IANOS

SUSTAINABLE SOLUTIONS
for islands' decarbonisation

D9.3 Fellow Islands Replication and Scalability Plan

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IANOS

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Executive Summary

This task deals with a thorough investigation of the replication potential of two decarbonisation scenarios demonstrated on Lighthouse Islands (LHs) on the IANOS Fellow Islands (FIs), aiming to enable and facilitate their energy transition. A long-term plan for replication activities will be demonstrated by the three Fellow Islands (FIs) of Lampedusa (IT), Bora Bora (FR), and Nisyros (GR) taking into account their current policies, specific needs and selected use cases. The political, social, legal, economic, technological, and environmental aspects of the replication framework specifically identified for each island ecosystem and its stakeholders are analysed. A Master Use Case associated with adopted technologies and use cases aggregated for replication in the context of islands' decarbonization will be documented by the municipalities, supporting partners and island stakeholders, considering replication actions either during the project or a few years after it ends. The LHs of Ameland (NL) and Terceira (PT) will serve as mentors for FIs. The technical and economic feasibility of the Master Use Cases, that have been defined and formulated from the use cases and solutions deployed in the project, will be investigated considering the future energy trends and how they may affect the replication potential, and identifying the most efficient pathway towards maximizing replication and exploitation. The Island Energy Planning and Transition (IEPT) toolkit (WP3) will be used to build upon the data and information coming from each FI ecosystem, in order to evaluate the impact of every defined Master Use Case and scenario (while taking also into account results from the CET-developed tool and T8.2). Results and outcomes aim to support IANOS FIs in the development of a detailed and comprehensive replication strategy and provide guidelines for the creation or update of their Sustainable Energy and Climate Action Plans (SECAPs).

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Abbreviations and Acronyms

BESS	Battery Energy Storage System
CBA	Cost Benefit Analysis
DSO	Distribution System Operator
EV	Electric Vehicle
EDA	Electricidade dos Açores
EU	European Union
FI	Fellow Island
GHG	Greenhouse Gas
IEPT	Island Energy Planning and Transition toolkit
iVPP	Intelligent Virtual Power Plant
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LH	Lighthouse
MUC	Master Use Case
PMEA	Azores Electric Mobility Programme
PV	Photovoltaic
RES	Renewable Energy Sources
SECAP	Sustainable Energy and Climate Action Plan
TT	Transition Track
UC	Use Case
V2G	Vehicle to Grid
WP	Work Package

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1. Introduction

1.1 Scope and Objectives

The IANOS project aims at decarbonising the energy systems of European islands that are characterised by common challenges in terms of energy requirements, population, climatic conditions and topographic characteristics. During this project, a set of innovative technologies will be demonstrated in two Lighthouse (LH) Islands, Terceira in Portugal, and Ameland in the Netherlands, while the possibility of replicating some of these solutions in the Fellow Islands will be explored. More specifically, a set of use cases and associated technologies in the context of decarbonisation scenarios will be examined for the 3 Fellow Islands (FIs), Bora-Bora, Lampedusa and Nisyros, based on the demonstration of the real-life operational Use Cases in the two LH Islands. In addition, and considering the specific FIs needs, the impact on the energy system will be evaluated.

Deliverable *D9.3 – Fellow Islands Replication and Scalability Plan* is inserted in Task *T9.2 - Fellow Islands Replication and Scalability Plan*, which is part of Work Package *WP9 – Replication/Scalability in EU Islands*. This deliverable will be gathering all knowledge, data and IEPT tool results of IANOS for the replication and scalability activities in the three FIs of Bora-Bora, Lampedusa and Nisyros, and will present a detailed replication plan for the FIs. The deliverable aims to cover all regulatory, technical, economic, and environmental aspects pertaining to the local ecosystem and the energy domain of the Fellow Islands as well as to describe the Use Cases that will be examined for replication in the context of IANOS and explore their replicability and up-scaling potential. For this purpose, a "Master Use Case" (MUC) for each Fellow Island will be defined and presented which will summarise the main actions to be taken in terms of RES penetration in the energy mix and decarbonisation of the islands' energy system, that could be easily replicated in other EU geographical islands.

For these purposes, this deliverable will also present the simulation results of the IEPT tool introduced in Task T3.3 concerning the impact of the decarbonisation scenarios on the islands in the medium and long-term. The outcome and conclusions of the islands' replication planning, analysis and

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assessment will be utilized in the development and/or the update of the Sustainability and Climate Action Plans (SECAP) for each island. Task T9.2 and deliverable D9.3 will result in a clear, sustained and comprehensive replication plan for the decarbonization of the three IANOS Fellow Islands (FIs).

The 1st **version** of the deliverable focuses mainly on understanding the island ecosystem and the key aspects of the replication framework in the context of the energy transition, describing the methodological background for assessing the replication potential across the FIs, as well as on analysing and presenting the current situation of the energy networks in the islands (baseline).

1.2 Structure of the deliverable

Deliverable D9.3 is structured as follows:

- Chapter 2 – Description of the replication framework is provided. A detailed description of the legal/regulatory context, economic, technological and environmental aspects for each Fellow Island is provided.
- Chapter 3 – The methodology for the replication potential assessment under two decarbonisation scenarios (high- and very high-RES penetration) is presented. Moreover, the definition of the Master Use Cases for each Fellow Island is provided. The set of Use Cases (based on those described in WP2 and implemented in WP5 and WP6, as well as the specific FI needs and goals), and the technologies that will be selected to be used for the replication actions will be presented. A Master Use Case will be built based on this set of desired and feasible use cases for each island.
- Chapter 4 – The IEPT simulation results will be presented having in mind the replication goals of each Use Case and Fellow Island. The IEPT tools and KPIs will be briefly described. The current state and operational situation of the island's energy system is initially presented. The impact and expected outcomes of the Master Use Case for the two decarbonisation scenarios will be evaluated.
- Chapter 5 – Conclusions. Conclusions regarding the energy characteristics and transition opportunities of IANOS Fellow Islands (FIs) are presented.

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In the **2nd version**, a summary of guidelines for the update of the Sustainable Energy and Climate Action Plans of each Fellow Island, including mitigation actions to be directly implemented by the municipalities will be added.

1.3 Relation to other activities

Task *T9.2 – Fellow Island Replication and Scalability Plan* in which this deliverable is inserted, is part of Work Package *WP9 – Replication/Scalability on EU islands* and will be utilizing the conclusions of several IANOS tasks in order to provide a clear plan for the decarbonization of the Fellow islands.

Most importantly, this task will be presenting the tools and knowledge gathered in the two demonstrator Work Packages (*WP5 – Deployment, Use Cases Realization and Monitoring at LH#1 Ameland* and *WP6 – Deployment, Use Cases Realization and Monitoring at LH#2 Terceira),* and summarising all aspects needed when elaborating a decarbonization plan, including social, economic, technical, regulatory and environmental aspects.

The social aspects that this deliverable addresses will be the conclusions of *Task T8.3 – Capacity building through training sessions for LHs, Fellows and EU Islands* inserted in *WP8 - Energy Cooperatives and Stakeholders Engagement*.

Furthermore, the simulations performed during T9.1 will be using the IEPT developed under *T3.3 - Energy Planning & Transition Decision Support Toolset* belonging to *WP3 - Transition and Investment Decision Support Framework*, as well as the pre-feasibility study conducted under *T3.4 – Decision Support Toolset Pre-Validation/Assessment of LH & Fellow Islands Plans* of the same WP3.

Finally, the results and conclusions presented in this deliverable will be used to feed the Islands Master Plans being developed under *T2.4 – Islands Decarbonisation Master Plan* in *WP2 - Requirements Engineering & Decarbonization Road-mapping*.

The relationships between T9.2 and the other Tasks and Work Packages of IANOS are highlighted in Figure 1.

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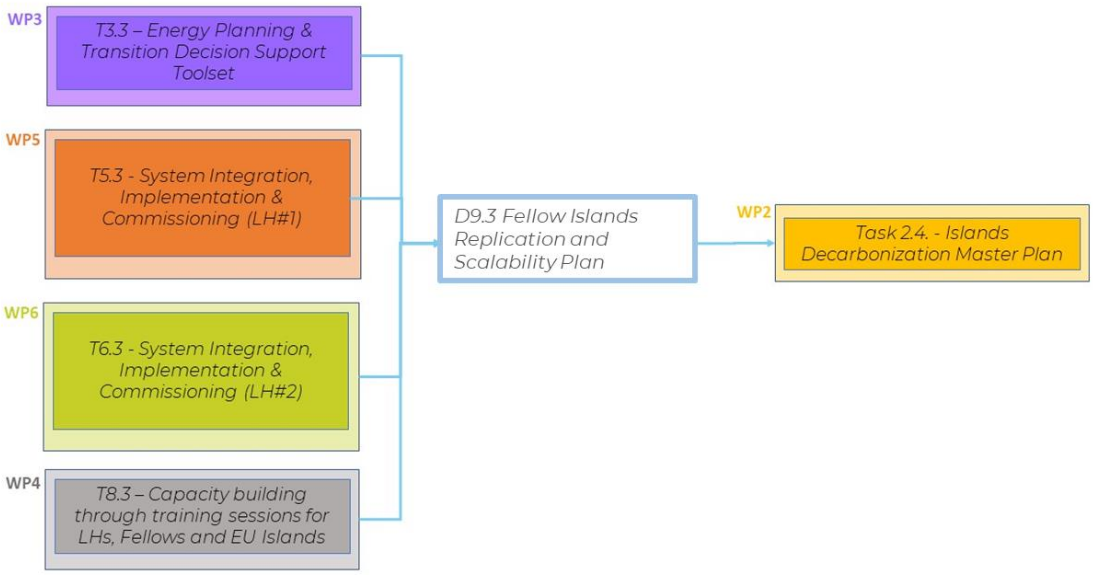

Figure 1 Relationship between D9.3 and other Tasks in IANOS

1.4 The Concept of Replication in IANOS

The term "**Replication**" in IANOS refers to use cases and innovative solutions demonstrated in the **2 Lighthouse Islands** (LHs), which are of interest to be replicated or even deployed on a large scale within the island context, both on the Lighthouse (LHs) and Fellow Islands (FIs). The two IANOS "LHs", Ameland (NL) and Terceira (PT), deal with different grid conditions, RES penetration levels, and technical challenges. The islands will help each other to select specific project solutions implemented from the "pilot use cases", in their future decarbonization plans in order to make further improvements in their energy systems and achieve their foreseen energy security and sustainability goals. This is a theoretical exercise supported by the **IEPT suite** of IANOS.

