulatory, and socio-economic boundary conditions of these sites have been analysed through desk research. Results from the research are reported in the following pages and briefly discussed in section 5. The qualitative analysis here reported was conducted with the only goal of identifying potential barriers and drivers for replicating the proposed solutions. Therefore, it should be by no means intended as replication plan.

4.1 Santa Maria island - Azores archipelago, Portugal

Santa Maria belongs to the eastern group of the Azores, a Portuguese archipelago that comprises nine islands. The island is located 80 km from São Miguel and 1460 km from the mainland. It has a surface area of 97,4 km² and a total of 5.552 inhabitants [18]. Like all the Azores, Santa Maria is not interconnected and, due to the high solar irradiation, it is known as the "Sunny Island" of the archipelago [19].

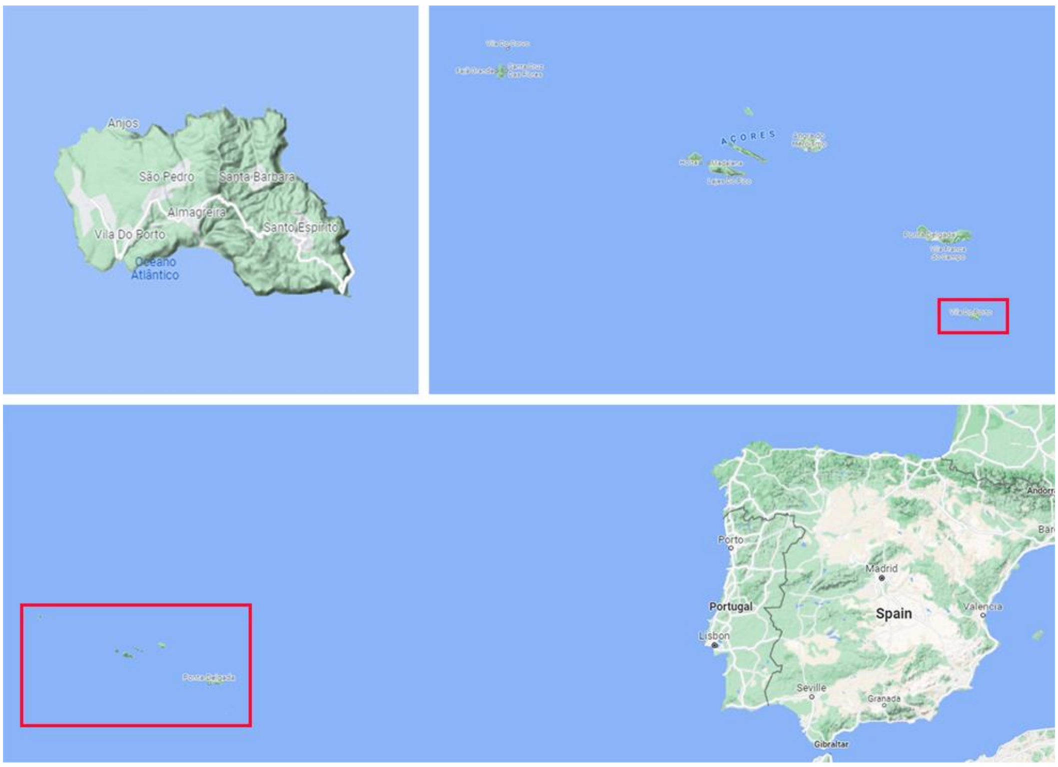

Figure 4.1: Location of the Azores Archipelago (bottom). Map of Santa Maria Island (top-left) and its location within the Archipelago (top-right)

4.1.1 Technical domain

Distribution network:

Eletricidade dos Açores (EDA, S.A.) is the entity responsible for producing, distributing, and supplying electric energy in all the nine islands of the archipelago [20].

The electricity supply on Santa Maria island is provided by two main sources: a 10 MVA diesel-fueled power plant and a 1,60 MVA wind farm, for a total of 11,60 MVA installed capacity. The wind farm – located in Figueiral – was built in 1988 and was the first wind farm of the archipelago. The distribution network of the island operates at both MV (10 kV) and LV (0,4 kV) [21]. The electrical MV networks of Santa Maria Island consist mainly of aerial lines, while underground cables are used in the area around the diesel-fuelled power plant, located in Vila do Porto, the capital of the island (Figure 4.2). Given the residual amount of RES in the grid, all existing distribution substations operate at MV.

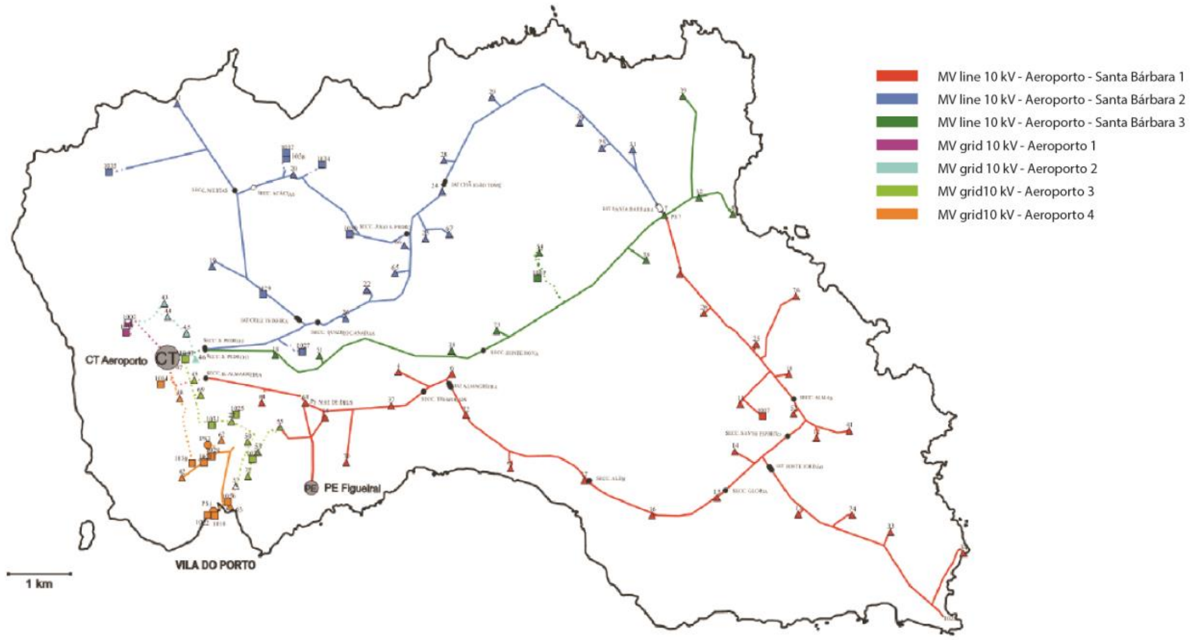

Figure 4.2: Geographical location of Santa Maria distribution network.

The current electrical network is outdated and consequently characterized by issues like power losses and discontinuity of the supply [21]. To help reducing such issues, two elevating substations have been installed at the two main generating stations to raise the voltage of the produced power. Yet, to address the current network constraints, EDA has included the renewal of the main lines in its plan of investments from 2021 to 2025 [21].

Concerning the energy mix, there has been an increase of RES in the archipelago, which accounted for 40,4% of the total energy produced in 2020 (see Figure 4.3). Nevertheless, generation from RES is not evenly distributed throughout the islands. In fact, only 12,6% of the electricity produced in Santa Maria Island comes from RES – i.e., wind (see Figure 4.3).

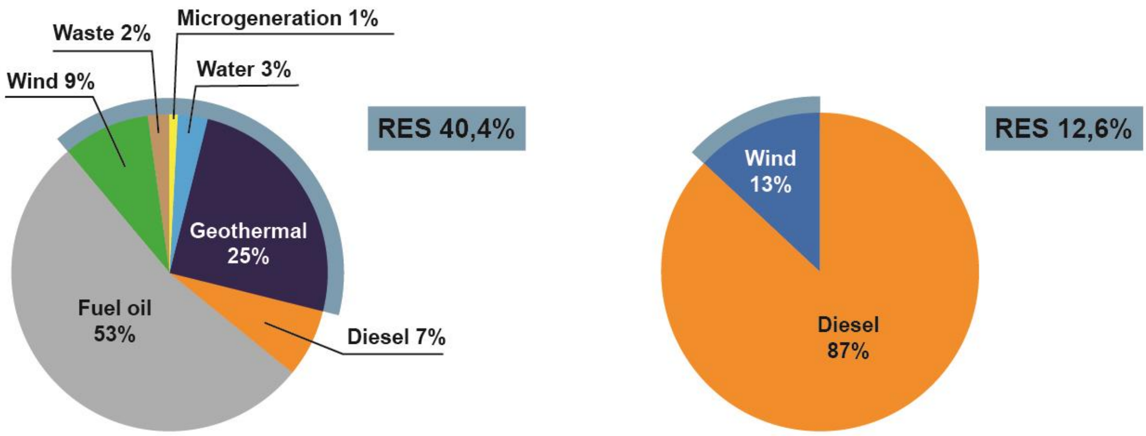

Figure 4.3: Energy mix in the Azores 2020 (left). Energy mix of Santa Maria in 2020 (right).

Therefore, it is not surprising that Santa Maria is the fourth island of the archipelago for the amount of CO2 emissions (see Figure 4.4). CO2 emission is one of the main indicators used by the government of Azores to set priorities for the implementation of decarbonization strategies in the region [22]. On this regard, one of the measures to be implemented on Santa Maria Island in the scope of the Regional Energy Policy Strategy 2030 [23] consists in the installation of a medium-sized solar PV plant – expected to be operational by the end of 2021 – combined with energy storage.

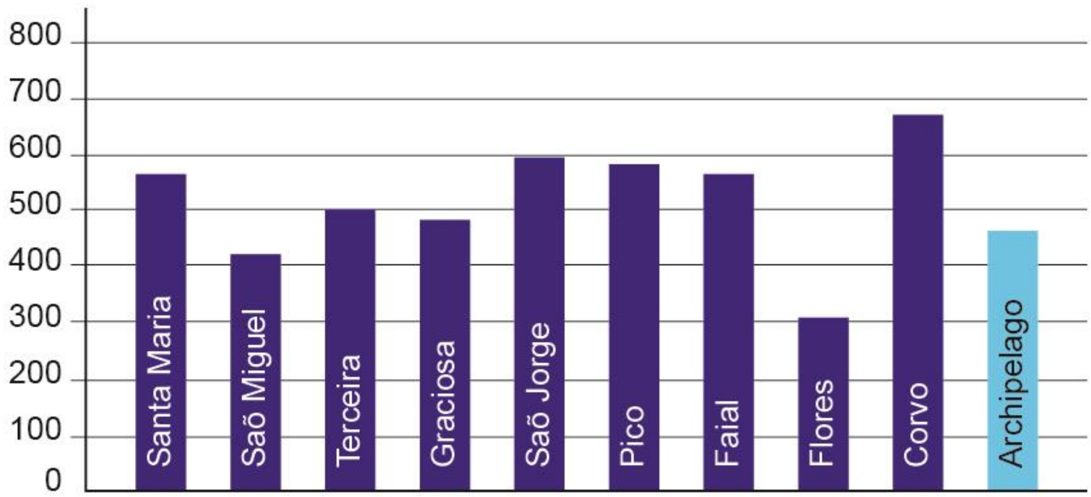

Figure 4.4: CO2 Emissions in the Azores Archipelago, in 2019 (gCO²/kWh).

Electricity demand and renewable energy:

Similarly to the other islands of the archipelago, most of the electricity demand in Santa Maria Island comes from commercial/service and residential sectors (see Figure 4.5 and Figure 4.6) [24].

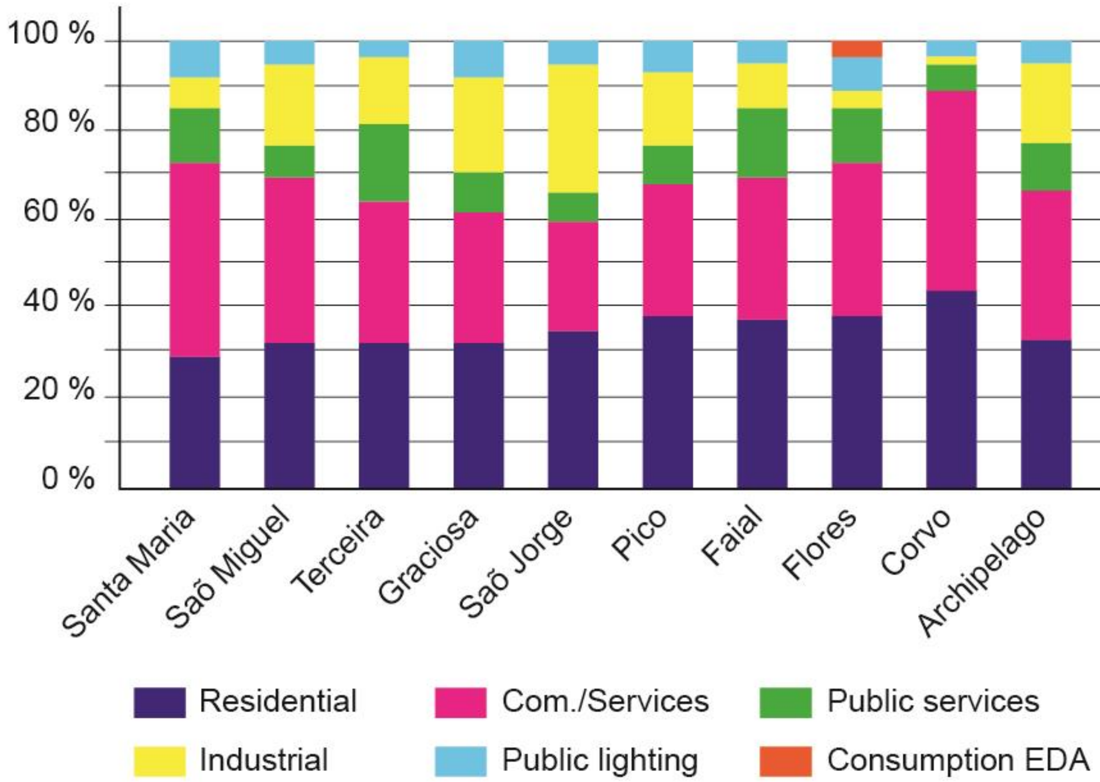

Figure 4.5: Electricity demand per sector in all the Azores islands (2017).

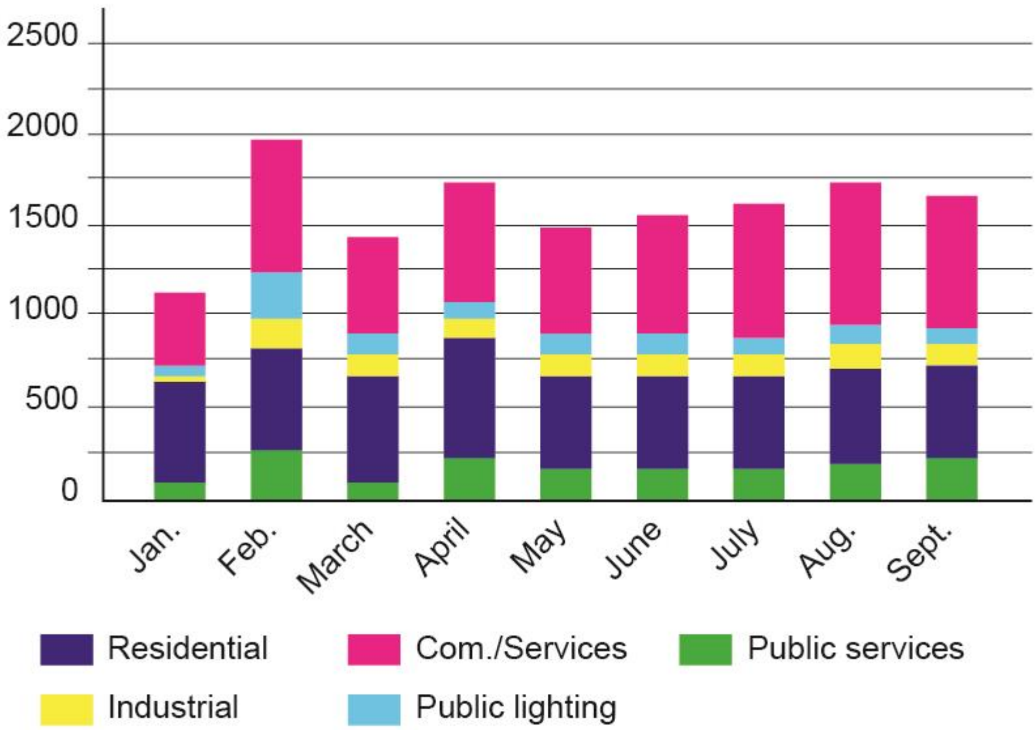

Figure 4.6: Electricity demand per sector in Santa Maria (Jan-Sep 2021).

Concerning the breakdown of renewable energy sources by type, it emerges that penetration of solar power in Santa Maria is still relatively low[2]. Nevertheless, the situation is expected to change soon, as the new solar PV plant will be fully operational by the end of 2021. In fact, the new generation facility - consisting of 2.160 PV panels with a total installed capacity of 734,4 kW - is expected to produce 1 GWh per year – enough to cover around 5% of the total electricity demand of the island [25]. Also, as shown in Figure 4.7, between 2020 and 2021 there has been an increase of 4,9% in distributed generation from solar [24]. Such an increase could be the result of the incentives provided by Regional Government (see section 4.1.2) and may indicate the beginning of a positive trend in solar PV adoption. On this regard, it should be pointed out the above-mentioned 4,9% of solar power does not include energy that was self-consumed.

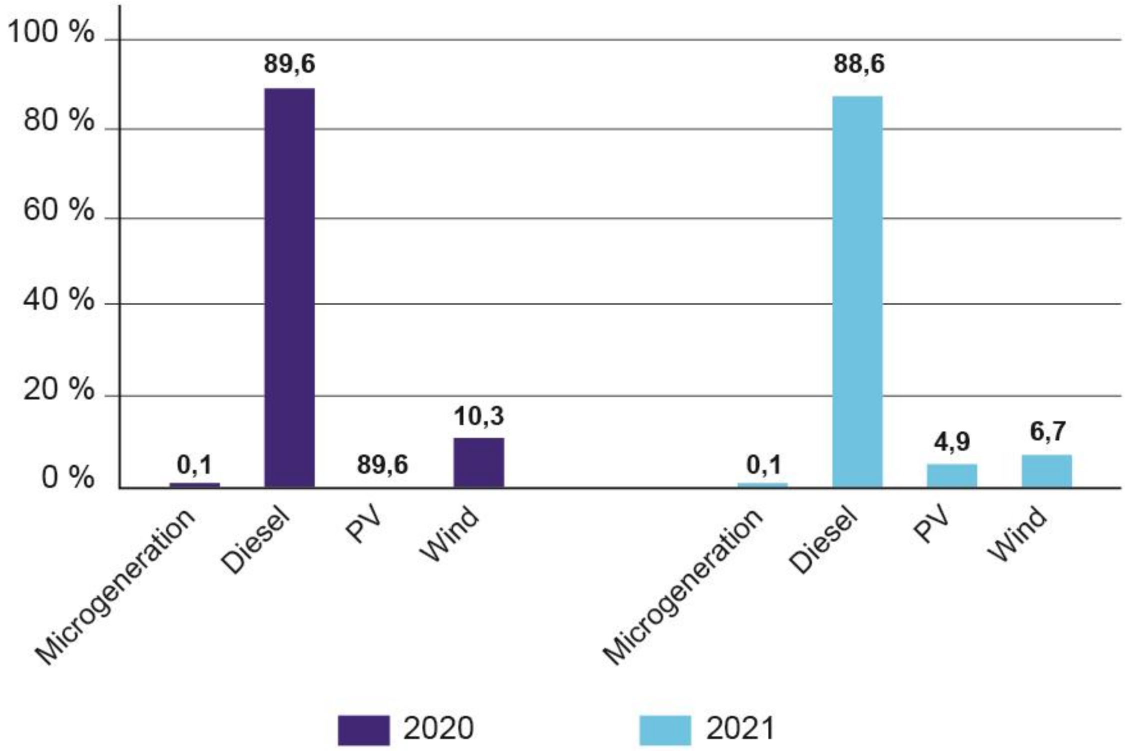

Figure 4.7: Evolution of energy generation sources in Santa Maria, September 2020-2021.

Information about the existing UPACs is limited, since registration of small-size PV installations has become mandatory only in 2019 [26]. The only data available regards the number of applications for PV financial incentives offered by the government, which led to the installations of five UPACs between 2017 and 2019 [27]. Nevertheless, accounting for the contribution of distributed solar generation in the energy mix, it is reasonable to assume that the number of new installations is higher than five.

Electric mobility infrastructure and penetration:
Electric mobility is still in an early stage in the Azores. Nevertheless, the regional government is planning to increase the amount of EVs and charging stations in all islands of the archipelago – targets for each island are set depending on the number of inhabitants. Moreover, the regional government

[2] It should be pointed out that there is no power generation from solar PV at all on 5 out of 9 islands in the archipelago [24].

is running a V2G pilot project in São Miguel Island, which was approved by ERSE and whose results are meant to inform future developments of such a business model nationwide [28].

Currently, the archipelago counts a total of 30 public EV charging stations performing both normal and fast charging; all operated by MOBI.E, S.A.: a public company that manages the energy and financial flows resulting from the operations of the electric mobility network [29]. The MOBI.E model is unique and innovative since "it was conceived with an open-access and market-oriented philosophy, with the goal of attracting private investors and benefiting the users" [30].

Santa Maria, as a medium-sized island, has four public charging stations of which only one performs fast charging. The remaining three charging stations – Pontos de Carregamento Normal (PCN) - must be equipped with at least 2 plugs or car connectors type 2, in compliance with the IEC 62196-25 standard, also known as "Mennekes" [31].

There is no data available about EV penetration in Santa Maria. Nevertheless, according to the mobility plan of the Azores archipelago [31], a significant evolution of the electric mobility sector is expected. Commissioned by the government, this document analyses the potential evolution of electric mobility over the next years along with the use of smart charging vs dumb charging. Results from the study suggest that the number of EVs in Santa Maria may reach 41 vehicles quota by 2024 and, most importantly, argue in favour of the implementation of smart charging – which is expected to reduce the electricity demand for EV charging (see Table 4.1 and Table 4.2). Additionally, increase adoption of EVs in the archipelago can help balance the electric system.

Table 4.1: Evolutive estimation of EVs in Azores from 2020 to 2024, Base and optimistic scenarios.

	S. Maria	S. Miguel	Terceira	S. Jorge	Pico	Faial	Flores	Corvo	Total
Base									
2020	4	239	66	3	15	12	2	1	348
2024	21	1.079	286	14	80	59	6	1	1.569
Optimistic									
2020	8	409	110	5	28	22	3	1	595
2024	41	2.088	550	26	157	114	12	2	3.034

Table 4.2: Results of the charge production diagram (kW), of EV charging in peak demand, in 2024, in Base scenario.

		Dumb Charging			Smart Charging		
Island	Total controlled power available	Season/Time	Peak Demand (kW)	% EV consumption	Season/Time	Peak Demand (kW)	% EV consumption
Santa Maria	6.907	Winter – 20:00	3.414	0,57%	Winter – 20:00	3.394	0,05%

Ultimately, a key factor that could influence widespread adoption of EVs in Santa Maria is the size of the road infrastructure. In fact, it was demonstrated that a full charge is enough to travel a circular circuit around the island [31].

4.1.2 Regulatory domain

The Azorean Directorate for Energy (Direção Regional de Energia) is the governmental entity responsible for all energy-related matters. Specifically, it:

- follows up all energy vectors within the Azores, as well as their local production and use
- oversees energy-related installations such as those of local electricity utilities.
- is responsible for adapting European and national legislation to the regional context as well as for proposing local ones.
- drives the regional programs for energy, namely, energy efficiency, renewable energy generation, energy transition and sustainable mobility programs, and is responsible for the promotion of energy literacy and cooperation with other regions.

All activities are conducted with the support of a widespread network of diverse stakeholders [32].

Electricity generation and storage:
In terms of self-consumption, the Azores archipelago follows the national legislation. Specifically, the Decree-Law nº162/2019 [33] and the rules mandated by the National Regulatory Authority of Energy (ERSE) under the regulation 2/2020 [34]. According to the DL 169/2019, UPACs - i.e., renewable energy production units for self-consumption primarily - are allowed not only to store excess production but also to feed/sell it to the grid [33]. Although this framework applies also to the Azores, there are some limitations. To inject electricity into the local grid a UPAC needs formal permission, which is granted only if the UPAC demonstrates to meet a set of technical parameters set by EDA [35]. This measure is meant to avoid potential grid stability issues that distributed generation could cause to isolated electricity grids. In terms of ownership of energy storage devices, the restriction imposed by the Article 36 "Ownership of energy storage facilities by distribution system operators" of the 2019 Electricity Directive [9] does not apply to Santa Maria. In fact, just like Madeira, the island benefits from a derogatory regime established by article 66 of the directive [9].

Incentives schemes:
Besides some national schemes for the promotion of renewable energy generation and electric mobility, the Azores benefit from a regional incentive scheme - "PROENERGIA" -, which was introduced in 2010 by the regional DL 5/2010/A [36]. The incentive scheme combines with other national incentives and aims to support (i) the installation of energy generation and storage (electricity and heating) technologies for self-consumption and (ii) the adoption of zero-emission vehicles (i.e., EVs). PROENERGIA is provided in the form of a non-repayable grant, whose amount varies depending on the type of technology acquired. In the case of a solar PV installation, for example, the grant covers 25% of the capital cost, up to a maximum set capping of 4.000€ per household. Concerning the electric mobility sector, the support mechanism can take two forms: tax exemption or financial incentives [37]. Financial incentives are provided to both households and companies for the purchase of electric vehicles (cars, bikes, or scooters) as well as the installations of EV charging facilities. Alternatively, the scheme provides for VAT exemption (applicable to both households and companies) and other tax regulation mechanisms (only for companies).

V2G deployment:
ERSE is the national regulatory authority for gas and electricity. As such, it also regulates the electric mobility sector (according to the disposition nº 203/2021 [38]) and is responsible for the implementation of V2G technologies. Although V2G applications have reached different levels of development in different regions of the country, the national regulator is committed to investigating the potential for large-scale implementation of this technology. In fact, in 2019 ERSE approved the pilot project "V2G Azores", which is being run on São Miguel Island to test potential business models for V2G applications [28].

Smart metering:
In Portugal, the smart meter rollout started in 2019 with the approval of Regulation nº 610/2019 - Regulamento dos Serviços das Redes Inteligentes de Distribuição de Energia Elétrica (Smart Electricity Distribution Network Services Regulation) [39]. In the Azores, however, the smart meter deployment is still in a pilot test stage. In fact, at the time of this writing, smart meters have been installed only on São Miguel Island under the scope of the `Smartmeter EDA´ project. Launched in 2019 by EDA, the project aims to integrate smart meters and associated devices, power line communication technology and an information system designed to manage energy data and interact with other services and applications provided by EDA [40]. So far, the project resulted in the installation of the following equipment:

- 287 smart meters;
- 5 Distribution Transformer Controller (DTC);
- 2 routers – GPRS.

Although the Smarmeter EDA project is currently being conducted only on São Miguel, it is planned to extend it to other islands of the archipelago. To this aim, EDA is currently conducting a technical assessment to verify the possibility of installing the monitoring equipment in other locations.

4.1.3 Socio-economic domain

The average individual income in Santa Maria (1.492,5€/month in 2019) is higher than both the national (1.209,9€/month) and regional one (1.100,5€/month) [41], while the purchase power in 2017 was the second highest in the Azores after Ilha do Faial [42]. These two economic indicators suggest that conditions for investments in renewable energy generation and EVs by islanders are favourable.
Agriculture and cattle production are the main economic activities of Santa Maria, followed by service and tourism sectors. An important niche of the local tourism market is represented by ecotourism[3] - defined as responsible travel to natural areas that conserve the environment, sustains the well-being of the local people, and involves interpretation and education. The Regional Tourism Authority is well-aware of the economic value of this market niche, as well as of its pivotal importance in fostering the adoption of sustainable practices by locals. For this reason, it has launched the "Ponto Único" initiative [19], consisting in a set of information kiosks located across the islands of the archipelago where both tourists and locals can learn more about the advantages of owning an electric vehicle.

Market design:
Eletricidade dos Açores (EDA) is the only DSO in Santa Maria and is responsible for all the activities related to production, distribution and supply of electricity. Since 2002, with the publication of the Decree-Law n.º 69/2002, EDA is being controlled and regulated by ERSE, the national regulatory authority for gas and electricity. The additional costs incurred by EDA for operating this isolated energy system are covered by a cross-subsidy financed by a levy on the energy bills off all customers in the mainland [44].
The same electricity tariffs apply to all islands in the Azores. Specifically, consumers can choose between three tariffs: (i) single-rate, (ii) 2-ToU, and (iii) 3-ToU tariffs [45]. Additionally, there is a `social tariff´ targeting the more vulnerable consumers – e.g., lower income households -, which provides a 13,8% discount on the bill [46]. Overall, the electricity prices in the Azores are higher than those of

[3] The Azores is the first archipelago certified as a sustainable tourist destination by the Global Sustainable Tourism Council [43].

Portugal mainland which, in its turn, is among the EU countries with highest electricity costs (mainly due to taxes).

Community engagement and attitude towards sustainability:
Together with all the other islands of the archipelago, Santa Maria is involved in several national and EU projects aimed at fostering sustainability and energy transition. Among them, the following are particularly relevant for the purpose of this analysis:
LIFE IP CLIMAZ - aims to support implementation of the regional climate change adaptation strategy and programme on the nine islands of the Azores, helping them adapt to and mitigate the effects of the changing climate. The project aims to: (i) increase knowledge about climate change within society, (ii) improve territorial resilience and adaptation capabilities, (iii) promote engagement and active participation of local communities and stakeholders, and (iv) facilitate the adoption of sustainable practices [47].
RESOR – the project aims at promoting best practices to support energy efficiency and renewable energy use by citizens and, especially, businesses of the secondary and tertiary sector in European islands and other remote regions by improving current regional policies. In the Azores, the project is specifically focused on (i) supporting the uptake of eco-efficient measures by businesses working in the tourism sector and (ii) promoting the adoption of more sustainable processes in the activities related to production, processing and marketing of agricultural products [48].
Clean Energy for EU Islands - in the scope of the initiative, the Azorean Directorate of Energy with support of the Clean Energy for EU Islands Secretariat have developed the energy transition agenda for the archipelago [49].
EMOBICITY - the main goal of this project is to facilitate the uptake of electric mobility in the participating countries/regions, by improving the local low-carbon economy policies. In the Azores, specifically, EMOBICITY aims to integrate the different policy and regional planning instruments related to climate change, electric mobility and energy efficiency into the Azores 2020 Operational Program [50].

The Regional Government is very committed in promoting energy education and sustainability. Hence, besides supporting the implementation of the above mentioned and other projects, is also carrying out campaigns to increase energy literacy among the local community and disseminate relevant information (e.g., [51]).
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4.2 Pantelleria – Italy

With a surface of 84,5 km2 and a population of around 7.500 inhabitants, Pantelleria is the fifth Italian island in size and the biggest among the twenty non-interconnected Small Italian Islands (Isole Minori Italiane - IMI) [52]. This volcanic island is located in the Strait of Sicily, at about 110 km southwest of Sicily and 65 km northeast of Tunisia [53]. Pantelleria is characterized by a Mediterranean climate, with warm summers and mild winters. Also, it has significant renewable energy potential. Among the IMIs, Pantelleria is indeed the first in terms of PV installed capacity [54] and, together with Lampedusa Island and the archipelagos of the Egadi and the Eolie, one of those with higher solar radiation [55].

Figure 4.8: Map and location of Pantelleria Island.

Like the other off-grid IMIs, Pantelleria is characterized by [56]:

- not having any connections to the mainland energy distribution grid;
- a high dependency of energy supply on fossil fuels, commonly transported by sea;
- frequent interruptions of the energy supply due to bad weather conditions and/or high fluctuation in the demand (tourist season vs. non-tourist season);

4.2.1 Technical domain

Distribution network configuration and operation

Due to its significant distance from the mainland, the energy supply on the island is a complex and expensive matter (both electricity and fossil fuels). Generation, distribution and network management are responsibilities of S.MED.E. Pantelleria S.p.A. The power network operates at MV (10.5 kV) and LV. It consists of 151 MV nodes, of which 133 are LV transformation substations, 2 are switching substations, 15 are MV end-users, and one is the main power plant.

Pantelleria is a popular summer holiday location. Between June and September, the number of tourists could reach peaks of 12000-15000 people per day [57]. For this reason, both power and energy demand vary greatly between the tourist and non-tourist seasons - e.g., the peak power demand (around 10 MW) is reached during summer, while the demand in winter is significantly lower (the overnight power demand is usually 2 MW) [55].

Most of the electricity supply is provided by a power plant consisting of eight diesel engines (total early generation of 39.000 MWh), situated in the city of Pantelleria. The power system is highly dependent on fossil fuels, which are transported by sea from Sicily [52-53]. In fact, although renewable sources such as solar (840 kW of installed capacity) and wind (32 kW of installed capacity) are part of the energy mix, they cover only 3,13% of the total energy demand of the island [52].

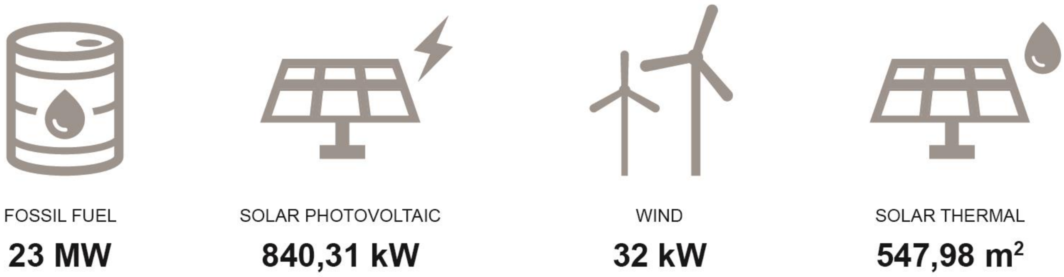

Figure 4.9: Energy generation in Pantelleria (main sources and installed capacity). Data source: Legambiente [52].

In such a scenario, unsurprisingly, electricity accounts for more than half of the total greenhouse gas emissions (see Figure 4.10).

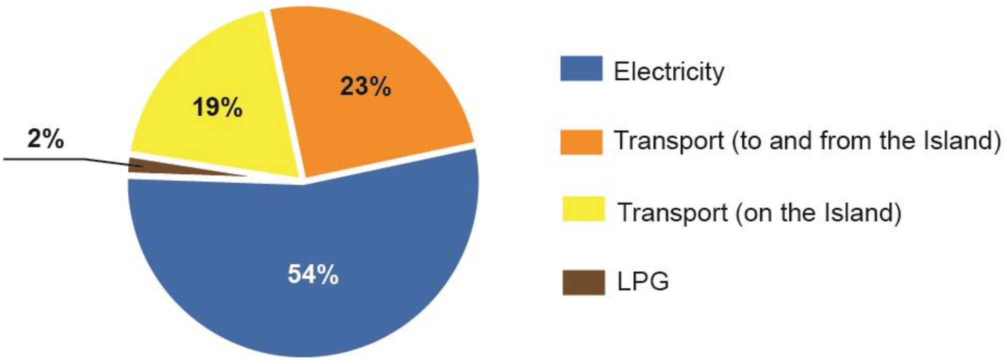

Figure 4.10: Breakdown of the greenhouse gas emissions. Data source: Pantelleria's Clean Energy Transition Agenda [53].

In terms of consumption, the most recent data was found in the Pantelleria's Clean Energy Transition Agenda [53] and refers to the year 2018 (see Table 4.3).

Table 4.3: Energy consumption in 2018

	Consumption (MWh)
Electricity	31067
Residential (LV)	11719
Public lighting (LV)	1000
Other uses (LV)	10191
Desalination (MV)	3749
Other uses (MV)	4408
Fossil fuels	40378
Petrol (transport)	19672

Diesel (transport)	16284
LPG (cooking)	4424
TOTAL	72439

As shown in Figure 4.11, electricity represented 43% of the total energy consumption of the island which, in its turn, was dominated by domestic consumption (38%) and services and tertiary sectors (33%).

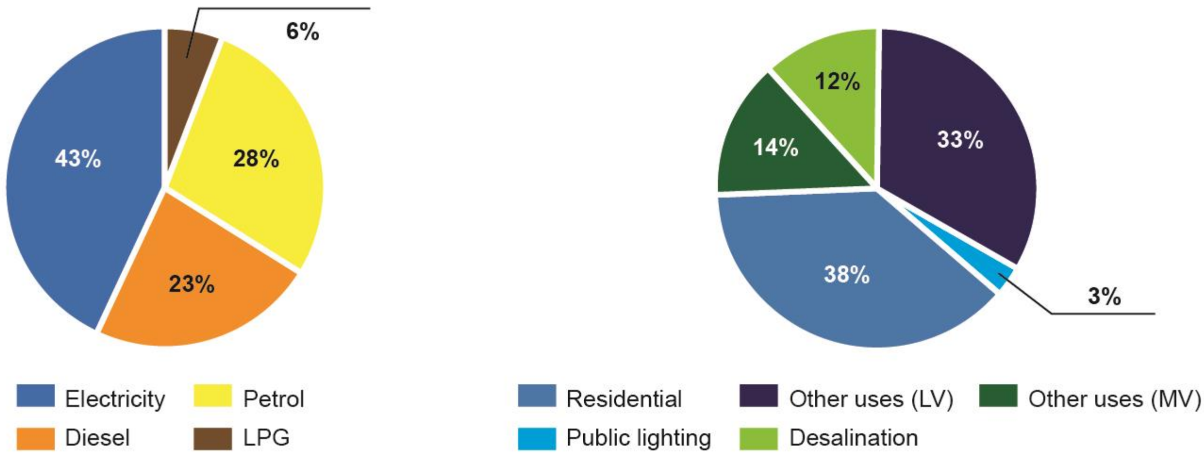

Figure 4.11: Total energy breakdown (left) and electricity consumption breakdown (right). Data source: Pantelleria's Clean Energy Transition Agenda [53].

As already mentioned, energy consumption is highly influenced by tourism and thus varies significantly throughout the year (see Figure 4.12) - for example, consumption in August 2018 was 60% higher than that of April 2018.

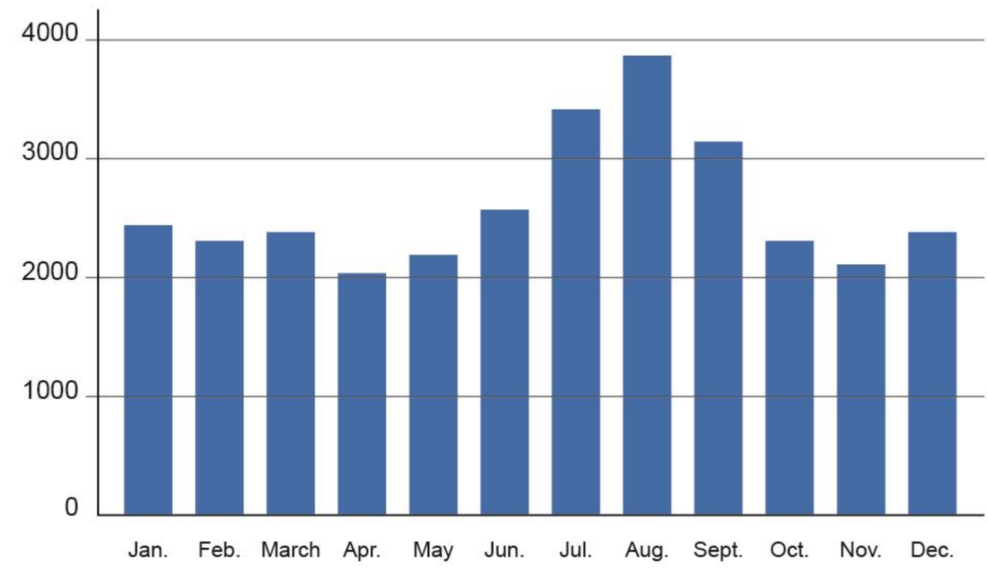

Figure 4.12: Monthly electricity consumption (MWh). Data source: Pantelleria's Clean Energy Transition Agenda [53].

Despite the integration of renewables into the energy mix being quite low, the potential for renewable energy generation (particularly solar and wind) in Pantelleria is significant, arguably among the highest in the country [53]. With an annual solar radiation above 2100 kWh/m2 [55], the potential solar generation is 1570 kWhel/kWp/a [57]. The South of the island and particularly the southern side of the mountain (around 840 mt above sea level) are the most suitable areas for solar PV generation. In 2019, the Italian Agency for new technologies, energy and sustainable development (ENEA) conducted an assessment of the solar generation potential on the Island [57]. The study analyzes a scenario in which rooftop PV systems are installed on all residential and commercial buildings - excluding those located in areas subject to landscape constraints - assuming 18% efficiency offered by the solar panels and an overall system performance ratio of 75%. Results are reported in Table 4.4.