The replication studies aim at evaluating the **technical and economic feasibility** of those specific use cases in IANOS islands through the modelling of **two scenarios of renewable energy penetration** in the energy mix of the islands' grid (in the range of 50% RES, and near Fossil Free). The **current state of the islands' energy system** serves as a reference point (**baseline scenario**) against which they can build their replication plans and evaluate the impact. Figure 2 depicts the IANOS approach for the replication studies.

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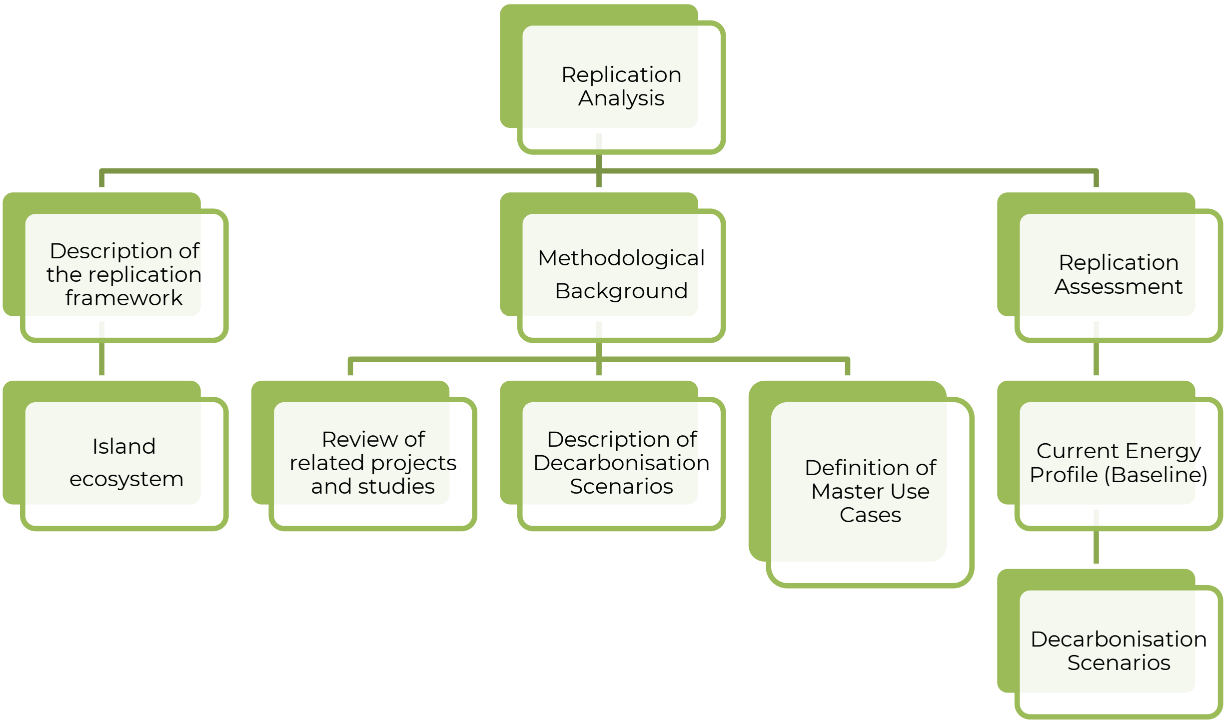

Figure 2 Replication Analysis in IANOS

As a first step, the **replication framework** sets the scene for the **islands' profile and ecosystem**. Next, the **methodology** for the replication analysis is presented, considering the specific context of IANOS, but also reviewing the approach of other relevant **projects and studies applicable in the island context**, dealing with **decarbonisation scenarios**. Building upon the island ecosystem and energy transition objectives, a **Master Use Case** (MUC) will be defined for each island aggregating selected use cases deployed in the LHs suitable for each FI, and including specific IANOS solutions to replicate and/or scale up in targeted areas on an island-wide scale to maximise impact.

The expected impact of the selected solutions will then be evaluated in terms of **energy, environmental and cost-benefit analysis**, taking into account the two foreseen **decarbonisation scenarios**, in the medium and long-term, aligned with the **EU Climate Law** and **Fit for 55 package** decarbonisation strategy. Results will provide useful guidelines to establish clean energy transition pathways towards the transformational socio-technical change in the energy systems of the islands. The outcomes will support knowledge and social awareness of innovative solutions to the island communities and the general public, fostering their adoption and replication among geographical islands, in line with the objectives of the **Clean Energy for EU Islands Initiative**.

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2. Description of replication framework

This section provides an overview of the replication framework of IANOS **Fellow Islands (FIs)**, which comprehensively summarizes the main aspects for the **island ecosystem** and the most important facts that should be considered when investigating replicable and sustainable solutions for their clean energy transition. Therefore, the **island dynamics** and the local conditions in terms of sustainable development are studied, based on literature review, research on national/regional regulations and governmental policies, as well as the local stakeholder perspectives and proposals. The next important step of the replication studies is the analysis of the **current state of the islands' energy system**, which serves as a starting point (**baseline scenario**) from which they can define their climate and energy strategy, build their replication plans, and evaluate the impact of the envisioned results.

To this end, the main contextual aspects pertaining to the energy transition and decarbonisation of IANOS islands are identified in this section, covering the most significant factors that shape current island dynamics at all levels. These factors constitute crucial elements of the island ecosystem and affect the choice of solutions to be considered for the replication actions of each island's decarbonisation plan. The aspects of the replication framework have been classified into the following, interrelated domains:

- Political & Social Aspects
- Legal Aspects & Regulatory Framework
- Economic & Technological Aspects
- Environmental Aspects

A qualitative assessment of the various political, social, legal, economic, technical and environmental aspects and conditions is introduced to provide the foundations on how to best define the master use cases, which will be tested for the replication and upscaling of specific IANOS technologies that can serve different functional purposes in the grid context, based on the **specific needs and targets** of each island. A detailed description for each FI island is presented below.

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2.1 Bora-Bora Fellow Island

2.1.1 Political & Social Aspects

Demography

The island of Bora Bora is a small and volcanic island measuring 30 km2. Bora Bora is located in the South Pacific Ocean (in the middle between Australia and South America) and is part of French Polynesia in the archipelago of the Society's islands, about 260 km northwest of Tahiti. During World War Two, the island served as a military supply base for the United States; in 2004, all of the French Polynesia islands were granted limited autonomy and citizenship, but would remain under French administration and legal jurisdiction.

The municipality of Bora Bora has 9,878 inhabitants (2023). Inhabited since the 4th century A.D. by the ancient Polynesians, it was first sighted by Europeans in 1722. Today, like most of the Polynesian islands, Bora-Bora bases its economy essentially on fishing and tourism.

Brief overview of the political system

French Polynesia is a French overseas collectivity, currently governed by Article 74 of the French Constitution of 1958 and Organic Law No. 2004-192 of February 27, 2004, on the status of autonomy of French Polynesia. It is a parliamentary democracy and enjoys broad political autonomy. The executive body is the government (formerly the Government Council), which is under the control of the Assembly and is chaired by the President of French Polynesia, who is elected by the Assembly. Legislative power is vested in both the government and the Assembly of French Polynesia.

Government policies regarding clean energy transition and decarbonization

Here is an overview of the electricity mix in French Polynesia. In 2019, renewable energies contributed to about 30% of the electricity production in French Polynesia, they are mainly located in Tahiti (hydroelectricity in majority), in the other islands the production of thermal origin is predominant. Because of this division, the carbon content is 510 gCO_2/kWh on Tahiti and 938 gCO_2/kWh on the other islands. The Polynesian electricity mix remains highly carbon-based [1].

In 2018, of the 689 GWh of electricity produced, 47.9% came from fuel oil combustion and 22.9% from diesel, only 23.7% from hydroelectricity and 5.4% from photovoltaics. Wind power is almost non-existent, representing less than 0.1% of the mix. The production of electricity is the second greatest source of CO2 emissions in French Polynesia, behind the transport sector.

However, these regional statistics hide significant disparities between the five Polynesian archipelagos and between the islands, each of which has an independent electricity system, making it all the more difficult to develop a common energy policy for the whole of French Polynesia.

Government Policies at the French Polynesian level

The energy transition appears to be a consensual issue in Polynesian politics, shared by the three main parties, the Tavini (pro-independence-left), the Tapura (autonomist-center right) and the Tahoeraa (autonomist-right). However, the fragility of successive government majorities, fourteen in seventeen years, has hampered the development of a coherent energy policy. Moreover, the conduct of the energy transition has suffered from the scattering of responsibilities for reasons of political balance in the Polynesian government. As an example, from 2011 to 2013, the energy transition was divided into four different ministries, between agriculture for biomass, marine resources for other renewable sources, finance for pricing, and the Ministry of Energy for the rest.