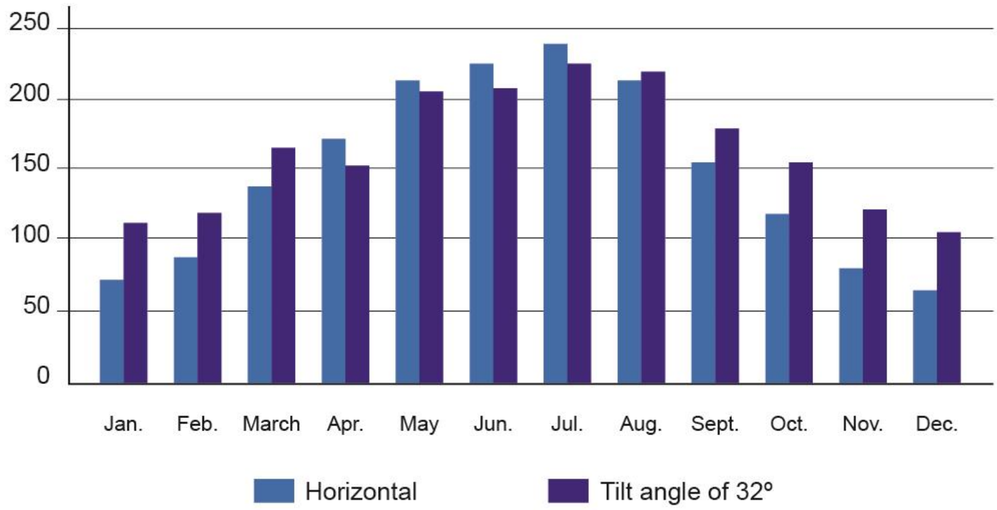

Figure 4.13: Monthly solar radiation in Pantelleria Island (horizontal and tilt angle) - Unit kWh/m2. Data source: Pantelleria's Clean Energy Transition Agenda [53].

Table 4.4: Results from the ENEA assessment of the solar generation potential on the Island. Data source: Associazione Nazionale Comuni Isole Minori (ANCIM) - ENEA [57].

	Potential production (kWh) - urban areas	**Potential production (kWh) - industrial areas**	**Potential production (kWh) - agricultural areas**	**Potential production (kWh) - TOTAL**
January	218.325,59	77.658,02	201.995,37	497.978,99
February	290.153,35	102.675,03	264.735,06	657.563,44
March	530.438,31	186.599,61	478.285,32	1.195.323,25
April	672.598,77	235.253,50	595.724,58	1.503.576,85
May	726.515,22	253.212,91	635.678,81	1.615.406,95
June	743.425,63	258.648,73	646.948,20	1.649.022,56
July	747.279,33	260.222,00	652.075,04	1.659.576,37
August	656.063,51	229.324,14	579.244,28	1.464.631,93
September	579.457,01	203.485,63	519.620,88	1.302.563,53

October	397.235,94	140.358,36	363.580,71	901.175,02
November	230.817,51	82.004,66	212.910,13	525.732,30
December	189.200,95	67.379,01	175.864,25	432.444,21
YEAR	**5.981.511,13**	**2.096.821,62**	**5.326.662,64**	**13.404.995,40**

Mobility:
In terms of mobility, it seems that in Pantelleria there is a reliance on older vehicles (see Table 4.5). In 2019, only 1246 of the 6262 licensed and registered vehicles were either 'euro 5' or 'euro 6' (less than 20%). Also, as reported in [53], all the 7 busses operated by the local public transport company are classified as ‘euro 0’ according to the European emission standards.

Table 4.5: Number of licensed and registered vehicles (2019) divided per category according to the European emission standards. Data source: Automobile Club d'Italia (ACI) [58].

	Euro 0	Euro 1	Euro 2	Euro 3	Euro 4	Euro 5	Euro 6	Not defined	TOTAL
Nº of vehicles	822	243	1.014	1.171	1.761	605	643	3	6.262

The promotion of sustainable mobility is one the five pillars of the Energy Transition Strategy for Pantelleria. As reported in the draft of the Energy Transition Agenda [53], the actions under this pillar include:

- Replacement of the entire public transport fleet with electric busses;
- Progressive replacement of the vehicles owned by the local administration with zero-emission vehicles (i.e., electric);
- Installation of EV charging stations in main urban areas, tourists point of interests and at the airport;
- Foster car-sharing and electric car rental services;
- Attract regional funding to provide financial incentives for electric mobility.

Moreover, the agenda highlights the need for developing pilot projects targeting the local community and aimed at raising awareness of the economic and environmental benefits of replacing old vehicles with zero-emission alternatives.

It was not possible to find data about the penetration of electric vehicles on the island. However, based on the limited information publicly available, it seems that some of these actions have been taken. Regarding the replacement of the public transport fleet, an ordinance published on the website of the Municipality of Pantelleria mentions the purchase of two electric busses [59]. While a car-sharing service has been implemented in July 2021. The fleet currently consists of 10 Renault ZOE that can be picked-up/dropped-off at five different parking lots (supposedly all equipped with EV charging stations) [60]. Also, a Google search for car hire companies was performed. At the time of this writing, no electric vehicles are included in the fleet of the companies analyzed.
Given the lack of data, it is reasonable to assume that electric mobility has not yet taken off in Pantelleria. Nonetheless, considering the strong commitment to energy transition of local stakeholders, the penetration of EVs is expected to grow.

4.2.2 Regulatory domain

Solar PV and solar thermal systems:
The regulatory framework in force in Pantelleria presents some limitations to the installation of solar PV and solar thermal systems. In particular, the article 88 of the general zoning plan of the municipality of Pantelleria 2005-2014 - Piano Regolatore Generale (PRG) - prohibits the installation of solar (PV and thermal) panels on the roof of the so-called "dammusi" - a traditional building characterized by the peculiar shape of its roof. This restriction, indeed, is meant to avoid damage to the roof due to the installation of photovoltaic mounting systems. Additional restrictions are set by the Landscape Plan of Pantelleria – "*Piano territoriale paesistico dell'isola di Pantelleria"*. Concerning rooftop solar and wind power generators, limits the installation of any generators to urban settlements and nearest suburbs [53].

Incentives and remuneration schemes:
The Ministry Decree 14/02/17 [61] - Decreto "Isole Minori" - promotes the installation of domestic renewable energy generation systems on non-interconnected islands by introducing a remuneration scheme for electricity production and self-consumption. With the resolution 558/2018/R/EFR [62], the Energy Networks and Environment Regulator – "*Autorità di Regolazione per Energia Reti e Ambiente (ARERA)"* - has established such a remuneration scheme. According to the resolution, renewable energy producers can choose among two different tariffs [63]:

- a fixed feed-in tariff for the energy generated and fed into the grid. The tariff varies depending on the installed capacity. In the case of Pantelleria energy is remunerated as follow [53]:
  - 147,5 €/MWh and 211,4 €/MWh - installed capacity between 0,5 kW and 6 kW;
  - 134,1 €/MWh and 193,8 €/MWh - installed capacity above 6 kW up to 20 kW;
  - 124,9 €/MWh and 178,5 €/MWh - installed capacity above 20 kW up to 200 kW;
  - 116,7 €/MWh and 162,4 €/MWh - installed capacity above 200 kW;
- a premium feed-in tariff for self-consumed electricity, which is defined on a yearly basis [63].

Additional incentives have been established by the Ministry Decree 4/7/2019 [64] and the Interministerial Decree 16/02/2016 n.51 (Conto Termico 2.0) [65], which promote, respectively:

- installation of new renewable energy generation units, and;
- energy efficiency measures and small plants for the production of thermal energy from renewable sources.

4.2.3 Socio-economic domain

Micro-economy, macro-economy and energy market:
The average per capita income of Pantelleria is 14.500€ [52] (against a national average of 21.800 €[4]). A low per capita income usually translates into low purchasing power which, combined with regulatory and infrastructural constraints, may partially explain the low penetration of distributed energy generation and electric vehicles.
Given the insular nature of Pantelleria, the price for fossil fuels on the island is about 25% higher than the national average. In November 2019, for example, the price of diesel was 1,860€/l (against a national average of 1,471 €/l), while petrol price was set to 1,965 € per liter (national average 1,576 €/l) [52]. Concerning the electricity supply, the market in pantelleria is regulated. Electricity price is set by ARERA (Autorità di Regolazione per Energia Reti e Ambiente) and consumers can only choose

[4] http://avvisi.istat.it/

between single-rate and ToU tariffs. As an example, Table 4.6 reports the energy prices applied to consumers between July and September 2020.

Table 4.6: electricity prices in Pantelleria (July-September 2020). Data source: S.MED.E. PANTELLERIA S.p.a.[5]

	Single-rate tariff	ToU tariff	
		*Peak**	*Off-peak***
Electricity price (€/kWh)	0,04309	0,04516	0,04200

* Peak period: from 19:00 to 8:00.
** Off-peak period: from 8:00 to 19:00.

Because of the high dependency of the local energy supply on fossil fuels, the additional costs incurred by the S.MED.E. Pantelleria for operating the energy supply and distribution systems are covered by a cross-subsidy paid by all Italian electricity consumers through their electricity bill [52]. In 2015, the subsidy corresponded to an amount of 297,9 €/MWh, which suggests that the average electricity production cost of the local diesel-fueled power plant is 5-6 times higher than that of the rest of the country [52]. In other words, the high reliance on fossil fuel for the energy needs of Pantelleria has a negative impact not only from an environmental point of view but also from the economic one.

Stakeholders engagement and attitude towards sustainability:
Piano Energetico Ambientale Siciliano (PEARS) and the Clean energy for EU islands initiative. The Sicilian Environmental Energy Plan - Piano Energetico Ambientale Siciliano (PEARS) - was stipulated in 2019 with the goal of defining guidelines for the sustainable development of the region (of which Pantelleria belongs) as well as a set of targets to be achieved by 2030 [66].
In particular, the plan builds on three main pillars:

- Development: increasing the energy production from RES as well as implementation of new technologies for energy management and efficiency.
- Engagement: the plan highlights that energy transition brings not only environmental but also social and economic benefits to the local community.
- Protection: the need for implementing solutions that integrate into the landscape as well as the cultural and historical fabric of the region.

Specifically, the regional authority aims to (i) foster the installation of solar power and solar thermal generation systems so as to increase self-consumption from RES, and (ii) promote the use of storage technologies to support self-consumption and provide grid stability services.
The PEARS also stresses that Pantelleria, together with islands of Salina and Favignana, have been included in the Clean energy for EU islands initiative[6]. In the scope of the initiative, the Clean Energy for EU Islands Secretariat provided technical support in drafting the energy transition agenda for Pantelleria [53], which foresees the following targets:

- achieve 35% renewable electricity;
- achieve 50% electric mobility in the private sector and 100% in the public transport sector;
- introduction of energy storage for grid balancing and peak-shaving;
- electrification of the island's desalination plants.

[5] http://www.smedepantelleria.it/?p=359#more-359
[6] https://euislands.eu/

The European and regional initiatives are supported and complemented by local stakeholders that see in the energy transition an opportunity for sustainable development - in all its three dimensions: environmental, economic and social. In Particular, the Municipality of Pantelleria is committed in promoting renewable energy prosumerism in all sectors (public and private) [53]. In this regard, the municipality has been granted national and regional funding for the implementation of energy efficiency measures in public administration buildings and the installation of solar PV systems on municipal buildings for a total installed capacity of 350kW [52].
The local DSO, S.MED.E. Pantelleria S.p.A., is part of the Energy Transition committee and will provide technical support in the design and implementation of the solutions proposed in the Transition Agenda for Pantelleria. Moreover, S.MED.E. intends to increase its renewable energy generation capacity and adopt storage technologies (centralized and distributed) to support the distribution network [53]. Another member of the Energy Transition committee worth mentioning is Resilea[7], a local cooperative which is actively involved in promoting community empowerment through the development of social and ecological resilience models [53]. Actors like Resilea are fundamental in this context and can play a major role in facilitating engagement and active participation of the local community in the energy transition process.

The "plastic free" campaign. In 2018 Pantelleria joined the "plastic free" campaign promoted by the Ministry of the Environment. The initiative resulted in a significant increase of the separate waste collection rate, which reached 73% in 2020 [52].

[7] http://resilea.org/

4.3 Astypalea – Greece

Astypalea is a 100 km^2 island of the Dodecanese archipelago, located in the southern Aegean Sea (Figure 4.14). With a population of about 1300 inhabitants, the island is a famous tourism destination visited by approximately 72000 tourists per year. Most importantly, Astypalea is one of the 29 Greek Non-Interconnected Islands (NII) [67].
According to the Hellenic Electricity Distribution Network Operator (HEDNO), the Greek NII [68]:

1) differ significantly by area and population and, in many cases, are not easily accessible, especially from the sea.
2) have significant availability renewable energy sources, particularly wind and solar.
3) face challenges in ensuring reliability and security of the energy supply because cannot exchange electricity with other electrical systems.
4) experience problems maintaining voltage and frequency stability - particularly in cases of high penetration of intermittent Renewable Energy Sources (RES).

Because of its distance from the mainland and any other islands, connecting Astypalea to other electricity networks is rather difficult and expensive. Hence, the island must rely on a completely autonomous energy system [69].

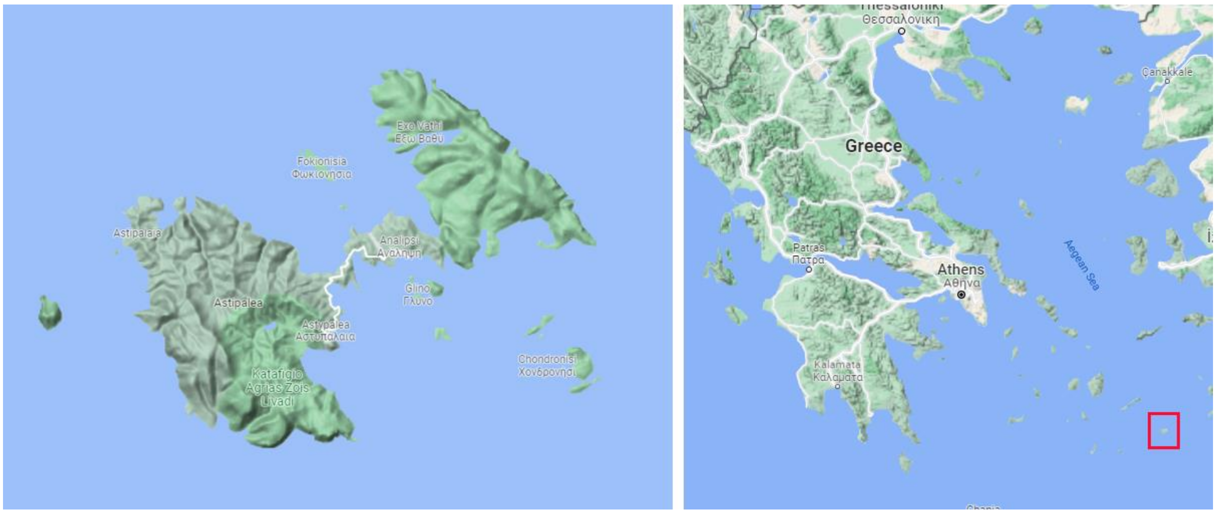

Figure 4.14: Map and location of Astypalea Island.

4.3.1 Technical domain

Distribution network:
The power system of Astypalea is the fifth largest in the Dodecanese. Most of the electricity supply is provided by a 4 MW thermal power plant, located over 1km north from the main settlement, which consists of four diesel engines H/Z Mitsubishi S16R-PTA. A minor part of the total supply is provided by small distributed solar PV generation units (with a total installed capacity of 350,76 kW). Therefore, the energy mix of the island is essentially based on fossil fuels, with only 7,9% of the total supply generated from RES – i.e., solar (see Figure 4.15).

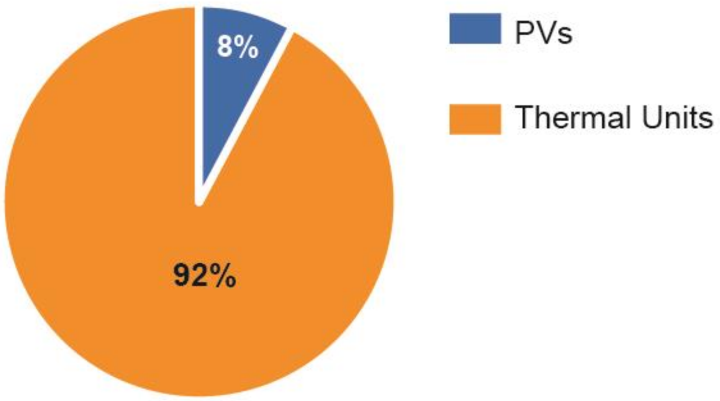

Figure 4.15: Energy mix in Astypalea, 2018.

Compared to solar, thermal power generation provides more stable power. However, it is also quite costly. In 2018, for instance, the production costs of the thermal units in Astypalea significantly exceeded the system marginal price - which that year was around 60 €/MWh (see Figure 4.16).

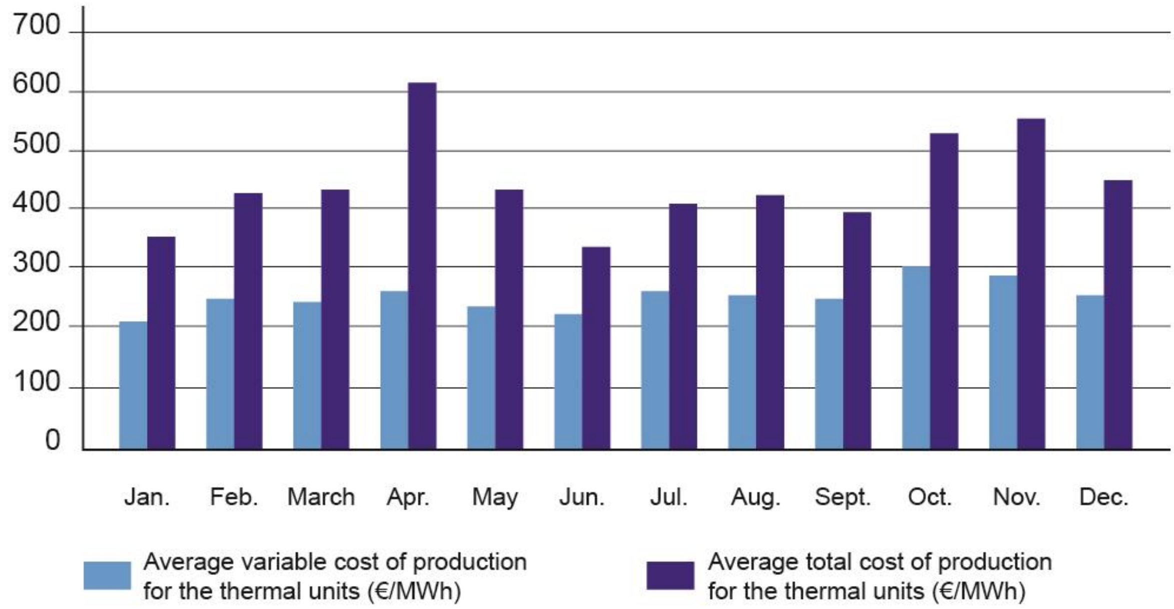

Figure 4.16: Thermal generation costs in Astypalea (2018).

Although most the electricity supply is provided by thermal units, the amount of solar power generated on the island is significant for a non-interconnected network and has already reached the limit set by the Greek Regulatory Authority for Energy (RAE). Therefore, in order to protect the grid by the harm that an additional integration of RES can cause, RAE has imposed the network operator not to accept the installation of new renewable generation units (with only a few exceptions for PVs and small wind turbines).

Considering the current scenario and the fact there are no plans for connecting Astypalea to the electricity network of either Greece mainland or any other islands [70], the island is involved in several projects aimed at fostering energy transition and increase the amount of RES. Among them, the one that may most radically transform the energy system is the "Smart & Sustainable Island" project [71]. The project (thoroughly described at the end of this section) aims at: (i) improving electric mobility, (ii) promoting wide use of RES, and (iii) foster the deployment of energy management systems and storage technologies.

Electricity demand and renewable generation:

Despite having similar characteristics, the annual electricity demand among the autonomous non-interconnected islands varies by dimension and population (see Table 4.7) [72]. The electricity demand of Astypalea is the second lowest in the Dodecanese and, since 2014, is showing the tendency for a minor but consistent increase.

Table 4.7: Annual Electricity Consumption (Demand) in the Dodecanese NII, 2012-2019 (MWh). Data source: [72].

Dodecanese NII	2012	2013	2014	2015	2016	2017	2018	2019
Astypalaea	7,089	6,670	6,599	6,772	6,856	7,008	7,064	7,268
Karpathos	38,988	36,931	36,928	37,966	37,799	37,319	38,455	39,805
Kos-Kalemnos	361,681	352,984	351,942	367,337	368,521	382,075	392,964	405,385
Megisti	3,126	3,005	3,152	3,207	3,479	3,549	3,762	3,866
Patmos	17,475	17,020	17,019	17,788	17,477	18,438	18,894	19,570
Rhodos	790,593	760,658	760,187	791,768	814,488	836,397	864,624	867,271
Semei	15,275	14,662	14,132	14,649	15,175	14,285	14,673	14,900

The total electricity demand of Astypalea is also influenced by the influx of tourists on the island, which is particularly high during summertime. The consequent increase in the energy production – particularly significant in the months of July and August (see Figure 4.17) – may also cause frequency issues and ultimately affect security of supply [70].