Nonetheless, The Polynesian government made a commitment in 2008 to achieve 50% renewable energy by 2020 and 75% by 2030 after the signing of the first "Climate-Energy Plan" in 2015.

Moreover, to influence international climate negotiations, the Polynesian government has invested in various regional cooperation bodies, such as the Polynesian Leader Group, which brings together Samoa, Tonga, the Cook Islands, French Polynesia, Niue, Tokelau, Tuvalu and American Samoa, whose climate talks it hosted in July 2015 a few months before the COP21.

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Policies at island level

Bora Bora has set itself the ambitious goal of zero carbon energy and 100% electric mobility within 10 years. In November 2021, Bora Bora council and the local grid operator Electricity De Tahiti (EDT) signed an amendment to the concession contract for the public energy service to integrate an investment program of 500 million FCFP in favor of the energy transition. It also entails the establishment of a production regulator facilitating the placement of renewable energies in the concession with the objective of reaching 20 to 25% of RE, that will allow the introduction of 5MWp of photovoltaic production.

The installation of a production regulator makes it possible to implement the SWEET project (Solar and Sea Water Experiment for Energy Transition), co-built between the Akuo group and the Bora Bora's municipality, consisting in the installation of two sources of production: solar production and the thermal energy of the seas.

The installation of a 5MW/5MWh battery to be built by the grid operator EDT at the same time that the SWEET project mentioned above to support the grid with the implementation of RE on Bora-Bora Island.

Local energy demand vs. energy poverty

On Bora-Bora, the total electricity produced in 2020 was 35.6 GWh (vs. 43GWh in 2019 – this is due to the pandemic context in 2020 which affected the tourism), of which 94,6% is generated by 8 diesel generators, whereas the remaining 5,6% stems from PV panels. The electricity networks are not built to cope with peak demand especially during high tourism season, when air conditioning can account for up to 50% of the electricity consumption.

Polynesia's dependence on energy imports is high, reaching 93.7 percent in 2018. The supply of hydrocarbons for electricity production is ensured by two companies, Pacific Petroleum and Services and PétroPol, both owned by Polynesian investors, respectively in charge of the supply of oil and gas to the country.

Additionally, electricity production and consumption are unevenly distributed over the territory as they are correlated with the geographical distribution of the population.

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• Tahiti, where most of the Polynesian population is concentrated, accounted for 79% of French Polynesia's electricity production and 71% its electricity consumption in 2019.

• Excluding Tahiti, Bora Bora and Moorea account for approximatively 60% of the total energy produced (in "small islands").

• Due to this uneven distribution, and due to the remote location of many small islands and atolls from Tahiti, energy poverty in these small and remote islands is a concern. To overcome this situation, the government is aiming at developing more RE on these islands to help them become more independent and allow inhabitants to have better access to electricity.

Engagement of islanders (including energy communities/cooperatives)

There is great interest and potential among local residents to engage in the island's decarbonisation process and the development of green energy solutions in sectors such as heating & cooling, transport, agriculture and tourism. Bora Bora's Island community is well aware of the need to protect the environment and foster sustainable development, incl. through the increase of RES. The Council held numerous public meetings on the preservation of the lagoon and water resources, as well as on the development of RES and scalability.

The IANOS project, as it will be implemented, eventually aims at durably fostering public commitment to the decarbonization process. The option to establish a local energy community, has been discussed among citizens and community stakeholders (and among involved IANOS partners). Several themes have already been guiding the discussion, such as powering fruit and vegetable cultivation in greenhouses with renewable electricity, or the use of electricity to power boat mobility on the lagoon.

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2.1.2 Legal Aspects & Regulatory Framework

Regulation authority

The Department of Energy (Service des Energies) has been created in 1982 and is in charge of:

- Regulating and controlling the electricity activities;
- Ensuring a technological watch and promoting RES development;
- Regulating and controlling the hydrocarbon activities;
- Suggesting updates of the laws to the ministry.

Key members include:

- Pierre Boscq (Office manager).
- Emilie Chapelier, in charge of Energy Affairs.
- Jimmy Gardan, in charge of Energy Affairs.

Bora Bora, located in French Polynesia, is located more than 16 000 km from Europe, thus is not under European laws. However, the island belongs to French Territories. Thus, French Polynesia is subject first to the French-Polynesian rules, then to the French ones which are most of the times linked directly to the European ones.

At the French Polynesian level, the energy transition is core to current development policies in French Polynesia. Within that perspective, the local authorities of the archipelago have been pushing policies to enhance the share of RES in the total primary energy consumption. Several energy transition targets were set in 2013, with the country's law n°2013-27 which envisaged increasing the share of renewable energies in electricity production to 50% by 2020. On this point, a multi-year agreement for the period 2015-2020 has been signed between French Polynesia and ADEME (Agency for the environment and energy management). Building on such endeavour, the recent law adopted in 2019 (Law of the country n°2019-27) has set an ambitious target of 75% of electricity production from renewable energy sources by 2030. This target is to be met through a support program designed by the French Agency for Development and the Polynesian authorities. Thus, grid operators are required to give priority to electricity from renewable sources over electricity from fossil fuels (priority flow of renewable energies).

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Instead, Bora Bora wants **to be the first island in Polynesia** to achieve targets **for the use of renewable sources of 75% up to 100% by 2030**. Within this objective, Bora Bora mayorship has been pushing new policies in the field of electricity production and transports, using renewable energies. The local authorities have set three intermediary milestones to reach its energy transition goals:

- **by 2023**: reach commissioning and start operation of a 2,5 MWp solar greenhouses power plant run by Akuo Energy, reach commissioning and start operation of an electricity battery storage run by EDT (grid operator) and stop one diesel generator.
- **by 2025**: reach commissioning and start operation of a 2,5 MWp solar farms and rooftops and stop a second diesel group.
- **by 2030**: implement hydrogen mobility, implement Pyrolyzer (thermal elimination of waste + energy production), reach commissioning of an OTEC (Ocean Thermal Energy Conversion) and reach 100% Renewable energy.

2.1.3 Economic & Technological Aspects

Economic situation and main economic sectors in French Polynesia

- French Polynesia is considered as a developed region with a service sector accounting for 75%. Their GDP per capita, which is around $22,000, is one of the highest in the Pacific Area.
- Tourism is a major source of revenue, as it accounts for about 13% of the GDP and brings in 160,000 tourists per year.
- The small manufacturing sector primarily processes agricultural products. Vanilla and pearls are its main export products.
- Public administration also accounts for a big part of the GDP and provides stable employment. The French Republic finances the functionaries working in education, justice, hospitals, military police, and military.
- Some parts of the economy involve quasi-monopolistic groups due to the small economy size. The local government is willing to maintain a healthy competition and to regulate the growth of the biggest groups but faces many challenges.

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Bora Bora's economic sectors and links with the energy demand:

• Bora Bora's main economic activity takes place in the service sector, where especially luxury tourism represents the largest electricity consumer.

• The local utility, Electricité de Tahiti (EDT), generates and distributes energy throughout French Polynesia on a vertically integrated market, with electricity generation that cost-intensive is due to shipping fossil fuels to the island and complex system operation. The installed capacity is 10 MW, with the peak power at 7,860 kW and an annual electricity production of 43GWh.

• At present, there are no storage solutions currently available yet, but a 5MW/5MWh battery is currently under development and should be in operation end of 2023.

• With its centralized system architecture, Bora Bora is similar to most islands in the Pacific, and therefore exposed to environmental degradation through the high usage of fossil fuels and price levels which - already before recent supply shortages of mainly natural gas and oil - were major concerns for residents.

• Further drivers for decarbonization efforts are the development of increasingly popular eco-tourism, as well as noise reduction and improved air quality through the use of electricity in mobility (for both cars and boats on the lagoon).

• The Bora Bora's RES objectives support food supply targets, which is a major issue for the island. There are currently 2 boats per week to supply Bora Bora with fresh fruits and vegetable from Tahiti and overseas. The production on the island is very scarce. This situation costs the municipality 1 million €/month, simply to import fresh fruits and vegetables. Building on the objectives for a greater independence and sustainability of the island, mostly through the boost of RES deployment, the mayorship of Bora Bora aims at developing agriculture on the island and to enhance its yield through the construction of solar greenhouses, thereby meeting the food security and energy transition goals of the islands, while considering its restricted land availability.

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Investment in RES

State of evolution of RES in French Polynesia:

• In 2020, the part of renewables amounted to 30.2% of the total net electricity production. The production from photovoltaic installations represented 20.1% of the renewable energy produced and only 0.04% of the total (The Polynesian Energy Observatory).

• However, this penetration mix is mainly due because Tahiti has 16 hydraulic power plants and a few solar installations, which provide 39% of RE on the island. All the other islands of the archipelago of French Polynesia only provide 4% or RE and are mainly dependant on fossil fuels. Bora Bora is part of them.

• In French Polynesia, the share of RES is strongly linked to hydraulic production, which varies according to rainfall and river flows. It represents on average 87% of the production of renewable energy production in the region.

Objectives and actions implemented to reach French Polynesia 2023 target:

• A call for tender has been launched on August 2021 to build 30 MW photovoltaic farms by 2025 on Tahiti. 3 companies have been awarded with 10MW each, coupled with a battery to support the grid.

• A second call for tender will be launched early 2023 on Tahiti with a similar sizing to be able to reach 75% RE by 2023

Implemented technologies

Implemented technologies in Bora Bora:

o 95% of the electricity comes from thermal sources.

o Some resorts have decided to install their own generating assets:

o Four Seasons: 600 kWp of rooftop solar

o Saint Regis: 130 kWp of rooftop solar

o Pearl Beach Resort: around 200 kWp to be installed in 2019.

o Based on conversation with hotel owners, it seems that EDT is limiting the capacity installed to 25% of the demand of the resorts, to avoid any impact on the grid stability.

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Some other technologies are being developed in French Polynesia:

• As Bora Bora is a volcanic and tropical island, there is a very interesting temperature profile thus creating a high interest for OTEC (Ocean Thermal Energy Conversion) and SWAC (Sea Water Air Conditioning) systems.

• A SWAC system has already been installed at the Intercontinental Hotel in Bora Bora in 2007. Additionally, another SWAC system is being developed and expected to be installed soon at Tahiti Hospital.

• It is important to note that a new thermal power plant is prohibited on Tahiti.

Main challenges

Cost and scarcity of resources

• Scarcity of skilled people to develop and build these technical projects.

• Scarcity of raw material for construction and resources dependency on importation.

• Restricted available acreage for new solar farms.

• Remote island with restricted water resources.

• Island with isolated micro-grids (unfeasible interconnection).

Remote island and double / triple insularity

• Logistics can be complex because of double or triple insularity. For example, on Bora Bora, the new solar farm will be built on a Motu (because this is where land is most available). A motu is a small island from the Bora Bora Island, which is itself and island from Tahiti. This complex geography implies a complex logistic and higher costs

•Lack of port infrastructures on small islands to unload containers.

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2.1.4 Environmental Aspects

Environmental strategies/policies

The following **strategies** are currently under development in Bora Bora to participate in the **energy transition and environmental & biodiversity protection**:

· Photovoltaic greenhouses (agriculture and electricity production on a same land);

· Electrical vehicle implementation with the associated charging terminal;

·Hydrogen, especially for green mobility and electric vehicles (EVs);

· Acoustic Buoy to measure global warming and evolution on time (salinity, CO2 levels underwater, algal development, temperature modifications, marine currents, acidity, pH) and help in the lagoon protection;

· Pyrolyzer for the thermal elimination of waste and energy production,

· OTEC for clean energy production.

Main sectors pollutants

As most islands, Bora Bora faces pollution from transports and dependency to foreign fossil fuels, whose price is structurally high because of its remoteness. This dependency affects the electricity production capacities of the island, for most of its electricity production relies on fossil fuels.

Electric mobility lies therefore at the crossroads of Bora Bora decarbonization challenges. Being equally important on the roads of the island (EVs) as on the lagoon (electrical boats), in the context of RES development is particularly promising, although the feedback from other islands is extremely important to build a strategy.

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2.2 Lampedusa Fellow Island

2.2.1 Political & Social Aspects

Demography

Lampedusa is the most southern European island, located 113 kilometers east from the Tunisian coast and 205 kilometers away from Sicily. The Municipality of Lampedusa and Linosa is in charge of managing the Pelagie Islands' archipelago, which includes the islands of Lampedusa and Linosa. The municipality of Lampedusa and Linosa has 6.337 inhabitants at present, with a population that increased from the post-war period more than in the other smaller Italian islands. According to an elaboration of ISTAT data of 2012 the age of the residents is on average one of the highest among the other minor Italian islands. The total number of dwellings is 4245 units distributed over 3380 buildings; of these, the dwellings occupied by residents are 2297 while the number of Housing belonging to non-resident people is 1948 units. Lampedusa has a 20.2 km^2 surface area and a 26 km long coastline. The island of Lampedusa presents an area of 19,86 km^2, while the island of Linosa stretches for 5,72 km^2. The Marine Protected Area "Pelagie" has been managed by the City of Lampedusa and Linosa since 2003.

Tourism and fishing are the main activities by local people. Water is produced locally and renewable energy penetration is very low, mainly for electricity purposes. Due to the lack of a direct interconnection with the mainland, electricity is produced locally with diesel generators, working via a diesel thermoelectric power plant run by S.EL.IS Lampedusa S.p.A. In the neighborhood of Pisana, close to the town center, the corporation has a power plant that consists of 8 generators connected to an equal number of diesel engines, with a combined output of 22.5 MVA. The engines operate alternately between the primary energy production system and the storage system, and the generators operate according to various schedules based on the hourly electrical load.

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Brief overview of the political system

Lampedusa and Linosa is an Italian municipality, a local autonomous entity with functions given by the Italian Republic, in the province of Agrigento. Lampedusa and Linosa, as it is for all the Italian Municipalities, has its own legal municipal status, an act that sets the municipal system and the rules for the internal administration. The covenant, voted by the majority of the citizens, is the head of the municipality and administrates it together with the municipal council, formed by councillors appointed by the mayor himself. The municipal council, comprised of municipal advisors representing all the political forces, oversees the work performed by the covenant and the councillors, approving the municipal budget, the resolutions and the issued orders (e.g. ordinances). The municipality of Lampedusa and Linosa is responsible for the administration of the islands mainly concerning the drafting of the annual municipal budget, the drawing up of the general municipal town plan, the maintenance of public order and safety, the management of municipal roads, public buildings, waste disposal and weather emergencies.

Government policies regarding clean energy transition and decarbonisation

In the past years the attention to climate change and the need to slow it down has become a more and more central topic worldwide. The ambitious goal to dismiss the energy fossil fuels in favour of sustainable and renewable energy sources is the objective of a process promoted at international and national level through legislative and regulatory policies.

EU policymakers have built on the global initiatives, as United Nations Sustainable Development Goals (SDGs) and Paris Agreement of 2015 and have spread and promoted the use of renewable energy, energy efficiency, environmental social and governance (ESG) policies.

Amongst these, it is worth acknowledging:

- the EU policy framework for climate and energy, aiming at a 40% reduction in greenhouse gas emissions by 2030 (as compared to 1990);
- Directive (EU) 2018/2001, recasting and repealing previous legislation on renewable energy;

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- Directive 2018/2002 amending directive 2012/27/EU on energy efficiency, setting out higher standards as compared to the 2012 directive, including meeting a 32.5% energy efficiency target by 2030;
- The EU governance regulation (no. (EU) 2018/1999) requiring member states to submit national energy and climate plans for 2021 to 2030 to the EU Commission;
- The Electricity Market Design, which is a comprehensive set of directives and regulations with the ultimate aim "to ensure secure and affordable energy supplies to EU citizens";
- The European Green Deal, set out by the Communication COM (2019) 640, a roadmap to make EU's economy sustainable, resource-efficient and competitive ensuring zero carbon emissions by 2050, economic growth as well as fair transition and inclusion;
- The Fit for 55 package presented in July 2021 by the EU Commission, a set of proposals to revise and update EU legislation ensuring the alignment between EU policies and the main climate goal, as the reduction of net greenhouse gas emissions by at least 55% by 2030. In order to meet this objective, the Fit for 55 is focused on, among the others, energy performance of buildings, energy efficiency, EU emissions trading systems, renewable energy, alternative fuels infrastructure, energy taxation and CO2 emissions standards for cars and vans.
- The Clean Energy for EU Islands, an initiative launched in 2018 by the EU Commission in cooperation with the European Parliament, with the aim to set up a Secretariat to share the objectives of this initiative. The Secretariat acts as a virtual space where best practices and lessons learnt are presented to islands' stakeholders, providing also advisory services as the "Island Clean Energy Transition Agenda", a roadmap for the clean energy transition process. The roadmap is focused on community engagement, decarbonisation plan and financing concept.

In 2019 Italy developed the Integrated National Energy and Climate Plan (INECP), a ten-year document mandated by the European Union to each of its member states with the aim to favour the achievement of European greenhouse emissions targets. With this plan Italy set the goals for energy, transportation, buildings and economy-wide sectors [2]. The objective is to increase the share of energy from RES by2030 compared to 2020 and reduce the GHG emissions:

- energy: increase the share of energy from RES by 30% in the gross final consumption of energy
- transportation: increase the share of energy from RES by 22% in the gross final consumption of transport sector
- buildings: increase the share of energy from RES by 1,3% per year (indicative) in the gross final consumption of energy for heating and cooling
- economy-wide: reduce in GHG for all non-ETS sectors by 33%.

In 2021, Italy adopted the National Recovery and Resilience Plan (PNRR) that includes all the projects to be developed with the funds financed by the Next Generation EU program. The actions are grouped in six missions covering three main sectors, as digitalization and innovation, ecologic transition and social inclusion. In particular in the framework of ecologic transition the main projects Italy will be invest on are related to:

- renewable energy (increase the share of energy produced by RES)
- hydrogen (promote its production, distribution and the final use)
- sustainable mobility (develop a more sustainable local transport)
- energy efficiency and retrofitting in buildings (energy efficiency in public buildings)
- land and water resource protection
- circular economy and sustainable agriculture

In this context, the PNRR allocates also financial resources to the Green Islands Program with the aim to strengthen the environment and energy sector of the not-interconnected islands municipalities through specific actions.

One of the first steps that set the stage for the subsequent norms concerning the energy production and distribution in Italy was the Legislative Decree n. 79 (1999), that implemented the EU directive 96/92/CE, introducing the liberalisation of electric energy market.