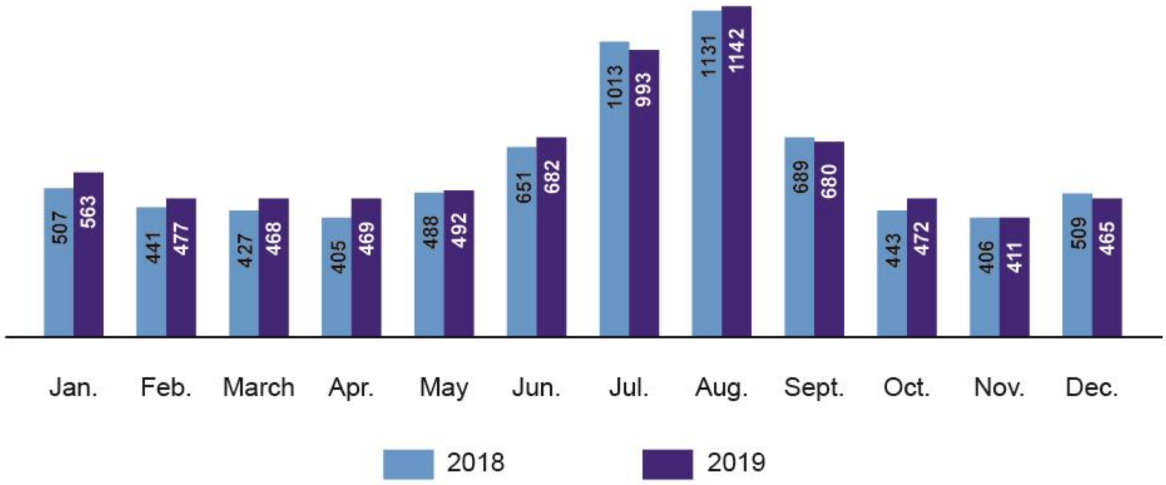

Figure 4.17: Monthly energy production by Astypalea's power plants in 2018 and 2019 (MWh).

As already mentioned, the electricity generated from RES (specifically from solar) is relatively low in Astypalea. Nevertheless, due to its high level of solar radiation (the global annual PV output is, on average, in the range of 1600 to 1700 kWh/kWp), the island has the potential for further exploiting solar PV generation technologies (see Figure 4.18) [73].

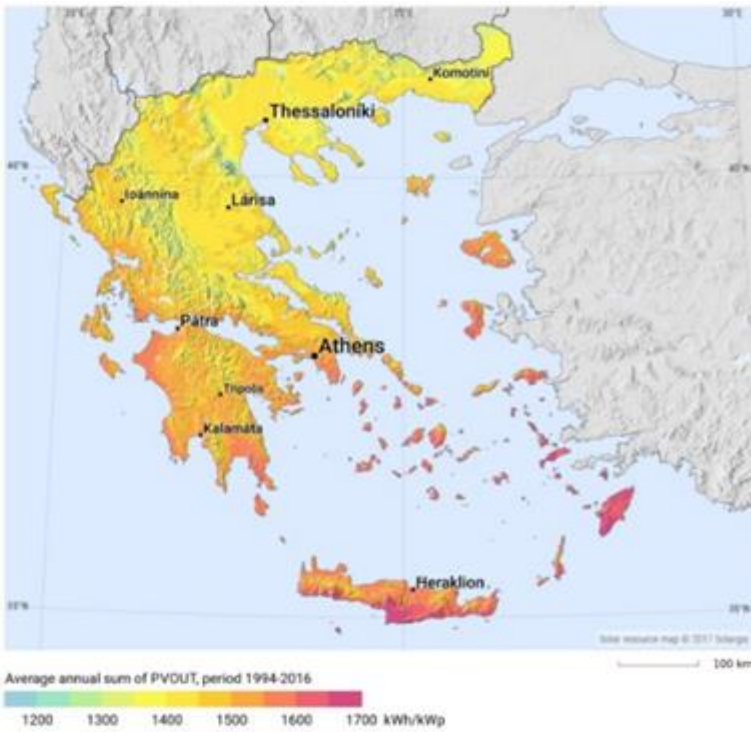

Figure 4.18: Average annual sum of PV output for Greece. Source: Solargis.

Most of the existing PV generation units (between 2 kW and 5 kW) have been installed as part of the "net-metering" and "rooftop" special programs. Nonetheless there are also larger stations with around 80 kW of installed capacity each [70]. The breakdown of the total electricity produced by these units in 2018 is shown in Figure 4.19.

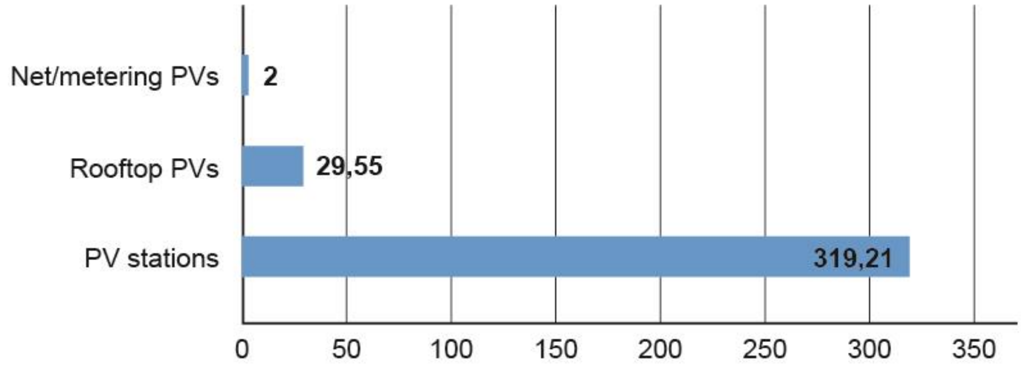

Figure 4.19: PV`s Installed capacity breakdown in Astypalea, 2018 (kW). Source: DAFNI, 2020.

The Greek government is committed to investing in turning Astypalea into a carbon-neutral island. In the future, most of the electricity supply on the island will come from solar sources thanks to the construction of a 3MW solar PV plant – which is part of the "Smart and Sustainable Island" project. Once completed, supposedly by 2023, the plant is expected to cover 100% of the EVs electricity demand and up to 60% of the total electricity demand of the island [74]. Additionally, the project involves the installation of a 7MWh back-up battery, which will be used to manage the power generated and balance the grid [74].

Electric mobility:
Data about the penetration of EVs on the island is limited but, in general, it seems that there is still a reliance on diesel vehicles. Nevertheless, the shift towards electric mobility is on its way. In fact, the Volkswagen Group is collaborating with the Greek Government to establish a ground-breaking mobility system in Astypalea through the implementation of the "Smart and Sustainable Island" project. The project goal is to develop an entirely new transport system complemented by digital mobility services, including an electric ridesharing service. Also, part of the traditional vehicle rental business will be transformed into a vehicle-sharing service composed of a fleet of e-scooters, e-bikes and electric cars [75]. The project also includes the electrification of vehicles from local businesses and the public sector as well as the installation of several public and private charging points across the island (equipped with Volkswagen Elli chargers) in such a way to ensure a comprehensive charging infrastructure [71]. In June 2021 Volkswagen provided the local administration with eight EVs, that is part of a larger fleet aimed at replacing about 1500 combustion-engine cars with zero-emission vehicles [75].

4.3.2 Regulatory domain

Distribution network and renewable energy generation:
For long time, the Greek Public Power Corporation (PPC) have had the monopoly over the energy market in the NIIs [76]. In order to promote competition and fair trading, the Regulatory Authority for Energy (RAE) has approved the "Non-Interconnected Islands Code" published in February 2014 under the Law 4001/2011. The code also includes additional measures aimed at lowering the costs for operating autonomous power stations (APS), ensuring secure and smooth operation of the energy systems, and increasing renewable energy share in all the NIIs [72].
As already mentioned, the electricity network of Astypalea is saturated – i.e., the penetration of RES has reached the limits set by RAE. The only PV generation units that can be installed on the island are those belonging to the "net-metering" and "rooftop" special programs [70].

Incentives and remuneration schemes:
Feed-in tariffs: the Hellenic Republic has established some premium feed-in tariff schemes - which vary by technology and installed capacity - for promoting renewable energy generation nationwide. Due to the absence of a wholesale market on the NIIs, renewable energy generation units on those islands can receive aids in the form of a fixed feed-in tariff instead of a premium one [77]
Public Service Obligation: the Greek regulatory system provides for a Public Service Obligation (PSO) to supply power to consumers on NIIs at the same electricity prices as those of the mainland. Suppliers operating on the islands are compensated for the difference between their (high) cost and the system marginal price on the mainland through a levy on the energy bills off all customers in the mainland. The total PSO is calculated by RAE, taking into account the costs for both conventional and renewable energy generation on the islands [76].
e-Astypalea – promoted by the Greek government as part of the `Smart & Sustainable island' project, this scheme aims to provide subsidies for (i) the purchase or leasing of an electric vehicle (cars, motorcycles, three-wheelers or bicycles), (ii) the installation of a "smart" charging point, and (iii) the scrapping of old vehicles. Only permanent residents and businesses operating on the island are eligible to access these subsidies [78].

4.3.3 Socio-economic domain

The amount of available information about the socio-economic characteristics of Astypalea is very limited, and most of the documents retrieved were not in English. This section reflects therefore such limitations.

Market design and energy prices:
The Regulatory Authority for Energy (RAE), among other tasks, is responsible for monitoring and controlling the transmission and distribution system operators in Greece. In Greece there is one TSO (ADMIE-IPTO) and one DSO (HEDNO). Nevertheless, in the Greek NIIs, HEDNO does not only acts as DSO, but also TSO, market operator and energy manager [72].
The power system of Astypalea currently operates without any wholesale electricity market, and "neither the producers nor the suppliers submit daily offers for their production or for their customers' loads" [72]. Consequently, there is no system marginal price but only an estimated clearance price of energy. Such an estimation is done monthly, based on the variable costs of the conventional power units, according to Law 4001/2011 and the Code of operation of the non - Interconnected islands [72].
The free energy marked was introduced in the NII at the beginning of 2018, leading to an increase of the number of suppliers in the islands. One year after, in 2019, there were about nineteen suppliers active in the market – five of which operate in Astypalea. The market shares of that year (see Figure 4.20) reveal that, despite having lost 5% of the market, the Public Power Corporation (PPC) were still dominating the market, holding a share of 88,24% [72].

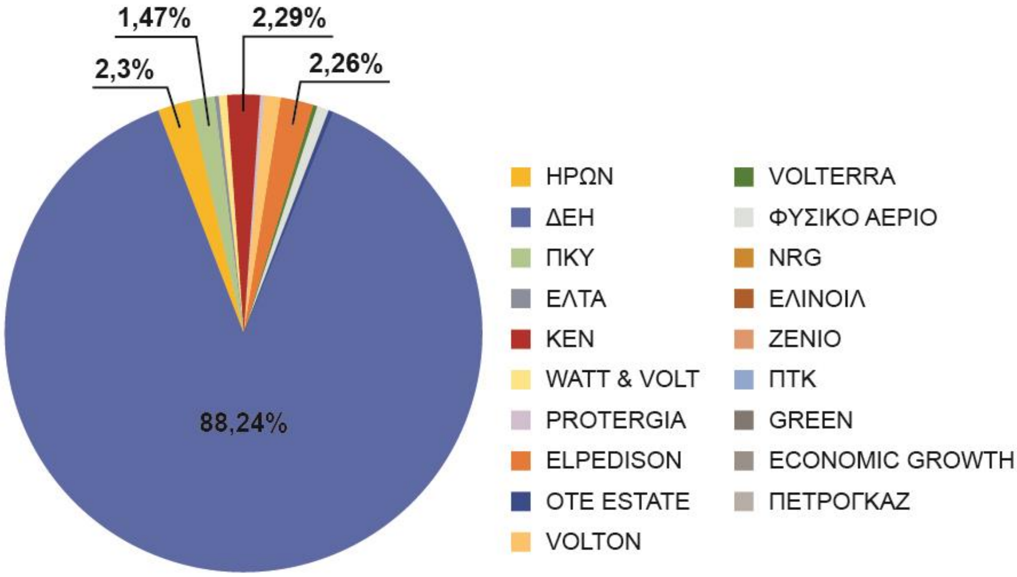

Figure 4.20: market shares 2019, NIIs (number of connections – LV and MV).

Stakeholders engagement and attitude towards sustainability:

Astypalea is involved in several projects and initiatives aimed at promoting energy efficiency and sustainable development. Among them, the most noteworthy are:

The "Smart and Sustainable Island" project: promoted by the Hellenic Republic with the support of the Volkswagen Group, aims at transforming the island into a model location by promoting e-mobility, smart mobility, and RES (more details are provided in the previous sections).

Astypalea 4.0: Astypalea 4.0 consists of a five-year strategic development plan developed by Deloitte, a consulting and financial advisory firm, with the cooperation of the Municipality of Astypalea [79]. Besides defining a vision and a strong value proposition for the island, the plan sets priorities and strategic goals for the long-term sustainable growth of the local economy and includes an investment framework for key stakeholders (e.g., tourism businesses, municipality, residents, etc.). Specifically, the plan has set eighteen strategic actions that develop around 4 main axes:

i) Development and improvement of infrastructures.
ii) Boost of the local economy and entrepreneurship.
iii) Sustainability and environmental protection.
iv) Digital transformation and networks upgrade.

The "Smart Island" pilot project: promoted by the Ministry of Energy, RAE, and HEDNO in collaboration with the National Technical University of Athens, the project aims "to increase RES penetration, while ensuring the supply of demand and the secure operation of the power systems in a cost-efficient way" on three NIIs: Symi, Megisti and Asypalea [80]. On each island, the project will demonstrate a new RES unit in combination with storage technologies controlled by a smart management system.

4.4 Ærø – Denmark

Ærø is located in the southern archipelago of Denmark. The 90 km^2 Danish island is largely rural and has a total population of around 6200 inhabitants.

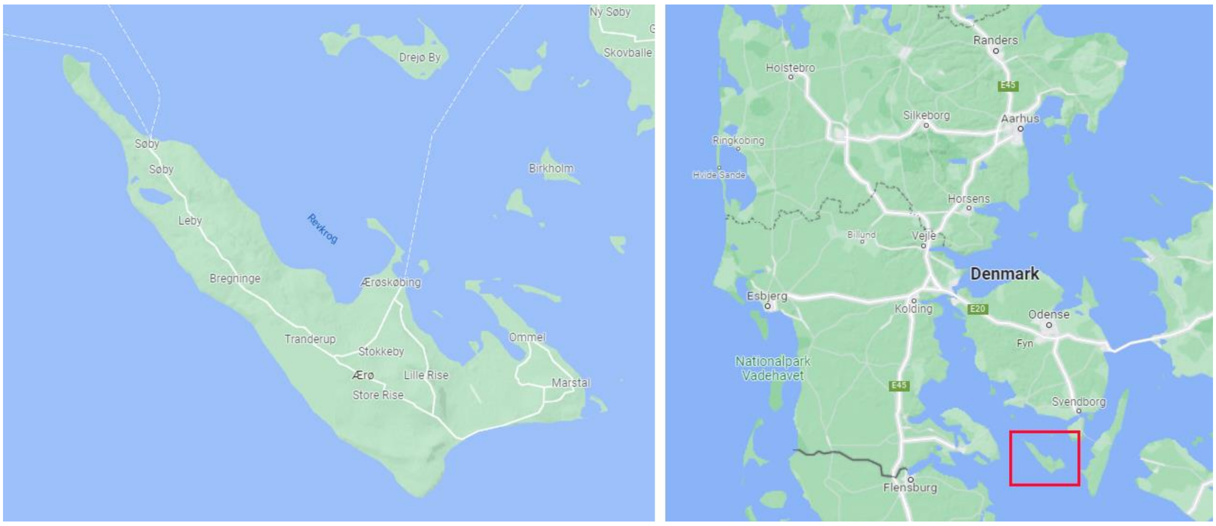

Figure 4.21: Map of Ærø island.

4.4.1 Technical domain

Distribution network:

As many other islands in Denmark, Ærø is electrically connected to other regions. The connection consists of two 60kV subsea cables with capacity of 21,3 MW and 23,4 MW each, connecting the island to Langeland (12,1 km) and Jutland (6,75 km) respectively. The island distribution network is composed of MV (60/10 kV) nodes and 170 LV (10/0,4 kV) distribution substations [81]. The network characteristics make it vulnerable to failure which influence energy losses, affect the quality of the supply and sometimes lead to a temporary disconnection of the submarine cables.

Ærø has a long history of grassroot RES and sustainable initiatives, therefore is very committed to become 100% green and self-sufficient. For this reason, the island is currently planning to disconnect and permanently disable the two cables linking the local energy system with Langeland and Jutland regions. In terms of supply, most of the electricity is imported while that generated locally is provided by onshore wind turbines, followed by residential PV installations source (see Table 4.8). Additionally, demand for district heating is mostly covered (about 65%) by 3 plants all based on RES (solar, biomass and bio-oil) plants [82].

Table 4.8: Energy Supply in Ærø.

Supply	Capacity/Quantity
Wind Turbine	6 x 12 MW (V90-20)
Residential PV	1.35 MV
Main Grid 1	21.3 MW (12.1 km)
Main Grid 2	23,4 MW (6,75 km)

Electricity demand and renewable generation:
According to the Danish Energy Agency, the annual electricity demand in Ærø is around 26 GWh [83], with an average daily peak of 5 MW. Since the island is a tourism location (receiving around 170000 tourists per year), such demand varies depending on the season. As reported by Santos et al. it usually "drops from July to January and raises afterwards" [84], with small peaks around Easter and summer months (see Figure 4.22).

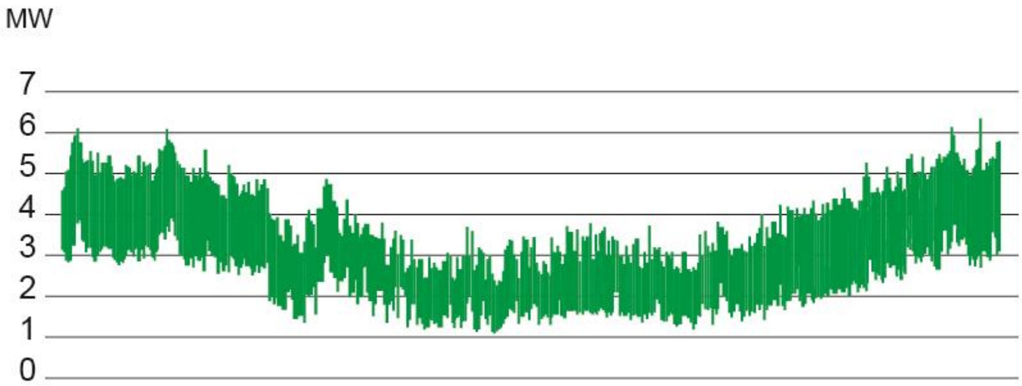

Figure 4.22: Annual average electricity demand in Ærø.

RES generation and PV penetration:
In 2019, Denmark ranked second among the top 5 countries with the highest RE power capacity per capita. "Its share of RE in electricity generation stood at 77%, with an increase over 97% in the last decade" [85]. Similarly, today over 55% of the total energy in Ærø comes from RES (wind, solar and biomass) – but the island aims to run 100% on renewables by 2025. There are already some significative peaks of renewable energy generation that could challenge the ability to balance production and demand. For example, in 2018 production from RES exceeded the electricity demand of the island for five months in a row, with wind power accounting for 70% of it [84]. Today, the combination of wind and solar generation corresponds to 130%/140% of the annual electricity demand. Yet, paradoxically, the island is forced to export the renewable energy generated locally and import power from other regions because the consumption pattern of the islanders does not match the production. For this reason, the Municipality of Ærø is now looking at storage or other solutions to tackle these issues and exploit RES as much as possible.
The municipality also provides citizens with free consultancy services about renewable anergy generation. As a result, many inhabitants have already installed renewable energy generation systems or undertaken energy-saving renovations. As for today, there are around 260 residential PV installations, and additional PVs are also owned by the Municipality [81]. Yearly, the hours of sunlight in Ærø are above the national average, thus making the island an attractive location for solar PVs.

Electric mobility:
In Denmark, there has been an increase in the consumption of electricity for road transport, which primarily stems from growth in the use of electric cars and light goods vehicles. At the end of 2018, the fleet of EVs in the country comprised around 16000 battery-powered vehicles, 5000 of which are plug-in hybrid vehicles and 900 are electric and plug-in hybrid light goods vehicles. According to the projections, Denmark is expected to reach a total of some 300000 EVs by 2030 [86]. To achieve this goal, it was proposed to stop sale of new conventional car. Nevertheless, such plan is not directly applicable according to EU directive 2019/631. Therefore, the national government is now examining other initiative to achieve large low-emission car penetrations and succeed the EU's CO2 requirements

for light vehicles. Among them, the two main ones under consideration are: i) making zero- and low-emission cars cheaper; ii) making conventional cars more expensive in terms of total cost [87].
In line with the national objectives, Ærø is on its way to achieve the desired EVs uptake. In this regard, a landmark in promoting electric mobility on the island is represented by the EM project, launched in 2012 by the municipality of Ærø with the financial support of the Danish Energy Agency [82]. The project led to the acquisition of 3 EVs that are available for tourists to rent during summer and, during the remaining months, are free to use by the municipality and the local community. At the moment, the municipality still owns three EVs, but more are expected to be added to the fleet in the near future. The public transport bus fleet will also gradually go through a green transition, which started in 2019 with the acquisition of two electric buses. Nowadays there are around twenty EVs on the island, mostly private. In order to speed up such transition in the private sector, the municipality is working on improving the charging infrastructure by setting up fast chargers at key locations on the island. Currently, there is a total of fourteen charging stations, 12 of 11kW and 2 of 50 kW charging power [81].

4.4.2 Regulatory domain

The Danish Energy Agency (DEA) is responsible for the electricity market legislation in Denmark. Thus, it regulates on everything that concerns electricity production, transmission and distribution, as well as market competition, consumer protection and security of supply.

Incentives for solar PV generation:
The national government's commitment to promoting renewable energy generation started in 1999, with the implementation of the annual net metering with electricity tax exemption. Since then, several regulatory changes took place, involving the introduction of a feed-in tariff for the energy generated and fed into the grid and the Public Service Obligation (PSO) scheme – i.e., the exemption of an additional surcharge of the electricity tariff. Nevertheless, the fast expansion of self-consumption caused by these measures posed a significant reduction of fiscal income for the State; thus, leading to the adoption of new measures intended to curb the PV deployment. Among them are included: (i) the shift from the annual to an hourly compensation scheme, and (ii) the progressive reductions in the feed-in tariff till its final elimination. With the introduction of these new measures, the percentage of distributed PV units connected to the grid fell from the 99% of 2012 to around 70% in 2019. As for today, "the only advantage for new PV prosumers under the Danish net metering scheme is the compensation of self-generation and consumption within an hourly basis, with total or partial exemptions on certain tariffs and taxes" [88].
All Danish consumers are obliged to pay a tax for the electricity consumed from the grid. In the case of a prosumer, the PV self-consumed fraction of the gross electricity consumption can be exempted from this tax. However, the way in which the exempted PV self-consumed electricity is determined depends on the type of consumer. While the residential PV facilities up to 6 kW retain the hourly net settled basis for the electricity tax, instantaneous settlement applies for the remaining cases [88] since the entry into force of Act nº1049 12/09/2017 amending the Electricity Tax Act [89]. Additionally, "several electricity tax levels are applied depending on the customer type and the final use of energy, and certain corporate customers can be entitled to either almost full or partial reimbursement of the paid electricity tax" [88].

Electric mobility incentives:
Currently, there are no incentives directed to households for the purchase of EVs or the installation of charging stations. The only incentive scheme available targets commercial EV charging and consists of a tax reduction of around 0,13€ per kWh applied to companies that provide electric vehicle charging on a commercial basis [87].

Smart metering:
According to executive order no. 1358 of 2013 on smart meters and metering of end-consumption of electricity, DSOs were obligated to install smart meters in the homes and businesses of all consumers in Denmark by no later than the end of 2020 [90]. The smart meter rollout in Ærø started in 2012, before the publication of the executive order, and is now completed [81]. According to the legal framework in force, the minimum functional requirements for smart meters include: (i) registration of metering data every 15 minutes, and (ii) direct data transmission to the DSO. The metering data are then sent by the DSO to the Danish DataHub for billing purposes.

4.4.3 Socio-economic domain

The DSO in Ærø is N1, an energy distribution company that serves most of the country (see Figure 4.23) [91], while there are several energy suppliers operating on the island.

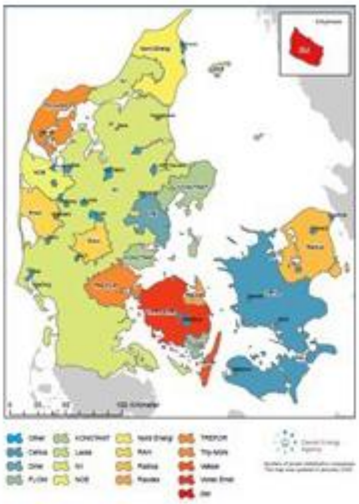

Figure 4.23: Power distribution companies.

The price of electricity in Denmark is among the highest in Europe [92] (see Figure 4.24).

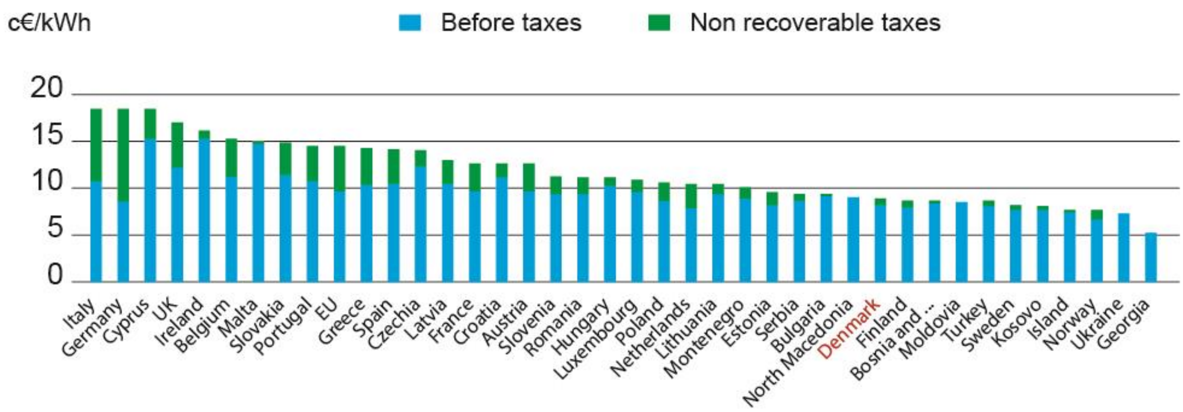

Figure 4.24: Electricity prices and taxes in European Union in 2020.

In terms of composition, the total energy price for household customers in the country is predominantly derived from taxes (62%), followed by electricity cost (20%) and grid fees (18%).

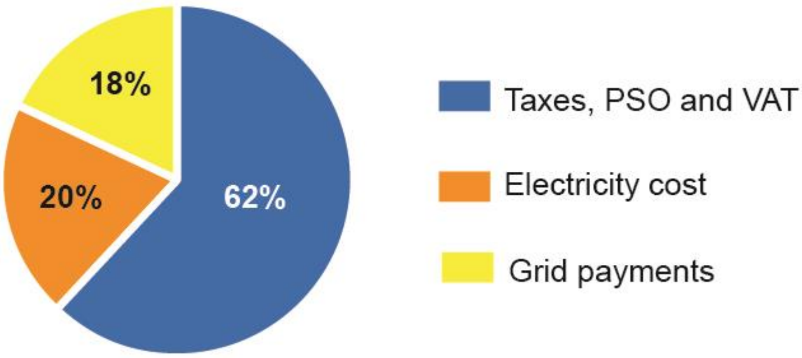

Figure 4.25: Composition of the total price for household customers, 2019.

Community engagement and People's attitude:
Ærø has been actively involved in sustainability projects for more than two decades. Since the 80's the island has focused on the self-sufficiency of renewable energy that led to an agreement with The Danish Society for Nature Conservation to be a "climate municipality" in 2009. In 1981 the local community established the Ærø Energy and Environment Office, which took the role of a local intermediary in the process of developing a community-owned wind farm. Also, Ærø municipality has committed itself to reducing its CO2 emissions by a minimum of 2% every year until 2025 [82]. Ærø's hard work in achieving its ambitious goals has been recognize several times. In 2020, the island won the "Danish solar city" prize [82], while in 2021, it was awarded by the European Commission with "more sustainable island" prize [93]. In summary, the commitment of both the municipality and local community towards sustainability is outstanding and involve the implementation of different projects aimed at making the island 100% carbon neutral and self-sufficient. Among them, two particularly worth mentioning are [82]:

- E-ferry project [8] - supported by the European Union's H2020 research and innovation programme, the E-ferry projects aim to demonstrate the design of a 100% electric, zero-emission, medium sized ferry. Has a result of this project, new battery-powered electric ferries have been introduced on the routes connecting Søby with Fynshav and Faaborg. This includes the ferry 'Ellen', which have been converted from diesel to electric and is now sailing between Fynshav and Ærø, and Tycho Brahe and Aurora.
- CarpeDIEM project[9]: the CarpeDIEM is a Danish-German research project, "where the last part of the name stands for Distributed Intelligent Energy Management". Goal of this project is to combine storage technologies (e.g., EVs, e-ferries, BESS, etc.) with the use of an intelligent control system to store and consequently increase the use of locally generated renewable energy.

[8] http://e-ferryproject.eu/
[9] https://www.th-luebeck.de/carpediem/publikationen/aktuelles-aus-dem-projekt/archiv/beitrag/2018-11-15-aeroe-becomes-a-new-network-partner-in-sdu-project-the-green-island-is-supposed-to-become-even-greener/

4.5 Texel - The Netherlands

Situated in the northwest of The Netherlands, Texel Island is the largest and most populous (in 2021, the island counts 6496 households for a total of 13656 inhabitants [94]) of the five (inhabited) Dutch Wadden Islands, as well as the one with highest solar radiation and largest number of hours of sunshine [95].

Figure 4.26: Location of Texel Island.

4.5.1 Technical domain

Distribution network:

Texel is energy connected to the mainland through “two cables of 29 MWA and two 50/10 kV transformers of 18 MWA” [96]. Concerning the power distribution system, the publicly available information is limited and only refers to the Medium-Voltage (MV) network, which consists of nine regions, with a total grid capacity of 33MW.

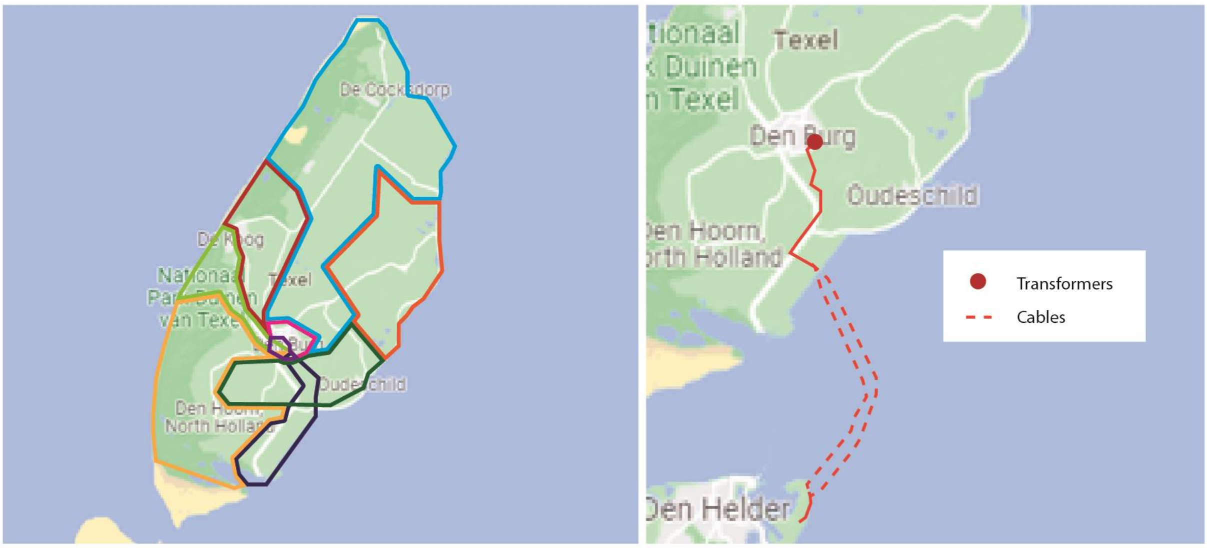

Figure 4.27: Components of the electricity connection between Texel and mainland (right) and map of the nine MV regions (left).

Although being energy connected, just like the other Dutch Wadden Islands that signed the Ambition Manifesto 'The Energy Future' ('De Energieke Toekomst') in 2007 [97], Texel is strongly committed to become energy neutral. However, the characteristics of the existing power network are the main barriers to achieving the desired fully self-sustaining, renewable energy supply. A simple increase of renewable electricity generation on the island, if not combined with further actions like the deployment of energy balancing solutions, is likely to result in an increase in the electricity exchange with the mainland. According to a study conducted in 2015 to assess possible scenarios for a "Sustainable Texel" [96], relying on electricity import/export to balance the energy system is not an ideal solution for Texel and might result in higher electricity dependence and significant investments to increase the grid capacity. Moreover, as highlighted in a study conducted in 2013 by the Dutch DSO Alliander as part of the "Proeftuin Texel" project [98], the two transformers represent a bottleneck to such an exchange since their capacity is smaller than that of both the cables and the existing MV regions.

Although it was not possible to find information regarding the strategies adopted to prepare the distribution network for an increase in renewable generation, it appears that the above-mentioned undesired scenario has partially occurred. The exponential growth of solar generation in the Kop van Noord-Holland subregion (which includes Texel) is significantly affecting the distribution network [99]. Between 2019 and 2020, the network operator Liander reported spreading bottlenecks due to increasing solar additions and had to include Texel in the list of "red scarcity areas" - i.e., those where bottlenecks are more serious and alleviation measures are not an option [100-102]. In Texel, the grid capacity limit has been reached and congestion management is not possible. For this reason, Liander had to impose restrictions on requests for new grid connections and contemporary implement grid expansion plans.

Electricity demand and renewable generation:

In 2019, the total electricity consumption of households in Texel was 63,36 TJ - which rises to 66,96 TJ if considering also behind-the-meter solar) [103]. As shown in Figure 4.28, the average electricity consumption per household, in 2019, varied between 2150 kWh (rental properties) and 3130 kWh (owner-occupied housing units) [104].

Table 4.9: Total electricity consumption of households in Texel between 2010 and 2019. Data source: Climate Monitor (Klimaatmonitor).

Year	Consumption (measured) - million of kWh	Consumption (incl. behind-the-meter solar) - million of kWh
2010	19,6	19,7
2011	19,5	19,7
2012	19,8	20,1
2013	18,8	19,2
2014	18,6	19,2
2015	18,3	18,9
2016	17,8	18,6
2017	17	18

2018	17	18,2
2019	17,6	18,6

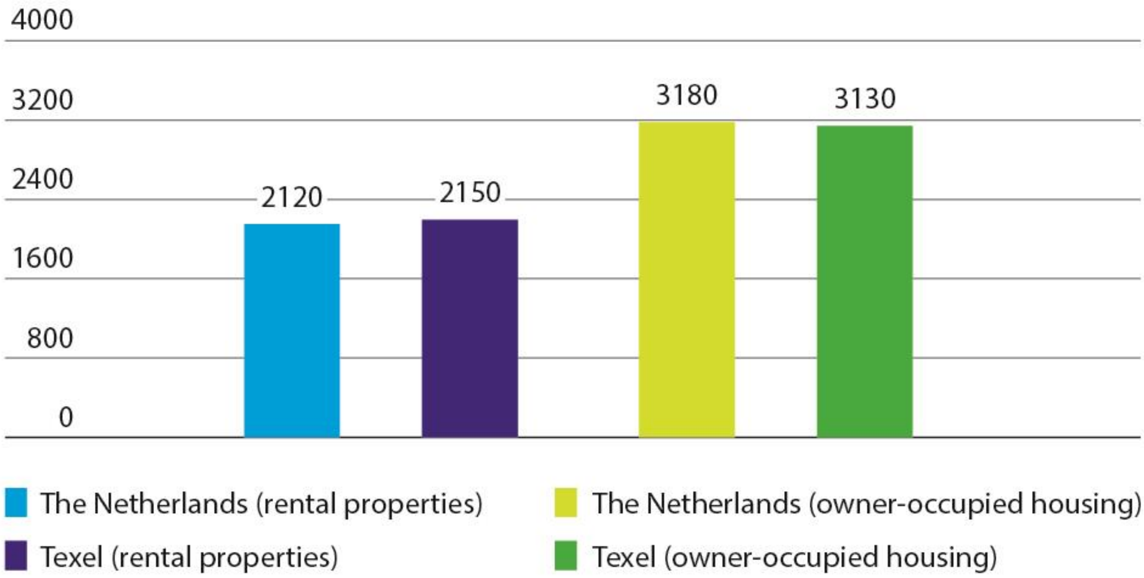

Figure 4.28: Average household consumption (kWh) in Texel and The Netherlands in 2019. Data source: The Association of Netherlands Municipalities (Vereniging van Nederlandse Gemeenten, VNG).

According to the data provided by the Association of Dutch Municipalities (Vereniging van Nederlandse Gemeenten - VNG) [104], in 2018, 3,7% of the energy consumption in Texel was from self-generated renewable energy [104]. While the remaining of the supply is imported from mainland.
In terms of solar PV generation, the installed capacity is constantly increasing (see Table 4.10) and the percentage of households with solar rooftop PV systems reached 20% in 2020 (the national average was 15,7%) [104].

Table 4.10: PVs installed capacity in Texel from 2014 to 2020. Data source: Climate Monitor (Klimaatmonitor).

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Installed capacity (kW)	2081	2579	3190	4391	6161	10156	13118

Over the last two years (see Figure 4.29), the kWh of energy generated from solar PV per inhabitant is higher than the national average.

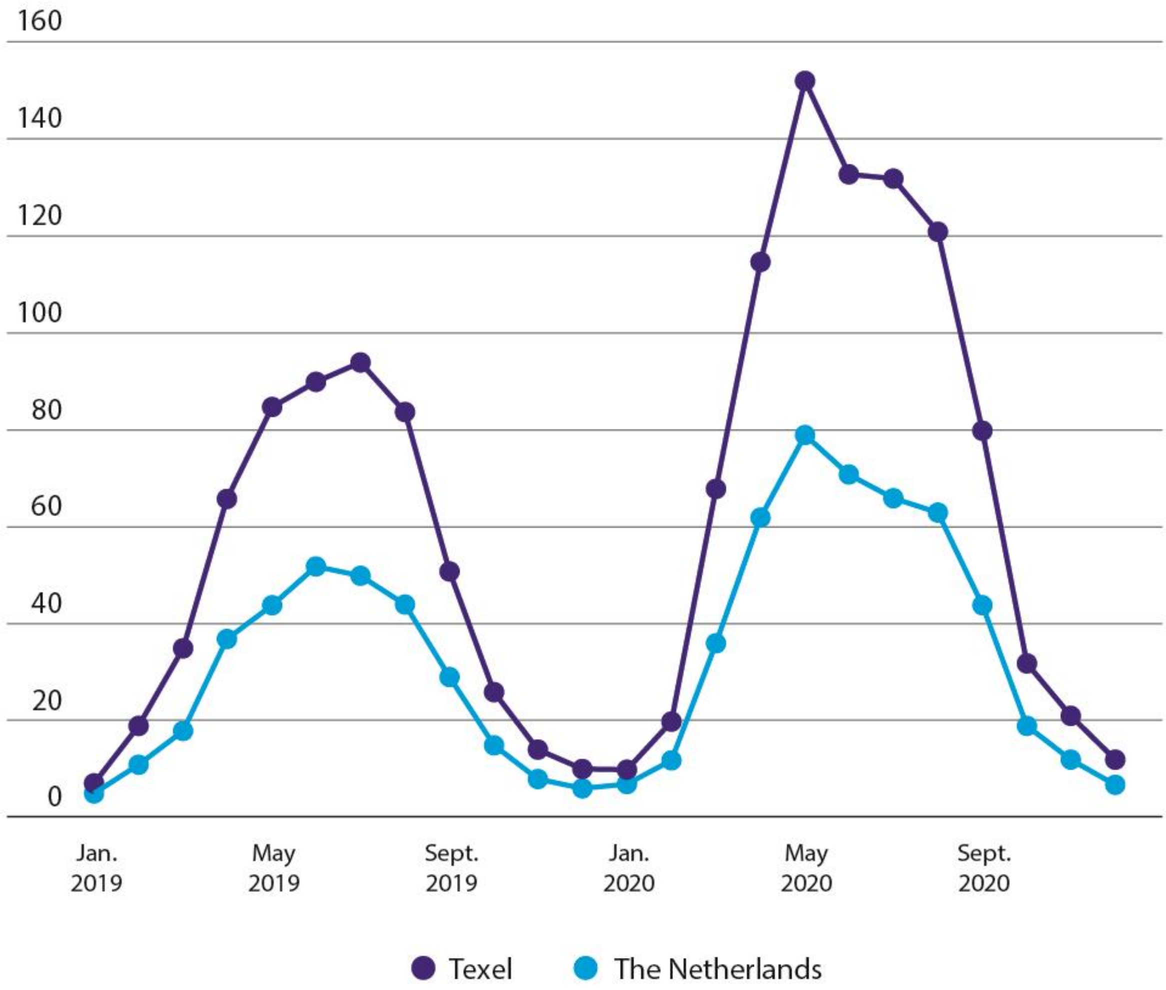

Figure 4.29: Solar energy generated (kWh per inhabitant) in Texel and The Netherlands in 2019 and 2020. Data source: The Association of Netherlands Municipalities (Vereniging van Nederlandse Gemeenten, VNG).