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Furthermore, Italy has implemented the EU Directive 2001/77/EC on renewable energy, through the Legislative Decree n. 387 (2003), subsequently repealed by Directive (EU) 2018/2001, that is focused on promoting the use of renewable energy sources for the production of energy in Italy, especially encouraging the development of renewable electrical micro-generation plants. In this sense the decree provides guidelines to meet the requirements for the authorization procedure and for the correct installation of renewable power plants in the territory, in particular wind farms[1]. Another reference Italian policy is the Ministerial Decree n. 219 (2010)[2], "Guidelines for authorization of renewable energy powered plants", concerning the indications for the authorization procedure in case of design and construction of a renewable power plant. In this case the goal is to meet the needs of economic and social development ensuring the protection and conservation of natural and cultural local resources.
In 2017 a ministerial decree, called "Minor Islands Decree", has been issued to improve the production of energy from RES in the Italian minor islands, indicating the energy goals and needs for every island, together with the methods to support the related investments[3]. In 2021, the Legislative Decree n. 210 was implemented setting, among the other measures, the rules for the establishment of energy communities, with the indications about their participation and energy sharing modalities. One of the last norms issued at national level and focused on the energy field was the Legislative Decree n. 17 (2022), concerning the urgent measures to mitigate the energy costs raising and to relaunch the industrial policies. For this purpose, one of the main aims is the enhancement of national renewable energy production and the energy savings.

At regional level, Sicily has adopted and updated the Energy and Environment Plan of Sicily Region – PEARS 2030, a tool to plan and address the structural and infrastructural interventions in energy field. One of the key points of the document is the enhancement of energy produced by RES and the

[1] Legislative Decree n. 387,: Attuazione della direttiva 2001/77/CE relativa alla promozione dell'energia elettrica prodotta da fonti energetiche rinnovabili nel mercato interno dell'elettricità., 2003.
[2] Ministerial Decree n.219, "Linee guida per l'autorizzazione degli impianti alimentati da fonti rinnovabili", 2010.
[3] Minister of Economic Development, "Minor Islands Decree," 2017

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empowerment of new more efficient technologies. In particular, the goal for 2030 is to increase the share of electricity produced by renewable sources from 29,3% (2020) to 69%. For this purpose, the implementation of PV panels and solar thermal is promoted for auto-production and auto-consumption, together with the installation of storages. Furthermore, a focus is also dedicated to the minor islands that are part of the Sicilian region, with actions, among the others, to achieve 25% of RES in electricity mix within 2025 and 30% by 2030.

Sicily has also issued the Presidential Decree n.29 (2015)[4] that outlines the criteria for the implementation of RES power plants and identifies the areas unsuitable for the construction. Another document, Presidential Decree 2017[5] has been drafted to speed up the authorization process for the implementation of electricity production plants powered by RES, especially wind, redefining criteria and updating the unsuitable areas of intervention. For Lampedusa and Linosa the Territorial Landscape Plan (Piano Territoriale Paesistico – PTP) is the urban planning tool that directly define requirements and constraints at municipal level. The installation of PV panels on the buildings roofs is not particularly limited. However, the territorial landscape plan provides that the PV panels must be installed so that they are not visible from the main roads and squares. Furthermore, the municipality of Lampedusa and Linosa adopted the Sustainable Energy and Climate Action Plan (SECAP) in 2018 having joined the Covenant of Mayors for Climate and Energy, a European initiative included in the actions towards its clean energy and sustainability goals. With this document the Municipality is committed to achieve a 40% reduction of CO_2 emissions compared to 2020 within 2030, implementing a series of actions focused on the optimization of energy consumptions and reduction of GHG emissions through the promotion of renewable energies. In addition, Lampedusa and Linosa participated the EU initiative Clean Energy for the EU Islands and obtained, together with Turin Polytechnic, the technical support to realize two projects in the framework of the Call for technical assistance. These two initiatives have been

[4] Presidential Decree n.29, "Norme in materia di tutela delle aree caratterizzate da vulnerabilità ambientale e valenze ambientali e paesaggistiche", 2015.
[5] Presidential Decree, "Definizione dei criteri ed individuazione delle aree non idonee alla realizzazione di impianti di produzione di energia elettrica da fonte eolica [...]", 2017.

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put aside at present, as the Municipality is now focused on the Green Island program in the framework of the PNRR promoted at National level.

Social Aspects

The ultimate goal of the Lampedusa through IANOS project is to test the replication of some IANOS solutions in its energy network in order to contribute to the decarbonisation and smartification of the island.

To implement its decarbonisation strategy, special attention will be paid to the impact specific use cases and innovative solutions will have on the grid, in order to include them in the replication plan, specifically for increasing energy efficiency on the island, better management and control of electricity produced from RES and on its potential to improve local quality of life; on the local communities through the involvement of the Region of Legambiente, given the incentive to boost local employment by using local and third-country human resources. The energy provider is currently a fossil fuels producer, aiming to gradually become a manager of a smart grid, moving from the baseline to a fossil free scenario, enabling the island energy revolution.

2.2.2 Legal Aspects & Regulatory Framework

Regulation authority

The supply of electricity, considering that there is no direct connection with the mainland, takes place through a diesel-fueled thermoelectric power plant managed by S.EL.I.S. S.p.A.; a company based in Palermo in charge of all the services related to electricity: production, selling, distribution and measurement. The company has a power plant located close to the city center in the Pisana district and consists of 8 generators coupled to many diesel engines that guarantee a total of 22,000 kW_e of power. These eight alternating motors ensure both the production system of primary energy and the reserve system. The diesel fuel needed for regular operation of the plant is brought to the island by tankers that dock at the port of Lampedusa; since the plant is not in close proximity of the port, the fuel from here is transported by road to the storage tanks inside the power plant. The total fuel consumption used to produce electricity is equal to

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approx. 7900 tons/year [3]. Considering that, due to the far distanced island location from the mainland, the costs to provide electricity is higher than in the rest of Italy, therefore pushing the Italian Regulatory Authority for Energy, Networks and the Environment (ARERA) to establish different rules for the islands. In this sense ARERA ruled for the end users that they should pay the energy at the average national price, "Prezzo Unico Nazionale" and that the energy companies, as S.EL.I.S., should be remunerated on the basis of the net assets and with the reinstatement of the costs incurred for the provision of the services, minus the profits derived from the energy selling.

Relevant Regulatory Framework

- National Energy & Climate Plan (NECP)
- Energy Decree, Law Decree 17/2022
- Minor Islands Decree, Decree of Ministry of Economic Development of 14 February 2017
- National Law 1150 from 1942
- Electricity market Law, Decree of 16 March 1999, n.79
- Law 8/2020
- Legislative Decree of 8 November 2021, n.2010

Main barriers

The main challenges towards the clean energy transition in Lampedusa and Linosa, as in the other Sicilian minor islands, are related to different aspects as further indicated [4]. The implementation of RES technologies and their massive use to dismiss fossil fuel systems can involve several issues related to the provision of services and to the instant balance between demand and supply of electricity. The design and installation of storage systems, as batteries, can mitigate the demand problems in case of unbalance between production and consumption. The energy can be stored during high production periods and can be used in case of low productivity of the system. Furthermore, the implementation of flexibility control algorithms can improve PV self-consumption and reduce peak load up. The introduction of RES technologies should be gradual, maintaining the

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traditional systems for an initial period in order to provide "aggregate inertia" to the grid for the purpose of primary frequency control [5].

Another aspect to be considered for the penetration of RES technologies is the difference in energy demand between winter and summer periods. The daily energy needed in summer is twice as high as the amount required during the winter months, due to tourism. This variation can represent a barrier concerning the availability of RES at different time scales, so a structured analysis of the energy demand and use should be performed in order to design the correct RES system with the most appropriate size and characteristics.

The regulatory system can also be an obstacle for the diffusion of technologies powered by renewable energy sources, as the environmental and historical constraints indicated by the different policy instruments, as PTP – Territorial Landscape Plan, can limit the installation of these systems on the territory. The regulations should be carefully analysed in order to identify the best locations where to implement the RES technologies, considering that the land spaces are limited in Lampedusa and Linosa, as in the other Sicilian minor islands. The latter is another barrier related to the spread of RES projects over the municipality. Renewable energy systems can occupy quite large amount of land space, as it is for the installation of PV panels and concentrated solar power, but there are also options for not using areas that can instead be dedicated to anthropic activities, as the off-shore wind and wave converters. For all these possible issues and challenges the RES interventions should be carefully planned through preliminary assessments and feasibility studies focused on the characteristics of the territory, the regulatory framework and the energy data (e.g. energy needs).

2.2.3 Economic & Technological Aspects

Main economic sectors and relation to energy demand

The main energy consumption is related to electrical energy, especially in the residential and tertiary sectors particularly between June and September, i.e. the summer tourist season, with a peak in August. The energy sector, just as the economic, relies mostly on tourism. The highest energy demand originates both from civil utilities and small businesses that are also supported by tourism.

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Between May and September restaurants, bars, accommodation facilities and private housing intensify their activities and the energy demand triples compared to the winter months. The total final energy consumptions in Lampedusa and Linosa in 2011 were 67.733,1 MWh, corresponding to 10,4 MWh/inhab. per capita, less than the national average. The energy consumptions are mainly distributed into transport (45%), residential (22%) and tertiary (19%) sectors (Table 1).