Electric mobility:

Electric mobility is slowly gaining ground on the Island. The percentage of registered electric vehicles is increasing (see Table 4.11 and Table 4.12) and has more than doubled in four years (2016-2020), reaching a total of 12,2 EVs per 1000 inhabitants [105].

Table 4.11: Percentage of registered electric vehicles over the total number of registered vehicles in Texel from 2016 to 2020. Data source: Data source: Climate Monitor (Klimaatmonitor).

	Passenger cars		Commercial vehicles
	Percentage of vehicles (BEV* and PHEV**)	Percentage of vehicles (only BEV)	Percentage of electric vehicles
2016	1,1 %	0,3 %	0,6 %
2017	1,2 %	0,3 %	0,5 %

2018	1,4 %	0,5 %	0,6 %
2019	1,7 %	0,8 %	0,6 %
2020	2,3 %	1,1 %	0,6 %

* Battery Electric Vehicles (BEV)
** Plug-in Hybrid Electric Vehicles (PHEV)

Table 4.12: Number of electric vehicles in Texel from 2017 to 2021. Data source: Data source: Climate Monitor (Klimaatmonitor).

	BEV	PHEV	Electric two- and three-wheel light vehicles (included speed pedelecs)	Speed pedelecs
Jan. 2017	23	56	84	26
Jan. 2018	24	56	85	27
Jan. 2019	36	65	91	31
Jan. 2020	58	68	131	31
Jan. 2021	80	87	182	44
Sept. 2021	100	109	356	46

Texel is a popular tourist location, with an average of 800.000 tourists over one year. The island counts several companies that offer the possibility to rent electric vehicles. According to the website of VVV Texel (the local Tourist Information Center), there are exactly ten e-bike rental companies, of which two also rent e-scooters, and one electric car rental company.
Another relevant indicator to understand the electric mobility on the island is the existing EVs charging infrastructure. The number of (semi-)public charging stations on the island is constantly increasing (see Table 4.13), reaching an average of 8,6 charging points per 1,000 inhabitants in the second quarter of 2021, against a national average of 4,3 [104] - a map of the charging stations on Texel Island can be found at https://www.oplaadpalen.nl/. Finally, according to the data provided by the Association of Netherlands Municipalities (Vereniging van Nederlandse Gemeenten, VNG), in 2020, the EV charging coverage rate on Texel was 47,7% [105] - i.e., the proportion of electric cars that can use a public charging station within a range of 250 meters.

Table 4.13: Number of (semi-)public EV charging stations on Texel. Data source: Data source: Climate Monitor (Klimaatmonitor).

	Number of (semi-)public charging points
December 2019	80
June 2020	103
December 2020	102

June 2021	128
September 2021	130

4.5.2 Regulatory domain

Distribution regulation:
Although grid operators in The Netherlands are entitled to deny access to the grid in case of insufficient capacity (Electricity Act art. 24 (2)), they are also obliged to expand the grid they operate according to general principles (Electricity Act article 16(1)(c)). This regulation is particularly relevant for Texel since the cost for grid expansion is covered by all users via a transmission charge added to the electricity bill (Electricity Act art, 27(1) and Fee Code 3.2.2) [106].

Smart meter deployment:
The Dutch government has mandated the roll-out of smart meters to every home in The Netherlands in 2014 [107], with the objective of achieving 100% installation by 2021 [108]. Although it was not possible to find recent data regarding the current status neither on Texel nor in The Netherland, it emerged that the implementation of smart meters may have faced some delays - in 2019 approximately 55% of households in The Netherlands owned a smart meter [109]. Specifically, results from desk research suggest that both technological problems [110] and issues related to data privacy [107] have been the main barriers to smart meters uptake.

RES promotion policies and incentives:
The Dutch government promotes electricity production from RES in several ways [106]. Particularly through:

- Premium tariffs - premiums on top of the wholesale price have been introduced to promote RE generation.
- Tax regulation: e.g., prosumers operating in a self-consumption regime may be exempt from the tax levied on electricity consumption. Also, a tax credit (EIA - Energy Investment Allowance) can be granted to enterprises for investments in RE generation facilities.
- Loans and investment subsidies - e.g., investors in RES-E projects are eligible for a reduction of the interest rate on loans.
- Net metering.

For the purpose of this analysis, it was decided to focus only on those incentives particularly relevant to solar PV generation. The main ones are described below:

Dutch Renewable Energy Transition Incentive Scheme (SDE++) [111]. Introduced in 2020, the SDE++ is subsidy for renewable energy generation and CO2 emission reduction granted to companies and organisations [111]. In a nutshell, the SDE++ scheme offers an operating premium feed-in tariff subsidy for renewable energy aimed at counterbalancing the cost of the technology with the market price of the CO2 emission avoided [112]. The SDE++ subsidy can be requested for all forms of renewable energy production, regardless of the amount of energy generated, or any other technology that reduce greenhouse gases emissions - unlike its predecessor (the SDE+ scheme) [113].

Reduction of environmental protection tax - tax regulation. The Environmental Protection Tax is due to all individuals on electricity and natural gas consumption. Consumers are exempt from this tax if the electricity consumed was self-produced from renewable energy sources [106].

Energy Investment Allowance (EIA) - tax regulation. Through the EIA scheme companies based in the Netherlands can write off against tax the investments in energy-efficient technologies and sustainable energy [114].

Net metering. When it comes to installation of PVs, the net metering scheme is still the most attractive. Net-metering applies only to electricity prosumer with a small-scale connection (throughput value smaller than or equal to 3*80A). Although all RES-E technologies are eligible, net metering applies mainly to PV installations [106]. Under this scheme, the power supplied to the grid is offset against that taken from the grid at another time. This means that the rate for the supply of electricity corresponds to the price a consumer pays for his electricity (about 22 cents per kWh in 2020) [115].
The scheme is going to remain as it is until the 1st of January 2023 and will then be gradually phased out by 2031 [116]. After that, households will receive compensation for the electricity supplied to the grid, which will be set by the energy supplier (currently about 6 cents per kWh) [115].

Renewable Energy Strategy:
Texel is part of the Regional Energy Strategy (RES) for the Noord-Holland province. RES is nothing but a policy instrument aimed at supporting regional relevant stakeholders - e.g., governments and civil society organizations - in making decisions and planning actions for a successful energy transition [117]. In particular, the strategy focuses on (i) renewable energy generation, (ii) use of alternative, more sustainable solutions for heating rather than natural gas, and (iii) storage and energy infrastructure.
The RES Noord-Holland puts particular emphasis on rooftop solar PV installations. This because, despite wind sources being a possible solution, some naturalistic and landscape constraints may limit the construction of wind farms (and solar parks) [118]. In fact, Texel is located in the Dutch Waddensea coast, which is Unesco World Heritage. Also, its characteristic dunes (part of Dunes of Texel National Park) are not just a sanctuary for birds and other animal species but also a tourist attraction. Thus, any renewable energy installation that could affect the landscape might consequently impact the tourism sector.

4.5.3 Socio-economic domain

Energy market:
After 2004, with the liberalization and unbundling of the Dutch energy market (electricity and gas), the competition in the wholesale and retail electricity market has increased significantly [119]. At the time of this writing, there are 49 energy suppliers in the Netherlands (see Figure 4.30).

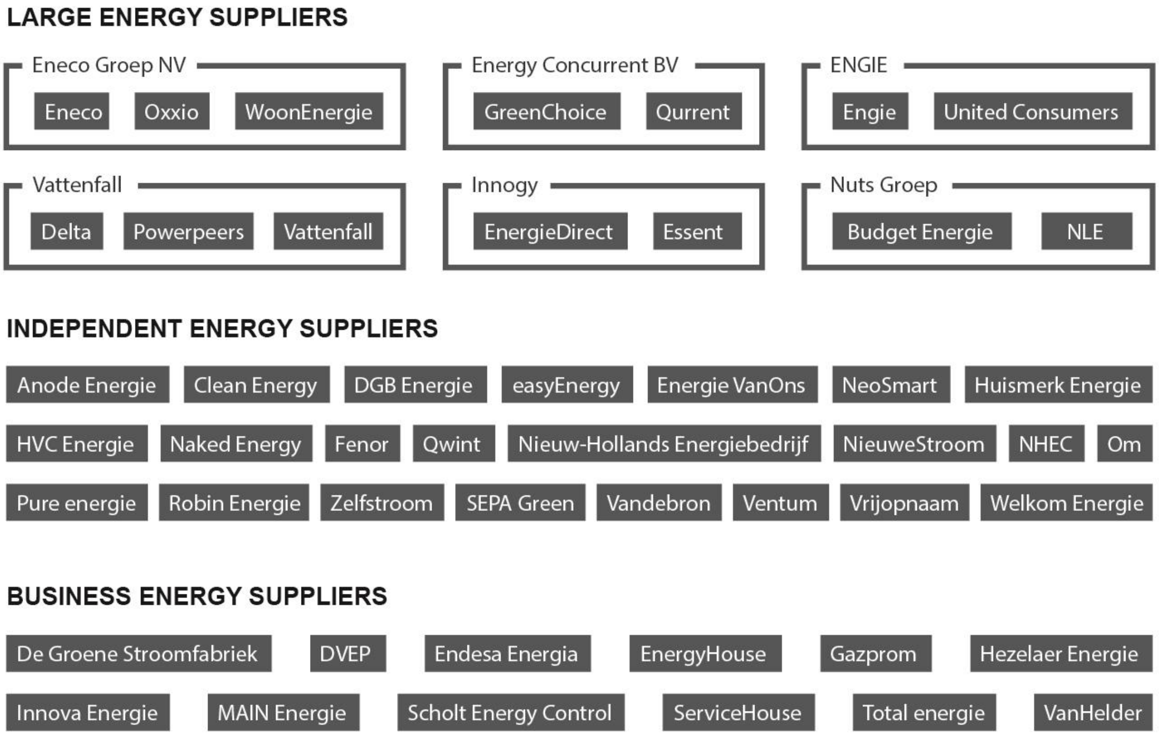

Figure 4.30: List of energy suppliers (electricity and gas) in the Dutch market. Data source: energievergelijk.nl. Note: business energy suppliers do not supply energy to consumers.

Energy suppliers are supervised by authorities such as the Dutch Authority for Consumers and Markets (ACM), whose responsibility is to ensure transparent market processes as well as fair practices and protection of consumer interests, according to the European and Dutch legislatures [120].
There are different typologies of energy contracts in the Dutch market [121]. For example, consumers can opt for yearly (e.g., one-, two-, and three-year) contracts with a fixed tariff, or variable tariff contracts. In the latter case, the tariffs vary about every six months according to the wholesale energy market. The one-year contract option is however the most common since many suppliers provide cashback to new consumers [122]. Moreover, several suppliers provide consumers with the opportunity to purchase electricity from renewable sources. In this case, since not all the electricity generated in The Netherlands comes from renewable sources, some suppliers import it from other countries.
The total energy cost for consumers consists of fixed costs - i.e., taxes and network fees - and a unit price for electricity (€/kWh), which varies depending on the supplier and the type of contract. Time-of-Use (ToU) tariffs are also offered - off-peak period is between 23:00 and 07:00 [122]. Although the electricity is billed yearly, most people opt for paying a deposit monthly [121].

Texel also has its own energy supplier (TexelEnergie), which is part of Om - the biggest energy collective in The Netherlands. Founded in 2007 by a group of Texelers, TexelEnergie (TE) is the first Renewable Energy (RE) cooperatives of The Netherlands [123]. It operates on a non-profit basis and is strongly committed to making Texel Island self-sufficient. In fact, all the revenue is reinvested in new sustainability projects or redistributed to consumers [116]. According to its bylaws, TE does not only purchase and supply green energy but is also engaged in its generation [123]. To this aim, over the years TE set up several solar PV projects (more info at https://www.texelenergie.nl/initiatieven/). While Texelers are free to choose their energy supplier, there is only one company responsible for the electricity network: Liander [119].

Macro and micro economy:
Data provided by the VNG further explain the observed growing trend towards self-generation [104] - which is now putting strains on the distribution network. In fact, over the last three years, there has been a constant increase of sustainability and energy savings loans (see Figure 4.31).

Figure 4.31: Total amount (€) of sustainability / energy savings loans in Texel (national fundings). Data source: The Association of Netherlands Municipalities (Vereniging van Nederlandse Gemeenten, VNG).

However, despite the competitive, liberalized energy market - combined with a high rate of self-generation and the net metering scheme currently in place -, the energy burden in Texel is surprisingly high. According to the data provided by the VNG, in 2018 the percentage of family's income spent on energy costs reached 9%, and 10% of households were at risk of energy poverty [104]. In such a scenario, the grid expansion and enhancement measures being implemented by Liander could add additional burdens on the local community. These types of measures, indeed, often translate into additional costs for the end-consumers and could therefore easily start a vicious circle.
A potential workaround for this situation would seem to be the implementation of energy balancing solutions - e.g., add flexibility on the demand side and balance it with the EMS [96]. This would benefit not only the network operator but also the energy consumers by (perhaps) avoiding increase of prices due to improvement to infrastructure and reducing electricity dependence.

Community engagement and attitude towards sustainability:
Texel has always had the ambitious vision of becoming energy neutral. As mentioned, in 2007, the island signed an Ambition Manifesto 'The Energy Future' ('De Energieke Toekomst') [97], together with the other Dutch Wadden islands: Ameland, Vlieland, Terschelling, and Schiermonnikoog. The commitment to sustainability involves all relevant stakeholders, from the municipality to citizens. The above-mentioned creation of a local (green) energy supplier by a group of Texelers is only one example of that.
Another relevant example of such commitment is the Foundation for Sustainable Texel (FST), a non-profit organization created in June 2000 with the goal of implementing sustainable initiatives on the island. The NGO operated for fifteen years, before being shot down in 2015. The initiatives started by the FST addressed sustainability in a broad sense, encompassing sectors like tourism, mobility and energy. The STF included representatives of a wide range of sectors and organizations - e.g., Texelse Vereniging van Logiesverstrekkers (TVL - association of accommodation providers of Texel) and Texels Verbond van Ondernemers (TVO - union of entrepreneurs of Texel) - and was financially supported by both the Municipality and the Province. Besides sustainability projects on the island, the FST was also actively involved in organizing initiatives for awareness creation. External experts were brought to the

island with the goal of helping the local community and entrepreneurs familiarize with the concept of sustainability and its applications on Texel. In 2007, because of its commitment on education and awareness creation, the FST also received the “iconic price” from Urgenda - a Dutch climate activist group [124].

The active engagement of local actors towards sustainability has led to the development of several projects. Some of them are briefly described below:

Installation of solar PV modules on the rooftops of residential houses.

The local supplier, TexelEnergie, offered subsidies and support to local households for installing rooftop solar PV systems. This initiative led to nearly 200 residential installations in 2019 [125].

Large PV installations (commercial buildings).

In 2010 TexelEnergie set up a big solar PV project involving four commercial buildings [126], with a total installed capacity of 1.4 MV. “The solar arrays are sited on the roofs of commercial complexes through a rental contract between TexelEnergie and the property owners. The produced solar electricity that the property owners consume is directly billed by the cooperative. When the contract period finishes, the hosts are entitled to keep the installation without further payments due” [123].

Postcode Rose project.

Promoted by TexelEnergie, InnoFundNL and the Municipality of Texel, the project aims at allowing those citizens that do not have the possibility of installing solar PVs to invest in solar generation by buying a share of solar panels installed on another rooftop [127-128].

Installation of a solar meadow.

TexelEnergie in collaboration with the Hollands Noorderkwartier Water Board, the Municipality of Texel, Waddenfonds and the Urgenda Foundation have installed a solar meadow consisting of 3000 solar panels at the Everstekoog sewage treatment plant. According to what is reported on the TexelEnergie website, the possibility of upgarding this installation with storage systems is under consideration [129].

Cloud Power Project.

Promoted by the Municipality of Texel, TexelEnergie, Capgemini and Liander, Cloud Power is a smart grid pilot project that “explores how a community can provide its own energy needs, by stimulating energy efficiency and behavioural change" [130]. Between 2012 and 2014, 300 households in Texel participated in the project. The households were provided with smart meters, energy generation units connected to the grid, in-home energy displays (providing feedback on energy consumption and generation), and finally a home energy management system. As reported on the Capgemini website, the driving idea behind the project was to create a community that "resembles the concept of a cooperative in which members own and operate the energy provider to their mutual benefits" [131].

Smart Public Lighting.

The project aims at reducing the energy consumption of public lighting [131]. It consists of a smart lighting system that allows controlling public street lights remotely. Around 23:00, the system dims down the street lamps and ultimately shuts them off completely later on during the night. Also, through the use of motion-sensing technology, the system allows adapting the brightness levels of the streetlights depending on the human presence.

4.6 The Shetland – Scotland

As reported in [3], the initial desk search conducted to select the Scottish replication site led to the identification of three locations: the islands of (i) Eigg and (ii) Muck, and the (iii) Shetland archipelago. The first two islands certainly meet the main selection criteria - i.e., they are not energy-connected to the mainland and there is sufficient information publicly available to conduct the analysis. Nonetheless, the population size of both islands is very limited (40 inhabitants on Muck and less than 90 on Eigg). Moreover, their energy supply already relies entirely on renewable energy sources [132]. Although they both are interesting use cases, from a market perspective, Muck and Eigg do not represent an ideal replication site for the solutions proposed. Therefore, the Shetland archipelago was preferred over them.
Located around 210 km from Northern Scotland, the Shetland archipelago consists of over 100 islands, of which 15 are inhabited [133]. With an overall population of 22870 (30 June 2020[10]), the Shetland archipelago is the farthest from mainland Great Britain as well as energy independent.

Figure 4.32: Map and location of the Shetland Islands.

4.6.1 Technical domain

Distribution network configuration and operation
The local Distribution Network Operator (DNO), Scottish & Southern Electricity Networks (SSEN), owns and operates the 33 kV and 11kV networks on Shetland. The roughly 1,650km of overhead lines and underground cables operate only at distribution voltages (with a core 33 kV network and local distribution at 11 kV and LV) - i.e., there are none operating at transmission voltages (132kV and above). Thirteen islands of the archipelago are connected to Mainland Shetland electricity network

[10] https://www.nrscotland.gov.uk/files/statistics/council-area-data-sheets/shetland-islands-council-profile.html

through subsea cables [134]. There are 11 Primary Substations[11] (8 on the main Island, 1 on Unst, and 2 on Yell) of which one, located roughly 1km from Exnaboe (Mainland Shetland) is a grid support point. Since the archipelago is not electrically connected to the GB network, demand (which varies between 11 and 47 MW [135]) and supply are balanced locally. Moreover, it is worth mentioning that there is no gas supply on the Shetlands so heating needs are met either by oil or electricity [136].

Most of the electricity supply is provided by two fossil-fuel power stations:

- **The Lerwick Power Station**: this 72.8MW diesel-fired station is the primary source of electricity for the Shetland (around 50%). Commissioned in 1953, the station is now approaching the end of its scheduled full-duty operational life and will transition into "standby operation" mode in 2024.
- **The Sullom Voe Terminal Power Station**: a 100 MW gas-fired power station whose primary purpose is to supply electricity to the Sullom Voe Terminal oil and gas terminal. However, thanks to a contractual arrangement, it also provides power to the Shetland system. According to what is reported on the SSEN website, the power station currently meets around 30% of Shetland's demand.

The rest of the supply is generated from renewable sources - wind and tidal generation [135]. In this case, the main generation source is the 3.68MW Burradale wind farm[12] - one of the most productive in the world -, which is owned and operated by Shetland Aerogenerators. The remainder is supplied by non-firm wind and tidal generators (with a total capacity of 8.545MW), whose output is managed using Active Network Management (ANM) system[13] and limited by a set of constraint rules designed to ensure the network stability [135].

Mostly due to its location, the Shetland Islands council area is the last in the UK in terms of solar generation capacity[14]. The limited solar radiation is offset by the high availability of wind resources in the area [135]. However, the lack of a connection to the GB electricity network implies that surplus production cannot be exported and thus limits the possibility to fully exploit the wind power generation. Like every isolated grid, the local network is sensitive to sudden variations in electricity demand and renewable energy generation since they may cause voltage and frequency stability issues. Several projects have been proposed and/or implemented to improve the network capacity of accommodating renewable energy and support grid management and operation. Among them, one of the most significant is the Northern Isles New Energy Solutions (NINES) project which has been developed by SSE - one of the biggest energy companies in the UK - and several local stakeholders, including the Shetland Islands Council. In a nutshell, NINES aims at creating a smart grid in Shetland by using an ANM system[15] combined with large - a 1MW, 3MWh Battery Energy Storage System (BESS) has been installed at the Lerwick Power Station - and small scale energy storage solutions.

[11] A map of the substations as well as additional details for each can be found at https://www.ssen.co.uk/GenerationAvailabilityMap/?mapareaid=3
[12] https://www.burradale.co.uk/
[13] The ANM system has been implemented as part of the NINES project https://www.ssen.co.uk/NINES/
[14] https://greenbusinesswatch.co.uk/uk-solar-power-county-rankings#shetland
[15] According to what is reported on the SSEN website, the Shetland ANM system is currently operational but closed for further applications.
https://www.ssen.co.uk/ConnectionsInformation/GenerationAndStorage/FlexibleConnections/FlexibleConnectionsOptions/

Probably the most important project, however, is the 600 MW Shetland HVDC project[16] - currently in the construction phase - which will link the Shetland to mainland Scotland electricity network. Besides the 257km high voltage direct current (HVDC) cable, the project includes:

- a 320/132kV substation and HVDC convertor station, at Kergord (on the Shetland) and;
- an HVDC Switching Station, at Noss Head in Caithness (mainland Scotland).

In addition, it is planned the construction of a new Grid Supply Point close to the existing Lerwick Power Station (expected to be completed by November 2024) [137].

The driving force behind this important transmission reinforcement project is probably the Viking wind farm (currently under construction). With 103 turbines and a capacity of 443MW, this onshore wind farm is expected to produce the energy needed for covering the consumption of almost 500.000 households[17] and save half a million tonnes of CO_2 emissions per year[18].

Alongside the Viking project, there is a plan to connect two additional wind generators, both consented and owned by Peel Energy:

- Mossy Hill[19]: a 12-turbine wind farm, with a total generating capacity of up to 50MW; and
- Beaw Field[20]: a 17-turbine, 57.8MW wind farm.

Electric mobility:

Concerning the penetration of electric vehicles, it was not possible to retrieve data specific to Shetland. However, we can assume that electric mobility is slowly taking off since Shetland has an EV charging network. According to the map provided by the digital platform Zap-Map[21], the network currently consists of 20 charging points (2 for rapid charging and the other for fast charging).

4.6.2 Regulatory domain

Distribution network regulation:

The criteria for planning and operating the Great Britain (GB) transmission system are defined by the National Electricity Transmission System Security and Quality of Supply Standards (NETS SQSS) [138]. In mainland GB, abiding by the SQSS is the responsibility of the System Operator (SO) - i.e., the National Grid Electricity Transmission. In the Shetlands, this role is fulfilled by SSEN Transmission, which must use the NETS SQSS [139] to plan and design the transmission system. Specifically, SSEN must ensure that there are neither equipment overloads nor voltage violations under intact conditions; and no unacceptable overloading of any primary transmission equipment or unacceptable voltage conditions under planned or unplanned outage conditions[22]. Besides the SQSS, the SSEN "is required to comply with the GB Grid Code in the same way as the rest of the UK" [140] and has a statutory duty - under the Electricity Safety, Quality and Continuity Regulations 2002 [141] - to ensure that the electricity transmission network is fit for purpose.

Smart meters roll-out:

The UK Government aims to complete smart meter rollout in England, Wales and Scotland by mid-2025; with supplying, installation and maintenance being the responsibility of energy suppliers[23].

[16] https://www.ssen-transmission.co.uk/projects/shetland
[17] https://www.sserenewables.com/onshore-wind/in-development/viking/
[18] https://www.vikingenergy.co.uk/the-project
[19] http://peelenergy.squarespace.com/mossy-hill
[20] http://peelenergy.squarespace.com/beaw-field
[21] https://www.zap-map.com/live/
[22] https://www.ssen-transmission.co.uk/
[23] https://www.ssen.co.uk/innovation/smartmeters/

Suppliers are currently rolling out second generation (SMETS2) meters, in line with the specifications provided by the Smart Metering Implementation Programme [142].
It was not possible to find data regarding the progress of the rollout in the Shetlands. However, from a statement on the matter made by a representative of the Citizens Advice Scotland (CAS) found on the CAS website[24], it's reasonable to assume that there have been some delays in the Shetlands.

Incentive schemes for renewable energy generation and CO2 emission reduction:
In Great Britain (Scotland, England and Wales), there are two schemes aimed at promoting generation from RES (both applicable to renewable generation facilities up to a capacity of 5MW):

- Feed-in Tariff (FIT) scheme[25]: introduced in 2010, the scheme applies to any renewables generation facility that fall under the following categories:
    - Solar photovoltaic (up to 5 MW)
    - Wind (up to 5 MW)
    - Micro combined heat and power (up to 2 kW)
    - Hydro (up to 5 MW)
    - Anaerobic digestion (up to 5 MW)

  Normally, the contract length for the FIT is between 10 and 20 years (in the case of solar PV can reach 25 years) [143]. FIT payments are made quarterly - based on meter readings - at rates set by the Feed-in Tariffs Order (FTO) 2012 [144] and adjusted yearly by Ofgem. As an example, for a broad range of rooftop unit sizes the tariff in 2019 was between £0.06 and 0.12£ per kWh [143]. The FIT scheme can serve as an indirect mechanism to help mitigate fuel poverty in the Shetlands. However, in a report published on the Ofgem website [145], it is reported that severe restrictions in grid access within the Shetland Islands have been a barrier to entry into the market (even at the household level). The FIT scheme closed to new applications on 1 April 2019.
- Smart Export Guarantee (SEG)[26]: the SEG is a government-backed initiative launched on 1 January 2020. Unlike the FIT, which was paid for by a levy on all customers' energy bills, the SEG is paid by electricity suppliers (SEG Licensees). Determining the rate and duration of the contract is therefore up to the SEG Licensees. Also in this case, payments are calculated on meter readings. The following typologies of installations (that must be located in Great Britain) could benefit from the SEG:
    - Solar photovoltaic (up to 5MW);
    - Wind (up to 5MW);
    - Micro combined heat and power (up to 50kW);
    - Hydro (up to 5MW);
    - Anaerobic digestion (up to 5MW).

  Unlike mainland Great Britain, it seems that there is no carbon tax in Scotland [146].

4.6.3 Socio-economic domain

Energy poverty and statutory schemes:
According to the definition provided in the Fuel Poverty (Targets, Definition and Strategy) (Scotland) Act 2019 [147], a household is considered in fuel poverty if:

[24] https://www.shetlandcab.org.uk/news/smart-meter
[25] https://www.ofgem.gov.uk/environmental-and-social-schemes/feed-tariffs-fit
[26] https://www.ofgem.gov.uk/environmental-and-social-schemes/smart-export-guarantee-seg

- the fuel costs necessary to maintain a satisfactory heating regime are more than 10% of the household's adjusted net income, and
- after deducting such fuel costs, benefits received for a care need or disability (if any) and the household's childcare costs (if any), the household's remaining adjusted net income is insufficient to maintain an acceptable standard of living.

"Extreme fuel poverty follows the same definition except that a household would have to spend more than 20% of its adjusted net income on total fuel costs to maintain a satisfactory heating regime" [148]. According to the key findings of the Scottish House Condition Survey [149], 24,6% of households (613000 units) in Scotland are in fuel poverty and 12,4% (311000 households) are in extreme fuel poverty. The most common heating fuel used in Scotland is gas (81%), followed by electricity (11%) and oil (5%). However, the primary heating fuel varies by type of dwelling, with flats having the highest levels of electricity (17%) as main heating fuel, and by geographic location. In fact, rural areas (where there has been a 10% increase in the rate of fuel poverty between 2018 and 2019) have higher rates of electricity (20%) compared to urban locations (9%). Interestingly, when considering households using electricity as primary heating fuel, the fuel poverty rate among this group is one of the highest (43%). The only statistics on fuel poverty specific for the Shetland has been found on an article published in June 2021 on a local newspaper[27], which suggests that 31% of households on the islands are in fuel poverty, with a 22% in extreme fuel poverty. If comparing this data with that of Scotland, therefore, it seems that the issue of fuel poverty is particularly pressing in the Shetland islands.

The costs associated with electricity distribution vary regionally and are particularly high in the North of Scotland. The UK Government has implemented several complementary measures to protect consumers from the high costs associated with electricity distribution in those regions. Specifically, the Shetlands benefit from three statutory schemes [150]:

- The Hydro Benefit Replacement Scheme (HBRS): the HBRS is established under the Energy Act 2004, section 184, order 2005 (Assistance for Areas with High Distribution Costs) [151]. The scheme "protects domestic and non-domestic consumers from the high costs of distributing electricity in the North of Scotland" and is funded through charges paid by all licensed electricity suppliers across Great Britain [150].
- The Common Tariff Obligation (CTO): the CTO is established under the Electricity Act 1989, section 7B, order 2005 (Uniform Prices in the North of Scotland) [152]. Unlike the HBRS - directed to every consumer in the North of Scotland, indiscriminately - the CTO provides targeted support to vulnerable households. In particular, those living in remote, rural and island areas within the North of Scotland where, inevitably, electricity distribution costs are higher than those of urban areas.
- The Shetland cross-subsidy: this cross-subsidy, as the name suggests, is intended specifically for consumers in the Shetlands. As per the Government Response to the 24 July 2014 Consultation [153] the cost of the subsidy is to be spread across all GB consumers[28] and delivered through the HBRS.

[27] https://www.shetlandtimes.co.uk/2021/06/30/shetland-tariff-hoped-to-bring-cheaper-energy-prices-by-the-time-viking-energy-windfarm-goes-online-in-2024

[28] The Department of Energy & Climate Change proposed to implement a two stage approach, "with the costs of the cross-subsidy being met by consumers across the North of Scotland until the new integrated power solution for Shetland is implemented at which stage the cross-subsidy costs will be spread across all GB electricity consumers" [154].

Electricity market:

The electricity supply chain in Scotland consists of three main components: (i) generation (described in section 4.6.1), (ii) delivery, through transmission and distribution networks, and (iii) supply to end consumers.

- Delivery - transmission: electricity transmission is a licensed activity, with Ofgem, the national energy regulator, issuing the licenses. Planning, design, construction and maintenance of a network is performed by the Transmission Owner (TO), while network operation (e.g., matching generation and demand) is the responsibility of the System Operator (SO) [155]. In mainland Scotland, the TO is the Scottish Hydro Electric Transmission plc (a licensed company of SSEN) while the SO is National Grid Electricity Transmission (NGET). In the Shetland, however, with the introduction of the British Electricity Trading and Transmission Arrangements (BETTA) of 2005[29], it was formally decided that both roles are the responsibility of SSEN [156].
- Delivery – distribution: electricity distribution is a licensed activity too and is the responsibility of the Distribution Network Operator (DNO). In the North of Scotland and Islands, the DNO is the Scottish Hydro Electric Power Distribution (SHEPD) – a licensed company of SSEN. Ofgem also awards licenses to independent DNOs for supplying electricity to industrial or housing developments through a small, private wire network [157].
- Supply: unlike transmission, electricity supply in the Shetlands is not a monopoly activity. Results from the desk research suggest that there are several energy suppliers operating in the Shetlands. Just like in the case of fuel poverty rates, it was not possible to retrieve data on electricity costs specific to the Shetlands. Nonetheless, according to the Annual Compendium of Scottish Energy Statistics 2020, "North Scotland residents are paying on average 6.0% a year more than South Scotland residents, and pay the highest electricity bills of all regions in the UK" [158].

Community engagement and attitude towards sustainability:

As mentioned in section 4.6.1, there are several ongoing projects aimed at increasing wind power generation on the islands. However, the plan of building these new wind farms is raising several concerns within the local community because of the environmental damages they could cause. Particularly active on this front is the Sustainable Shetland group[30], which was funded with following objectives [159]:

- To oppose plans for very large wind farms in Shetland
- To support renewable energy projects in Shetland which are fit for scale and fit for purpose
- To support social, environmental and economic sustainability in Shetland.

According to what is reported in several local newspapers, not only the group [160] but also experts [161] and members of the local community [162] are calling for a moratorium on Shetland's wind farm projects.

Concerning the attitude of the local community towards electric mobility, some interesting information was found in a report commissioned by Highlands & Islands Enterprise (HIE) in 2016, which presents results from a study aimed at investigating the status of the energy systems of a shortlist of

[29] https://www.ofgem.gov.uk/publications/betta-user-guide-summary-new-british-electricity-trading-and-transmission-arrangements-betta-and-high-level-guide-key-activities-required-implement-new-arrangements-and-run-pre-betta-arrangements

[30] http://www.sustainableshetland.org/

Scottish Islands [163]. Although the study investigates the energy system of 10 out of the 15 Shetland islands[31], it is reasonable to assume that the results are generalizable to the entire archipelago.
The qualitative information regarding EV uptake collected through a set of interviews with islanders and HIE representatives results in the following key aspects:

- Price is the main barrier towards EV ownership. This is particularly true on remote islands, where relying on old vehicles has several additional advantages - i.e., old vehicles "can be maintained locally and are robust enough to drive on rough terrain".
- The EV charging infrastructure is still not very robust, and this could limit the ability to travel around the island. Nonetheless, it also emerged that journey times are normally short. Therefore, EVs could still be a relevant technology to islanders.
- Compared to conventional cars, despite the high capital cost, EVs have lower operating costs (i.e., fuel and maintenance). Therefore, they are likely to be more attractive for those islanders that travel regularly across islands.
- Finally, considering the entire islands' energy system, an increased penetration of EVs could bring additional benefits. In particular:
  - reduce generation constraints due to increasing electricity demand, and
  - increase flexibility by providing Vehicle to Grid services.

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[31] The 10 Shetland islands are included in a total of 49 Scottish islands for the study.

5 Discussion

This section presents an overview of the opportunities for replicating the Madeira demonstrator in the selected sites. For each island, benefits as well as potential barriers or drivers for implementing the proposed solutions are briefly discussed.

5.1 Santa Maria island - Azores archipelago, Portugal

5.1.1 Solution 1: DSM and BESS for Optimizing self-consumption

The electricity network of the island is outdated, a condition that affects the continuity and quality of the supply. This aspect could work as a driver for replicating the proposed solution. Indeed, by upgrading existing UPACs with a BESS, excess production can be stored and used as a reliable **backup in case of power outages**.

Moreover, another driver is represented by **the cost of electricity**, which is significantly higher in the Azores compared to mainland Portugal. As demonstrated in Madeira, this solution can lead to a notable increase of both SC and SS, which results in monetary savings on the electricity bill. Considering the current characteristics of the local energy market, a battery management approach aimed at maximizing self-consumption could be preferable also for those UPACs that are allowed to inject excess production into the grid. Indeed, the rates of the **feed-in tariff scheme** currently in place are lower than the residential retail electricity rates.

Finally, the adoption of this solution by local prosumers could be boosted by the **incentive schemes** provided under the PROENERGIA scheme to support the acquisition of renewable energy generation units and associated technologies.

Adoption drivers apart, there is also an aspect that could work as a barrier to the effective replication of this solution on the island: the lack of familiarity with storage technologies. The optimal use of BESS is sensitive to consumer **knowledge and prior experience with the technology**. In Santa Maria, however, there is no evidence of any use of storage devices at the household level.

5.1.2 Solution 2: Voltage Control and peak-shaving

Santa Maria and Madeira have several common characteristics, in particular the need for a solution to **increase penetration of RES while maintaining grid stability**. In this perspective, the "Voltage control and peak-shaving" pilot represents an ideal way to help achieve these goals.

That being said, it should be pointed out that the system demonstrated in Madeira operates at the LV level, while Santa Maria does not have any LV networks. Hence, in order to be implemented, the proposed solution has to be **adapted to the local conditions**.

At the moment, Santa Maria electricity network represents the main barrier to replicability. However, the number of UPACs is expected to grow, fostered by the incentives and programmes promoted by the regional government. In such a scenario, it is likely that EDA will have to make significant changes to the electricity network, which may include building distribution lines operating at LV [164]. Finally, it is worth mentioning that there are **no regulatory barriers** to ownership of storage facilities by the DSO. In fact, just like Madeira, Santa Maria is considered an 'outermost region' and, as such, it benefits from a derogatory regime to the rule imposed by Art. 36 of the EU electricity directive 2019 [9].

5.1.3 Solution 3: Smart Charging of EVs

Results from desk research show that the penetration of EVs on the island is still quite low; a fact that could be partially explained by the limited existing charging infrastructure. Nevertheless, with the

implementation of the Plan for Electric Mobility in the Azores (PMEA) and the incentives provided by the regional government, the number of EVs is expected to grow in the near future. Yet, considering that electricity prices in Santa Maria are higher than those of mainland Portugal, maintaining an electric vehicle may not be economically viable to some segments of the population. In such a scenario, implementing a smart charging approach based on pricing could facilitate wider uptake of EVs.
Moreover, this solution could be implemented to provide flexibility services to the local grid through V2G technologies. Although V2G is not yet possible (and regulated) in the Azores, a pilot test is currently running on the main island (São Miguel). The regional government is intent on leveraging the lessons learned from that pilot to plan a wider deployment of V2G. Thus, it is reasonable to assume that in the future V2G will be introduced in Santa Maria too.

5.2 Pantelleria - Italy

5.2.1 Solution 1: DSM and BESS for Optimizing self-consumption

Supplying energy on Pantelleria is complex and expensive since the power system of the island is highly dependent on fossil fuels, which are transported by sea from Sicily. The residential sector, together with services and tertiary sectors, represent most of the total electricity demand on the island - 38% and 33% respectively -, thus constituting a major target group for energy conservation and management activities. As reported in the Sicilian Environmental Energy Plan (PEARS) [66], the main goals of the regional authority are to (i) foster the installation of solar power and solar thermal generation systems so as to increase self-consumption from RES, and (ii) promote the use of storage technologies to support self-consumption and provide grid stability services. In such a scenario, the "DSM and BESS for optimizing self-consumption" solution represents an ideal means to help achieve such objectives. In particular, the implementation of the standard greedy control algorithm (see section 2.2.1) has demonstrated to be particularly effective in **increasing both Self-Consumption** - i.e., percentage of PV generation used for self-supply, and not sold to the grid - and **Self-Sufficiency** - i.e., the relation between the energy supply from local renewable sources and the total energy demand [4]. On the other hand, implementing the pre-charge control strategy could bring **economic benefits to commercial installations** (and domestic UPACs with high consumption and limited PV installed capacity) and contemporary benefit the grid operator. In fact, although the primary goal of this battery control algorithm is not the increase of self-consumption from RES, it still benefits the grid operator by **shifting the demand to off-peak periods**. Furthermore, the use of distributed storage for grid balancing and peak-shaving is included in both the Island's Energy Transition Agenda and the PEARS. Thus, the introduction of this solution is expected to be fully supported by the local stakeholders.
Nonetheless, a potential regulatory barrier towards replicating this solution does exist and is represented by the **remuneration schemes for electricity production and self-consumption** implemented by the DM 14/02/17 [63]. In fact, according to results from desk research, the feed-in tariff rates are higher than the residential retail electricity rates, thereby making self-consumption less attractive. At the same time, the premium feed-in tariff for self-consumed electricity applies only to "electricity produced and instantly consumed on-site" [63], thus raising the question of whether consumption of stored power is included in such compensation scheme or not – the legislation is not clear on this point. Therefore, both remuneration schemes need to be revised in order to favor the implementation of the proposed solution and, more in general, to help achieve the regional authority's goal of promoting the use of storage technologies to support self-consumption.
Another aspect that could affect the effective implementation of the proposed solution is **the limited penetration of renewable energy generation technologies**. Based on what emerged from desk research, it is possible to assume that there are three main barriers to the uptake of distributed generation technologies. The first one is regulatory. In fact, several <u>landscape constraints</u> limit the installation of rooftop PV systems to a few areas of the island. Nonetheless, results from an assessment

study conducted by ENEA [57] suggest that solar generation potential from rooftop PV systems in Pantelleria is significantly high despite the regulatory constraints in force. The initial investment cost for electricity generation and storage assets is another potential barrier, especially considering that the average per capita income of Pantelleria is significantly lower compared to the national average. Moreover, it is reasonable to assume that - just like in Madeira - the cost for installation and maintenance of PV and energy storage systems is particularly high on the island, given its remote geographic location. Economic constraints affecting electricity storage development in Italy mainland and Italian non-interconnected islands have also been highlighted in SMILE deliverable D7.1 Regulating Electricity Storage - Annex 3 [11]. Therefore, it is argued that financial incentives should be implemented to promote the deployment of these technologies by small-scale residential and commercial UPACs. Ultimately, one of the lessons learned from the Madeira demonstrator is that a low rate of adoption often translates into low awareness and limited understanding of the technologies. These technologies - and particularly storage - are very sensitive to consumer knowledge and behavior. Therefore, as it is also highlighted in the PEARS [66], promoting initiatives to foster education and awareness-raising is fundamental to ensure adoption and optimal use of the technology. Local stakeholders like Resilea can play a major role in facilitating the engagement and active participation of the local community in the energy transition process.
Finally, the implementation of the proposed solution in Pantelleria has the potential to **boost job creation** since the installation and maintenance of these systems require skilled labor.