Table 1 Yearly energy consumption per sector in Lampedusa and Linosa Municipality in 2011

Sector	Final consumptions (MWh/year)	%
Private and commercial transport	29.000,5	42,8%
Residential buildings	14.940,1	22,1%
Tertiary buildings/facilities (not public)	12.534,3	18,5%
Municipal buildings/facilities	4.299,4	6,3%
Industries (excluding ETS)	4.290,0	6,3%
Public lighting	1.075,0	1,6%
Public cars	847,0	1,3%
Public transport	737,8	1,1%
TOTAL	67.733,1	100%

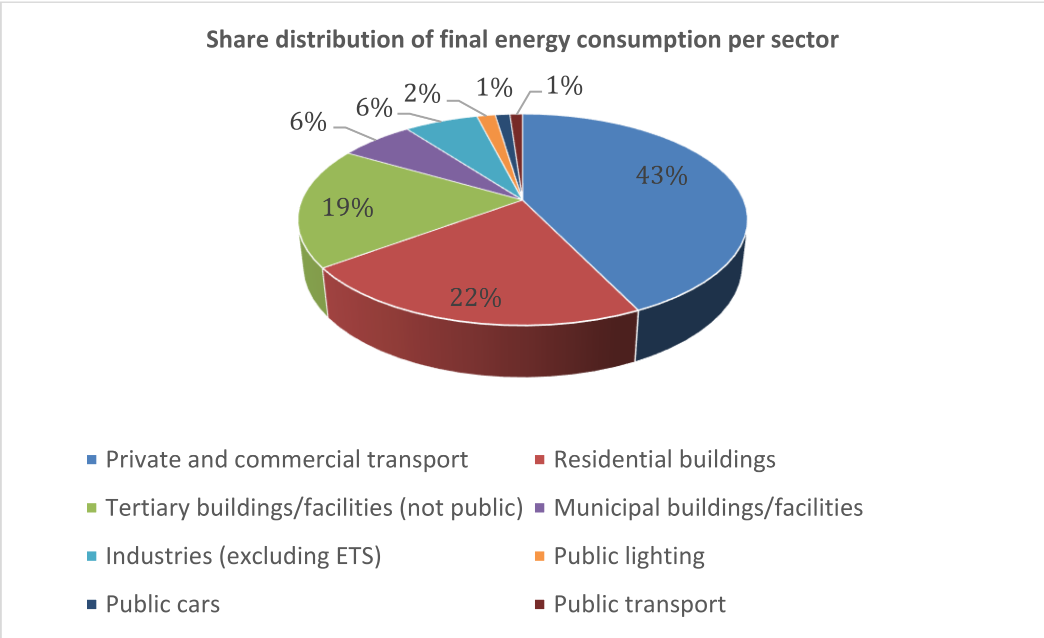

Figure 3 Share distribution of final energy consumption per sector

The analysis of energy consumption per energy carrier clearly shows (Table 2), that electric energy has a high energy demand in residential, tertiary and public service sectors, while oil products are mainly used in transport sector especially in relation to private/commercial transports (Figure 3).

Table 2 Yearly electrical energy consumption per sector in Lampedusa and Linosa Municipality

Sector	Final electric energy consumption (MWh/year)	%
Tertiary buildings/facilities (not public)	12.534,3	37%
Residential buildings	11.665,1	34%
Municipal buildings/facilities	4.299,4	13%
Industries (excluding ETS)	4.290,0	13%
Public lighting	1.075,0	3%
TOTAL	33.872,8	100%

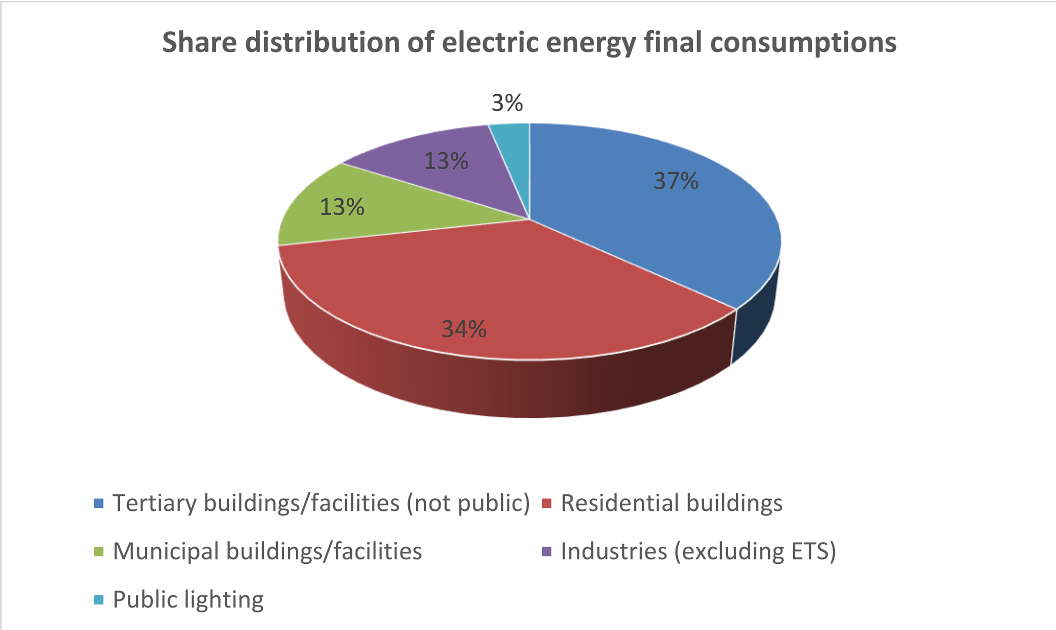

Figure 4 Share distribution of electric energy final consumptions

Table 3 Yearly LPG energy consumption per sector in Lampedusa and Linosa Municipality

Sector	LPG final energy consumption (MWh/year)	%
Private and commercial transport	29.000,5	85,6%
Residential buildings	3.275	9,7%
Public cars	847,0	2,5%
Public transport	737,8	2,2%
TOTAL	33.860,3	100%

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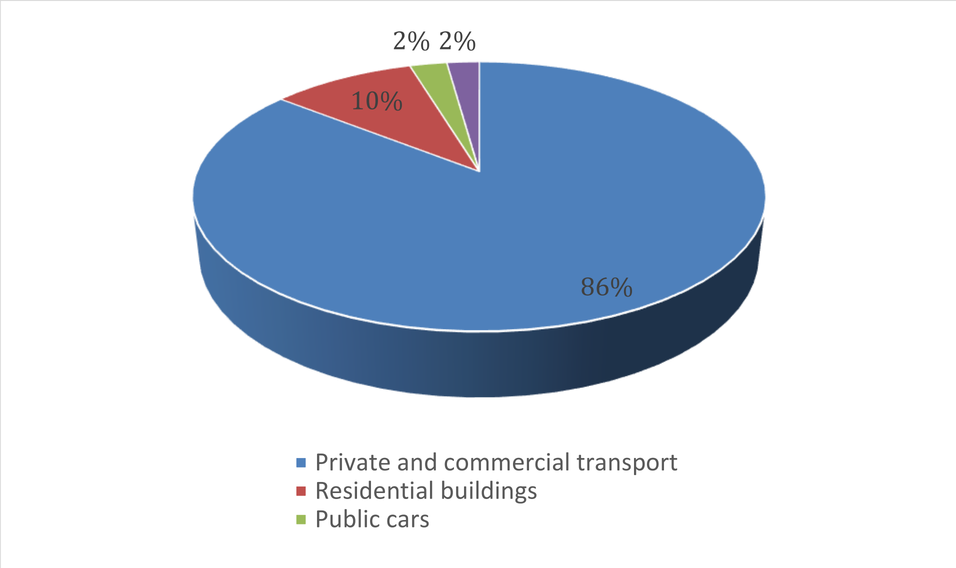

Figure 5 Share distribution of LPG final energy consumption

Investment in RES and its impacts

Several actions were programmed in Lampedusa and Linosa for the period between 2018 and 2030, according to their Sustainable Energy and Climate Action Plans (SECAPs). In this view the main projects foreseen include: i) installation of thermal solar and PV plants on public buildings, ii) buildings' renovation to reduce their thermal and electric demand, iii) installation of thermal and PV plants in private buildings, iv) the establishment of a Smart Energy Island project, v) of a SMART GRID pilot project and vi) pilot project investment relevant to energy production from sea wave motion. However, this situation has changed at present with the new municipal administration who decided to set aside all the previous energy-environmental projects and plans, in order to implement a new plan using the funds provided for the Green Island project promoted in the framework of Italian PNRR.

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Implemented technologies

According to an analysis performed by Sustainable Islands Observatory in 2021 [6], the systems powered by renewable energy sources in Lampedusa and Linosa at the end of 2020 included only PV systems and no other technologies.

In the table below the summary of RES power installed is indicated together with the 2020 RES power objectives set by Minor Islands Decree (2017).

Table 4 Summary of RES power installed and power objectives

Photovoltaic power installed (kW)	Wind power installed (kW))	Electricity needs covered by RES (%)	RES power 2020 objectives (kW)
605,1	-	2,25%	2.310

The goals had not yet been met at the beginning of 2021, as it appears in the table above.

2.2.4 Environmental Aspects

Main sectors pollutants

The total CO_2 emissions for the municipality of Lampedusa and Linosa are included in the Sustainable Energy Action Plan (SECAP), using 2011 as the reference year, following the methodology "Standard IPCC 2006" and Guidebook. The analysis performed using the Emissions Factors indicated that the CO_2 emissions in the municipality in 2011 corresponded to 24.985,7 tons (4,1 $tonCO_2$/inhab.), distributed in the main sectors, as summarised in the Table 5. The highest shares of CO_2 emissions belong to transport and building sectors, in particular the private and commercial transportation and residential and tertiary buildings.

Table 5 CO_2 emissions per sector

Sector	CO_2 emissions (tCO_2)	%
Transports		
Public cars	218,40	0,87%
Private and commercial transportation	7.466,38	29,88%
Public transport	196,99	0,79%
Buildings, Facilities / Plants and Industries		
Agriculture	0	0%
Residential buildings	6.377,62	25,53%
Public buildings, facilities/plants	2.076,61	8,31%

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Tertiary buildings, facilities/plants (not public)	6.058,41	24,25%
Public lighting	519,23	2,08%
Industries (excluding ETS)	2.072,07	8,29%
Other		
Waste water management	0	0
Waste management	0	0
Other	0	0
TOTAL	24.985,72	100%

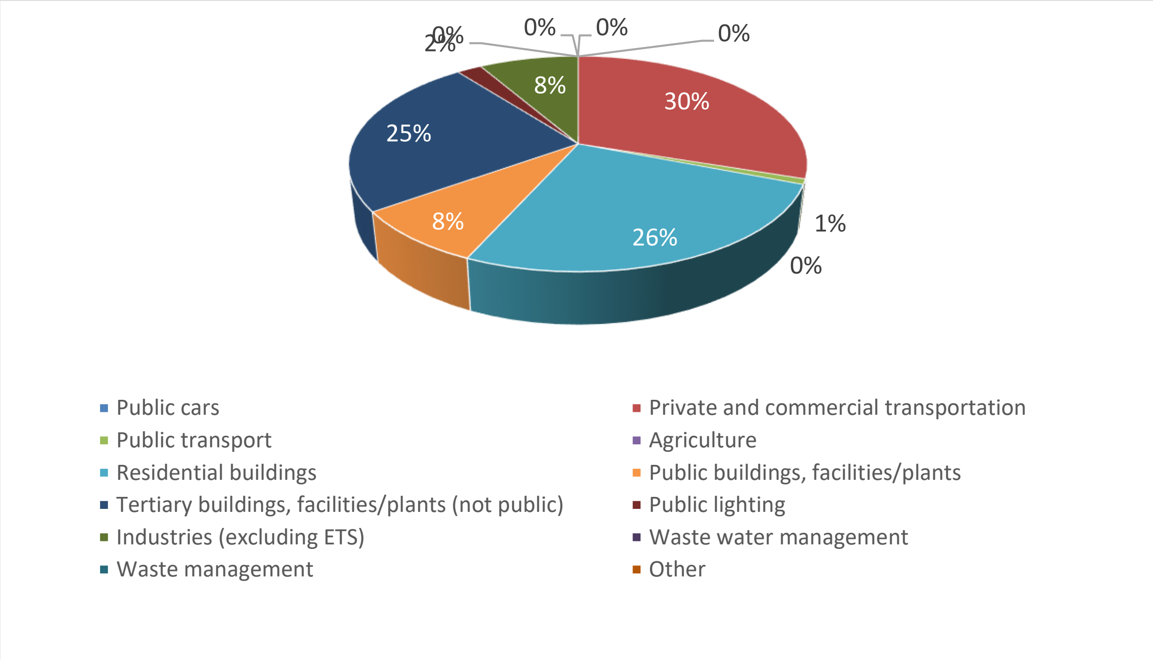

Figure 6 Share distribution of CO_2 emissions per sector

The specific emissions of the municipal administration were estimated as 2.814 tCO_2 in 2011 (Table 6), with the highest share represented by the electric energy consumed by the watermaker. Table 6 summarises the emissions due to the different public energy carriers.

Table 6 CO_2 emissions per energy carrier

Energy carrier	CO_2 emissions (tCO_2)	%
Electric energy for P.I.	519,22	18,45%
Electric energy for water supply and sewer	159,39	5,66%
Electric energy for watermaker	1.753	62,30%
Electric energy for public buildings	163,93	5,83%
Diesel fuel for transport	107,2	3,81%
Petrol for transport	111,21	3,95%
TOTAL	2.814	100%

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The final goal of Lampedusa and Linosa concerning the reduction of CO_2 emissions corresponds to lowering them by 63% (approx. 15700 tCO_2) in 2030 compared to 2011. This achievement would exceed the target of 40% reduction (approx. 9.900 tCO_2) as indicated by EU for the municipalities committed to the Covenant of Mayors, representing a significant contribution to the European objectives related to clean energy transition of its member states.

2.3 Nisyros Fellow Island

2.3.1 Political & Social Aspects

Nisyros is a volcanic Greek island and municipality located in the Aegean Sea. It is part of the Dodecanese group of islands, situated between the islands of Kos and Tilos (Figure 7). Its shape is approximately round, with a diameter of about 8 km, and an area of 41.6 km^2. Several other islets are found in the direct vicinity of Nisyros, the largest of which is Yali, with a population of 22 inhabitants. The Municipality of Nisyros includes Yali, as well as uninhabited Pacheia, Pergoussa, Kandelioussa, Agios Antónios and Stroggyli. The island has a 3 to 4 km wide caldera, and was formed within the past 150,000 years, with three separate eruptive stages, which range from explosive and effusive andesitic eruptions to explosive and effusive dacitic and rhyolitic activity. The entire volcanic complex includes the seafloor between Nisyros and Kos, Yali Island and a part of Kos Island.

Figure 7: Nisyros location in the Dodecanese complex of islands

Demography

Nisyros has a population of approximately 1,100 inhabitants. The population density is 20.14 citizens per km^2. Mandraki is the capital of the island. The average

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tourists' arrivals during the summer season are 70,000 for short-term visits (one-day or so), 10,000 for long-term stay and 6,000 arrivals by yachts. There are two mines in the Island of Yali, producing pumice and perlite providing many of the jobs for the islanders. Tourism is the one major sector on which the economy of Nisyros is based [7].

Greek islands are either interconnected to the electrical grid of the mainland, or non-interconnected. Dodecanese group of islands (including Nisyros) is parted from non-interconnected islands (NIIs). NIIs have isolated island networks and need quite higher investment and operating costs for energy generation, exceeding in many cases 200 €/MWh [8].

Brief overview of the political system

Within the state's organizational framework, Greece's municipalities are the lowest tier of government. There are 332 municipalities as of 2021, which are further broken down into 1036 municipal units and 6136 communities.

The role of local governments and its connection to the greater state are outlined in Article 102 of the Greek Constitution:

- Municipalities and communities exercise administration of local affairs independently.
- Leadership of municipalities and communities is elected by universal and secret ballot.
- Municipalities may voluntarily or be mandated by law to work together to provide certain services but elected representatives from the participating groups govern these partnerships.
- The national Greek government supervises local government agencies but is not to interfere in any local initiatives or actions.
- The State is required to provide funds necessary to fulfil the mandate of local government agencies.

A mayor-led municipal council and municipal consultation committee govern each municipality. Municipalities and communities are in charge of managing their local jurisdiction in a way that takes into account the social, financial, cultural,

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and spiritual interests of their residents. Although the Municipal and Communal Code still gives communities and municipalities legal sovereignty over the management of their allocated territories, the State ultimately has the final say in how local governments conduct their affairs.

With regards to **Strategic Energy Planning**, the following are noteworthy:

Government policies regarding clean energy

The Integrated **National Energy and Climate Plan (NECP)** [9] for the period 2021-2030 aims to increase the overall share of renewable energy sources (RES) in its gross final energy consumption to 35% by 2030. In the electricity sector, the share of renewables is targeted to at least 60% by 2030. In the heating and cooling sector RES share in gross final energy consumption is expected to 42.5% by 2030 (30.6% in 2020) and RES share in final consumption for transport to go up from 6.6% in 2020 to 19% in 2030. The ratio of the **installed capacity of RES power plants** to the total generation capacity was **over 18 %** for the non-interconnected islands (NIIs) in 2019 [10].

The **National Energy and Climate Plan (NECP)** sets the transmission connections and the drastic decrease in carbon emissions from thermal power plants generation as the major objectives for the Greek islands. However, there is no specific guide developed for how a clean energy transition will be accomplished on the islands. Ongoing initiatives include accelerated **action for the implementation of RES projects and hybrid plants on the NIIs**, and **digitalization and upgrade of the distribution network**. One of the main barriers facing the electricity generation sector in the NIIs is related to the fact that the regulated price for electricity generation hinders clean energy transition. The lack of policies to support energy storage is also very important, especially for isolated power generation systems.

The critical role of islands for the energy transition and national economic growth is clearly outlined in the **Ten-Year Network Development Plan (TYNDP)**[6] of the

6 https://www.admie.gr/en/nea/anakoinosi/preliminary-draft-ten-year-development-plan-hets-period-2022-2031

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Hellenic Electricity Transmission System (HETS) for the period 2022-2031, presenting the main challenges that Greek islands are facing. Planned measures will focus on the interconnection of the islands with the mainland, or the development of self-sufficient RES systems, when the proposed solutions are not feasible due to financial constraints or technical limitations, while aiming to contribute to a significant reduction of electricity generation costs, and various environmental benefits via the replacement of thermal with RES plants.

The **Territorial Just Transition Plan**[7] of Greece will leverage a total investment of €1.63 billion from the Just Transition Fund of the EU for the decarbonisation in Western Macedonia, Megalopolis and adjacent municipalities, and the phasing out of fossil fuel power stations in the **islands of North-South Aegean** and Crete. The **National Action Plan for the Alleviation of Energy Poverty** for the period 2021-2023 defines a set of policy measures, incentives and subsidies for the energy poor households, within the framework of the Territorial Just Transition Plan.

Specific island policies regarding clean energy and mobility

There are also some unique policies, incentives and programs designed exclusively for islands. The national subsidy scheme called "**GO ELECTRIC**"[8], which is currently in operation, based on Ministerial Decision 77472/52024, aims to encourage transport electrification and increase adoption of **e-mobility** on a national scale by offering grant-in-aid to individuals, tax and legal entities for the purchase of EVs, electric motorcycles, electric bikes, or electric scooters, as well as for the installation of private home EV chargers. The second phase of the subsidy scheme, GO ELECTRIC 2, began in July 2022. In particular, for the islands, it offers additional incentives to a legal entity to buy up to 6 vehicles (instead of 3 vehicles for the rest of the country) and tax benefits (larger decrease of taxable income). Moreover, renewable energy projects may be eligible for special licenses in certain circumstances. One example is the project on the island of Agios Efstratios, which is permitted under L.4495/2017, art.152. According to Law 4001/2011 Art. 58B on "Ensuring uniform pricing of electricity users," energy providers in Greece are

7 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_3711
8 https://kinoumeilektrika.gov.gr/

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required to provide uniform pricing to all end-customers throughout the Greek territory. While each energy provider is free to set its own retail pricing, they are required to do so for both the end users of the linked system and the islands that are not connected.