5.2.2 Solution 2: Voltage Control and peak-shaving:

Pantelleria island, just like Madeira, is a total energy island. Thus, the local grid is very sensitive to variations in the energy produced by RES. Considering that one of the main objectives of Pantelleria's Energy Transition Agenda is to achieve 35% renewable electricity consumption by 2030, Distributed Energy Generation (DER) is expected to grow significantly in the coming years. In such a scenario, the "voltage control and peak-shaving" solution demonstrated in Madeira could help **prevent grid stability issues caused by an increase in DER**, and ultimately help **ensure the quality of the supply**. Moreover, this solution proved to be extremely effective in **leveling peak demand** [4]. Such a feature is particularly relevant to Pantelleria during summertime (June – September), when the electricity demand increases significantly due to the influx of tourists on the island.
As per the previous solution, the use of energy storage devices for grid balancing and peak-shaving is already included in the local energy transition plans [53, 66]. Hence, it is very likely that the local stakeholders would favor and support the replication of this solution on the island.
Moreover, results from desk research suggest that there are no **regulatory barriers** to ownership of storage facilities by the DSO that could hamper the implementation of this solution. In fact, according to the national legal framework, energy storage can concern every sector, from residential to utility. DSOs and TSOs are allowed to own storage facilities, in which case storage is considered as a grid asset [11]. In the specific case of non-interconnected islands, the DM 14/02/2017 Art. 5 (1) (a) [61] specifically includes energy storage systems among the assets that can be used by the grid operators to improve grid quality and increase penetration of RES in the mix.

5.2.3 Solution 3: Smart Charging of EVs

Results from desk research suggest that the mobility sector in Pantelleria is highly dependent on fossil-fueled old vehicles. Nevertheless, the number of EVs is expected to grow significantly over the coming years. The promotion of sustainable mobility is indeed one of the five pillars of the Energy Transition Strategy for Pantelleria, which set the goals of achieving 50% and 100% electric mobility in the private and public transport sectors, respectively [53]. Considering the future scenarios envisioned by the Transition Agenda, the implementation of the smart charging of EVs solution would further boost the energy transition of the Island. For example, the implementation of a charging strategy based on renewable availability would help **take further advantage of the local renewable energy generation**, which, in its turn, is expected to increase after the implementation of the measures envisioned in the Agenda. Contemporary, the proposed solution could provide **load leveling services to the grid** by managing the public charging infrastructure based on electricity demand. In this regard, it is relevant to mention that the energy demand on the island varies greatly between the tourist and non-tourist seasons. The seasonality of electricity demand could be incorporated in the control model and, combined with V2G[32], effectively smooth the load curve throughout the year according to such variations. The influx of tourists on the island impacts not only electricity demand but also the number of vehicles circulating in the road network. Being tourism the major economic activity of Pantelleria, implementing solutions that favor sustainable mobility is crucial and could help boost **sustainable tourism development**. At the household level, a charging strategy based on pricing could result in **economic savings** - especially when considering that the price for fossil fuels on the island is about 25% higher than the national average [52]. Ultimately, as for the "DSM and BESS for Optimizing self-consumption" solution, the implementation and maintenance of this system require skilled labor, thus fostering **job creation**.

Despite the potential benefits that the proposed solution could bring, the **limited penetration of zero-emission vehicles** represents an obvious barrier to its effective implementation. Several are that possible factors that are currently contributing to the low level of EV uptake. The fact that EVs have a high capital cost (although the operating cost is lower than that of conventional cars) is probably one of them. Although the Municipality is committed to attracting regional funding to provide financial incentives for electric mobility, it seems that there are no such incentives at the moment. Also, the high air salinity level on the Island discourages residents from replacing vehicles before the end of their useful life [53]. Desk research has further suggested that the charging infrastructure of the island still needs significant upgrades to allow for wider uptake. Hence, the effective replication of the proposed solution in Pantelleria would depend on the implementation of infrastructural development plans set out as part of the local energy transition strategy. Finally, it's argued that initiatives aimed at **raising awareness of the economic and environmental benefits of smart charging and electric mobility** are fundamental to ensure technology adoption. Indeed, based on the experience gathered in Madeira, it emerges that the general lack of knowledge of smart charging technologies could severely hamper the implementation of this solution.

[32] Currently, the implementation of V2G technologies, which should comply with the dispositions of the DM 30/01/2020 [165], is still limited to pilot projects. Nonetheless, it is reasonable to assume that an interest to implement V2G technologies nationwide does exist.

5.3 Astypalea - Greece

5.3.1 Solution 1: DSM and BESS for Optimizing self-consumption

Based on the knowledge gathered through desk research, the replication of the proposed solution in Astypalea appears to be particularly advantageous for the network operator, both in the present and future scenarios. By allowing prosumers to increase SC and SS through DSM functionalities, the proposed solution could help reduce the amount of RES injected into the grid - which is currently saturating the network - and ultimately create the conditions for allowing new installations.
Now, looking at the future scenario, the implementation of this solution appears to be even more crucial. The island has indeed the ambition to have its energy system running 100% renewables. The local stakeholders are very committed to achieving this goal. Several initiatives have been launched, with the "smart and sustainable island" project leading the effort of increasing penetration of (distributed) renewable generation and storage technologies. As observed in other locations (e.g., Texel), the increase of renewable electricity generation must be combined with the deployment of energy balancing solutions. In this sense, wider adoption of the proposed solution at the household level could help manage DG in a more coordinated manner. However, it should be pointed out that at the moment there are no incentive schemes for the acquisition of storage technologies. This lack of financial support could represent a barrier to the large-scale implementation of the proposed solution.

5.3.2 Solution 2: Voltage Control and peak-shaving

The penetration of RES on the island is causing grid stability issues and has already reached the limit set by RAE. Thus, except for a few exceptions, no more PV generation units can be installed at the moment. The proposed solution, if replicated in those areas of the grid particularly affected by distributed renewable electricity generation, could help reduce the strains on the local grid and ultimately create the conditions for allowing new installations.

5.3.3 Solution 3: Smart Charging of EVs

The issues related to RES penetration that are currently affecting the grid can be seen as an opportunity for implementing the proposed smart charging solution. Specifically, a mixed approach could be implemented to manage the entire public EV charging infrastructure in such a way to (i) absorb excess production from RES (i.e., a strategy based on renewable availability) and (ii) flatten load profiles at peak times (i.e., a strategy based on electricity demand).
This solution could also bring benefits if implemented at the household level. For example, families that own both an EV and a solar generation unit can maximize self-consumption by scheduling the charging according to their production patterns. On the contrary, a charging strategy based on pricing would be particularly suitable for households that do not own any energy generation asset.
A further aspect that is worth mentioning when assessing the replication potential of this solution relates to end-user acceptance of smart charging technologies. As emerged in Madeira, the adoption of smart charging can be significantly affected by users' prior experience and knowledge of the system. In Astypalea, thanks to the Volkswagen project and the initiatives promoted under the framework of Astypalea 4.0, the local community is being actively engaged with the development of electric mobility and informed about the potential offered by EV-related technologies like smart charging. These initiatives are crucial and would definitely facilitate the adoption and effective implementation of the proposed solution by the local community.
Finally, another important driver to the replication of this solution is represented by the incentives for the installation of smart charging points provided by the e-Astypalea scheme.

5.4 Ærø – Denmark

5.4.1 Solution 1: DSM and BESS for Optimizing self-consumption

Based on the knowledge gathered through desk research, it emerges one circumstance characterizing the local energy system that could be leveraged for replicating the "DSM and BESS for Optimizing self-consumption" solution on Ærø. Specifically, it relates to the fact that, in some periods of the year, electricity production from RES exceeds the demand. Despite this information refers to the overall renewable energy production on the island, we can assume that the same pattern characterizes production from small-scale solar PV generation units. In fact, by crossing the data gathered about nº of residential PV installations and total installed capacity, it results that the average capacity per unit is fairly high (approximately 5kW). In this scenario, the system deployed in Madeira would provide households with a solution to maximize SC. This outcome, in its turn, would result in economic savings since the cost of electricity in Denmark is among the highest in Europe.
At the same time, in those cases where there is no significant excess production, the very same outcome can be obtained by implementing a pre-charge control strategy.

5.4.2 Solution 2: Voltage Control and peak-shaving

The implementation of the "voltage control and peak-shaving" solution is particularly relevant for Ærø as it has the potential to help solve several issues that the local energy system is currently facing (as well as some problems that might arise in the future if the island becomes energy independent).
As previously mentioned, there are periods of the year when production from RES exceeds the electricity demand of the island. In those cases, the "voltage control and peak-shaving" solution can be leveraged to store excess production for later use - for example to meet district heating demand - instead of exporting electricity to other regions.
Also, considering the weaknesses of the grid connection infrastructure, storing excess production could offer a backup solution to manage the supply when failures in the infrastructure cause the submarine cables to disconnect.
Moreover, the flexibility offered by such a system can be used to help cover the increase of the energy demand that characterizes some periods of the year. Finally, once the external grid connections are removed, it can serve as a highly responsive storage backup to help balance demand and generation locally.

5.4.3 Solution 3: Smart Charging of EVs

The analysis of the local boundary conditions suggests that there are opportunities for replicating this solution on the island.
First, the implementation of a smart charging approach based on the availability of RES would be particularly relevant during those periods of the year when renewable energy generation exceeds the total electricity demand.
Secondly, this solution could bring economic benefits if implemented at the household level. The cost of electricity in Denmark is indeed among the highest in Europe. Hence, a charging strategy based on pricing could help reduce the impact the charging an EV may have on the electricity bill.
Finally, considering a future scenario where external grid connections are removed, the large-scale implementation of this smart charging solution, combined with V2G functionalities, would provide an effective grid management mechanism.

5.5 Texel - The Netherlands

Although Texel is electrically connected to the mainland, there is a strong commitment to making the island energy neutral by leveraging the significant availability of renewables in the area – particularly sun and wind. However, results from desk research have shown that the characteristics of the local power network are acting as a barrier to achieving such an ambitious goal, suggesting the **need for implementing energy balancing solutions** – e.g., Demand Side Management (DSM) and EVs to provide flexibility to the grid [96].
In such a scenario, the implementation of the proposed solutions on Texel could help improve the overall grid performance by providing the flexibility that the local network needs.

5.5.1 Solution 1: DSM and BESS for Optimizing self-consumption

The exponential growth of distributed solar generation on the island is affecting the distribution network by causing grid congestion. For this reason, the system operator has temporarily imposed restrictions on new grid connections while implementing network expansion measures. A possible workaround to reduce grid congestion is to **favor self-consumption** over power injection into the grid. In fact, the data provided by the Association of Dutch Municipalities shows that, in the face of the high penetration of distributed solar generation, the self-consumption rate on the island is still relatively low – corresponding to 3,7% of the overall consumption in 2018 [104]. Hence, implementing the "DSM and BESS for Optimizing self-consumption" solution offers a way to reduce the strains that are currently affecting the distribution network and, in the future, may help avoid further grid expansions. In the long term, end-consumers are those that would benefit the most from the implementation of this solution; and not only because **grid expansions costs** are paid for by a levy on all customers' energy bills [106]. The **electrification of the heating system** envisioned by the Regional Energy Strategy (RES) for the Noord-Holland province, together with the **removal of the net-metering scheme**, are likely to increase the already high rate of energy poverty on the island. Depending on the characteristics of the solar generation units, both battery control strategies – i.e., greedy and greedy with pre-charge – can help reduce the households' electricity bills.

5.5.2 Solution 2: Voltage Control and peak-shaving

Compared to other replication sites, the information regarding the distribution network design of Texel is limited. Solely based on the knowledge gathered, we can speculate that the "Voltage Control and peak-shaving" solution would help the network operator deal with the issues caused by the high penetration of RES from DG - particularly **grid congestion**. By installing a BESS in those <u>areas of the grid with a high number of small generation units connected to it</u>, excess production can be stored and then used as a backup to balance the grid; and ultimately, reducing electricity import from the mainland by maximizing the consumption of renewable energy generated on-site. However, in order to work, **this solution needs to be adapted to local conditions**. The system has indeed been developed to operate at the LV level while, according to desk research, it seems that the network on Texel only operates at the MV level.
Similarly, the system could be adapted and **deployed at the new solar meadow** located at the Everstekoog sewage treatment plant. According to what is reported on the TexelEnergie website, the possibility of upgrading the generation plant with storage systems is already under consideration. If a positive decision is reached, the proposed control system would represent <u>a fully automated solution to achieve better management of the power generated</u> according to the grid needs.
That being said, the information gathered is not enough to fully assess the replicability potential of this solution. For that purpose, further research is needed.

5.5.3 Solution 3: Smart Charging of EVs

According to the data provided by the Association of Netherlands Municipalities, EV uptake is increasing at a rapid rate in Texel [105]. Hence, the implementation of the EVs smart charging solution here proposed could bring significant benefits to the local grid, especially when considering the current capacity issues caused by RES. In fact, the system can be used to manage the entire public/semi-public charging infrastructure (around 130 charging points [166]) according to renewable energy availability. At the household level, different smart charging strategies can be implemented to meet the needs of diverse EV owners. For example, households owning both an EV and a solar PV generation system could manage the charging of their vehicles in such a way to take advantage of self-generated energy - and perhaps other incentives (e.g., reductions on the Environmental Protection Tax). On the contrary, those individuals that do not have the opportunity of generating their own electricity, can use the system to schedule the charging according to their electricity tariffs, thus lowering their electricity bills. While, for scenarios where more than one EV are under charge at the same time (for example, a common parking lot at an apartment building), the charging can be optimized according to aggregated energy consumption so as not to exceed the building power limit. Finally, another important market segment for this solution is represented by the ten EV rental companies currently operating on the island. Besides the obvious advantages of adopting charging strategies based on pricing, these company can also access incentive schemes directed to companies for installing or upgrading their EV charging stations, such as the Environmental investment allowance (MIA) [177].

5.6 The Shetland - Scotland

At the time of this writing, the Shetland archipelago is energy independent. However, the **project for connecting the local electricity network to mainland Scotland** is expected to solve (or at least significantly mitigate) most of the issues characterizing every isolated grid - e.g., voltage and frequency fluctuations, which are addressed by the solution nº 2. The proposed solutions are particularly suited for non-interconnected energy systems. Nevertheless, if replicated in the Shetland islands, they can still bring benefits after the completion of the planned grid connection.
Another aspect worth mentioning before discussing the RA results concern the RES available in the archipelago. In fact, unlike the other islands analysed, **the main RES available in the islands is wind**, while solar radiation is very low. Therefore, the proposed solutions should be adapted to wind power in order to be effectively replicated in the Shetland.

5.6.1 Solution 1: DSM and BESS for Optimizing self-consumption

The isolated nature of the local grid, which makes it very sensitive to sudden variations in renewable energy generation, has forced the network operator to impose restrictions on grid access [145]. These restrictions, in their turn, are preventing prosumers to enter the energy market and benefit from incentive schemes for renewable energy generation such as the Smart Export Guarantee. In such a scenario, the "DSM and BESS for Optimizing self-consumption" represents an ideal solution for a genuine problem. Through this system, prosumers can indeed maximize the use of self-generated energy while lowering the amount of electricity purchased from the utility. In this regard, it is worth recalling that, despite electricity consumers are free to choose their supplier, the electricity bill in North Scotland is the highest of all regions in the UK. This is particularly relevant for those households located in rural areas, which are characterized by higher fuel poverty rate and the use of electricity as the primary heating fuel [149]. Since the proposed solution allows to achieve monetary savings by maximizing both SC and SS, it will still benefit end-user; even after the connection of the local electricity network with the one of mainland Scotland.

User acceptance of energy storage technologies is a prerequisite for implementing this solution. In the case of the Shetland, it is reasonable to expect a positive attitude towards the adoption of these technologies by the local community. Small-scale energy storage solutions have indeed been already deployed as part of the NINES project and, apparently, no relevant adoption barriers have emerged so far.

5.6.2 Solution 2: Voltage Control and peak-shaving

As mentioned above, the connection with mainland Scotland's electricity network is expected to solve the stability issues that currently affecting the local grid. However, when considering the present scenario, the "Voltage Control and peak-shaving" solution presents itself as a possible way to temporarily reduce the strains that variations in renewable energy generation are putting on the grid - and possibly help lift some of the current restrictions on grid access. In this sense, it does not only offer a mechanism to manage the power from distributed generation and turn it into an asset to support the grid, but also provides a solution for increase the penetration of RES.
That being said, when considering that in the near future the Shetland will be able to exchange energy with the mainland (and also benefit from several upgrades to the network infrastructure included in the HVDC project), replicating the proposed solution may not be economically advantageous.

5.6.3 Solution 3: Smart Charging of EVs

Results from desk research suggest that electric mobility is slowly gaining ground in the archipelago. In the current scenario, the implementation of the smart charging solution here proposed has the potential to bring significant benefits to the local energy system and ultimately help boost the uptake of EV in the archipelago. First, the existing public charging infrastructure could be controlled with an approach based on the availability of RES, so as to maximize the use of the wind power that will be generated by the several wind farms currently under construction. Such a strategy is expected to be even more relevant once the connection with Scotland mainland is completed. Indeed, by favoring consumption from RES generated locally, it could help limit electricity export to the mainland.
Finally, in the current scenario (i.e., with no connection to any other landmass network) the implementation of a mixed smart charging approach (i.e., based on electricity demand and RES availability), possibly combined with V2G services, would provide additional flexibility to the grid by absorbing (charging) excess of RES and returning power (discharging) to the grid when needed - e.g., at peak times.

6 Conclusions

This report presents the results of an assessment conducted to investigate opportunities for replicating the Madeira demonstrator on other EU islands. The research approach adopted was informed by the analysis of relevant literature and is heavily based on the one used to investigate replication potential of the Grid4Eu project demonstrators in non-EU contexts [17].
The framework used for the present analysis (thoroughly described in Section 3) is structured around three domains - (i) technical, (ii) regulatory, and (iii) socio-economic - and for each identifies a set of factors that could either limit or facilitate the replication of the proposed solutions in other locations.
In order to ensure a certain degree of heterogeneity within the sample while keeping the task of information gathering manageable, it was decided to select one replication site for each country of the project consortium (Portugal, Scotland, Denmark, Italy, Greece, and the Netherlands). The selection was conducted according to the set of criteria described in section 3.3 and resulted in the identification of the following replication sites:

- Santa Maria island - Azores archipelago, Portugal
- Pantelleria island – Italy
- Astypalea island – Greece
- Ærø island – Denmark
- Texel island - The Netherlands
- The Shetland islands – Scotland

The technical, regulatory, and socio-economic boundary conditions were analysed through desk research. The potential for replicating the proposed solutions on the selected sites was elaborated based on the results from the analysis (reported in Section 4) and is discussed in Section 5.

The reader should be warned that by no means this report should be intended as replication plan. Rather, it consists of a qualitative analysis of the technical, regulatory, and socio-economic boundary conditions characterizing the selected sites, conducted with the only goal of identifying potential barriers and drivers for replicating the proposed solutions.

6.1 Challenges and limitations

The RA reported in this deliverable presents some limitations due to the several challenges that emerged during desk research. Among them, it is worth mentioning that the amount and quality of the publicly available information varies significantly from island to island and domain to domain. In some cases, it was only possible to find information related to the entire archipelago (e.g., the Azores) or island group (e.g., IMI and NII). This, in particular, is true for the regulatory domain since most of the existing renewable energy policies and sustainability programmes target the entire island group. In most of these cases, it is not possible to say whether or not the way these programmes are administered varies from island to island. Moreover, much of the information available was not in English, and recent data (i.e., related to the present or previous year) was not always available. For these reasons, results from the analysis are often presented in the form of assumptions.

To conclude, it is important to remark that the present report is a qualitative assessment of the technical, regulatory, and socio-economic boundary conditions that could influence the possibility of implementing the Madeira demonstrator in the six selected replications sites. Therefore, it should not be intended as a replication plan.

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