SOCIAL ASPECTS

Nisyros is part of the Autonomous Grid connecting the islands of Kos, Kalymnos, Leros, Nisyros, Pserimos, Telendos and Tilos. The installed capacity, however, marginally covers the load requirements, especially during the peak of the tourist season. The extended nature and complexity of the grid affects the quality of supply, often resulting in instability (voltage/frequency fluctuations), breakdowns of the diesel generator sets and sometimes blackouts, leading to both increased insecurity of the islanders as they feel that power supply is not guaranteed, as well as posing barriers to economic growth in the area [11].

Local Energy demand

The demand for electric energy of Nisyros, matches the typical profile of the Greek Aegean islands. Based on information for the annual energy consumption profiling of Nisyros per key sector (domestic, commercial and industrial), an increase in demand from 43approx. 4GWh/y in 2010 to approx. 6.5GWh/y in 2021 i.e., almost a 50% increase, is observed. A small additional increase can be assumed for year 2022.

The operation of a desalination plant with three desalination units, which can produce a 1000m^3/day of fresh water, is the most significant source of energy consumption in the island. The desalination plant has limited operation to working 5days/week during summer months, producing 500-600 m^3/day in order to cover daily demand for water and at the same time store 1000 m^3, representing weekend demand. This corresponds to a consumption of around 400 m^3/day on an annual basis (note that corresponding demand during summer is almost double), leading to an annual required capacity of around 1.500.000 m^3/year. This capacity is compatible with the annual demand for electricity by the desalination plant, which is close to 2 GWh$_e$, or 1.2-1.5kWh$_e$/m^3 of fresh water produced [12]. The

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energy demand of public buildings of all kinds/uses constitutes 6%-7% of the total energy consumption. This is primarily due to the use of solar panels to power public lighting, the use of LED lamps and better power use management.

The prime consumer of energy is the greater area of Mandraki, given that the consumption of the villages of Emporios and Nikia is very limited. The desalination plant is located near Mandraki – less than 1km from the centre of the village, thus, the total demand for electric energy is attributed mainly to Mandraki.

Clean energy transition island projects

The implementation of projects focusing on innovative solutions and best practices on islands, such as storage systems, e-mobility schemes, and energy communities on the Greek islands, as of the projects in Tilos, Sifnos and Astypalea, as well as projects through the GR-eco islands initiative[9] (such as Chalki) are just a few examples in Greece aimed at decarbonization and energy transition of islands. A feedback loop from local to national scale regarding lessons learnt and best practices of completed island projects is missing though.

Energy communities

Greece included the concept of energy communities into the national legal framework in 2018. The participation in EU projects, ownership of RES plants, and operation of virtual net-metering schemes are the advantages provided for Energy Communities by the Act. The definition of the Energy Community will be redefined. Legal definitions of prosumers are lacking. However, the concept of autonomous producer bears many similarities with the notion of prosumer. Practically, only PV autonomous producers could benefit from a net-metering scheme.

Moreover, all RES technologies used by autonomous producers for self-consumption can receive subsidies. Energy efficiency measures are promoted/supported for the refurbishment of buildings in the case of citizens, and for replacement and upgrade of public lighting and installation of EV charging stations in the case of public authorities. Greek islanders can benefit

[9] https://www.pv-magazine.com/2021/11/05/greece-launches-gr-eco-islands-initiative-with-e100-mlllion-pot/

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from energy efficiency funds. An energy audit must be conducted first and then islanders can apply for financial support that can be between 30% and 70% of the total intervention costs.

2.3.2 Legal Aspects & Regulatory Framework

Regulation Authority

Greek islands are either interconnected to the mainland electricity grid or non-interconnected. The island complex of Dodecanese consists of islands which are **non-interconnected islands (NIIs)** to the grid of the mainland. In the case of non-interconnected Greek islands, the electricity distribution and commercialisation market are regulated by the **Hellenic Electricity Distribution Network Operator** (HEDNO)[10], the national DSO of Greece. HEDNO is responsible for the management of operation, and the incorporation of RES, CHP and hybrid generators into the autonomous non-interconnected energy networks, and the specifications for conventional generating units.

Regulatory Framework for islands in Greece

There are no laws and regulations on a local level to address the **clean energy transition agenda** of the different islands. This is primarily based on the **national policy and regulatory framework** [13]. No regional or local framework exists also for the promotion of smart grids and smart islands in Greece. The laws and regulations are the same as those applied in the mainland. The difference is Law 304/2014 [14]. To a large extent, the principles for islanded energy systems are incorporated in the Law 304/2014 "**Electric Grid Management Code for non-interconnected islands to the Mainland Grid**", which applies for the island of Nisyros, as well as for the rest of the non-interconnected islands of the Aegean Sea. There is no regional legislation for the active involvement of energy communities. RES penetration on the island is still basic, limited to home, and especially non-grid connected buildings (isolated) and some community lighting applications. Amendment of the national regulatory framework is needed for the **realisation of smart grids** that would eventually benefit the energy system and its users, especially for the case of non-interconnected Greek Islands.

[10] https://deddie.gr/en/

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The **New Climate Act (L.4936/22)** [15] has been adopted in May 2022. This act obliges all municipalities, including island municipalities, to define local plan for emissions reduction in line with National Energy and Climate Plan by 31/03/2023. It also forbids the use of oil for power production on the islands (unless there is a risk for the energy supply security for the island) starting from 1/1/2030.

Main Regulatory Barriers

Based on thorough analysis of the current legal and regulatory framework which supporting clean energy projects in Greece, as well as surveys, interviews and consultation with relevant Greek stakeholders, conducted by the **Clean Energy for EU islands secretariat**, the most important barriers to the clean energy transition of Greek islands were identified and prioritized [16], as follows:

- Lack of clear strategy for energy transition on the islands, lack of coordination and monitoring of implementation
- Lack of island specific energy planning and integration with spatial planning
- Complex and long permitting procedures for RES projects
- Lack of clarity regarding short and mid-term actions to allow clean energy transition and ensure security of supply on the islands
- Bureaucracy and administrative burden for the community energy initiatives
- Clean energy project subsidies equalise interconnected islands and mainland
- The regulated price for electricity generation in non-interconnected islands hinders clean energy transition

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2.3.3 Economic & Technological Aspects

The deployment of RES in Greece is totally based on the distinction between the mainland grid, interconnected and non-interconnected islands (NIIs). This distinction is essential because it determines the kind and level of support that RES plants are eligible for. Greece supports solar PV, onshore wind, and hydro power with a focus on hybrid plants (plants that use two or more RES technologies) for NIIs. Solar thermal, biomass, aerothermal, geothermal, and combined heat and power (CHP) facilities are encouraged for self-consumption in heating and cooling. Different incentives and motives are offered between residents for their personal/building energy use, and private businesses or cooperatives. District heating and cooling infrastructure investments are not promoted on the islands.

In Greece, RES projects on non-interconnected islands can receive a Feed-in Tariff regardless of their capacity (size), however on connected islands to the grid, the upper threshold is 400 kW. A Feed-In Premium price may also apply for RES on connected islands that participate in the electricity market, allowing also tendering for larger PV (>500kW) and onshore wind (>3MW) installations. Greece uses tenders and auctions for large projects and application/approval process for smaller projects. Additionally, there is a subsidy for RES plants using two or more RES technologies that are located on non-interconnected islands.

While Greece is focusing on significant investments over the next ten years for the interconnection of the island networks, much has to be done to expand its capacity for RES integration and promote flexibility and modernization of the current grid. The deployment and use of innovative storage systems in conjunction with new renewable installations should be encouraged, necessitating also the update of relevant grid regulations and codes. Regulatory sandboxes are suggested as a tool to evaluate cutting-edge technologies and implementation strategies.

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Main challenges

The development of sustainable energy resources is directly impacted by the unique characteristics of the Municipality of Nisyros. The distinctive qualities address a variety of areas, including administrative, energy, and infrastructure:

- Non-urban municipality. The inhabitants of the island are concentrated in the settlements of the 3 municipal apartments with the main settlement being the capital of the island, Mandraki, while some houses are scattered on the rest of the island or concentrated in very small settlements.
- Large seasonal variation of the population. The very small population of the island (~950 inhabitants) changes significantly during the summer months when the island is overrun by tourists for at least a month. During this period energy consumption increases significantly.
- Part of an autonomous electrical network. As already mentioned, its electrical network Nisyros is part of the Kos - Kalymnos network.
- Extended nature and complexity of the power grid. Two undersea power cables that come from Kos are used to power the island. The grid's unusual geography has an effect on the quality of the supply, frequently resulting in instability (voltage/frequency variations), diesel generator set failures, and sporadically blackouts.
- Proximity to the sea. While the sea provides many possibilities for sustainable actions, it is also a sensitive ecosystem that needs special responsibility.
- Limited staff. The Municipality's staff and resources are insufficient to maintain a dedicated employee.
- Transportation restrictions – Increased investment costs. The lack of connections between the island and mainland Greece is one of the Municipality's biggest issues, despite the fact that Kos is so close by and provides relatively easy access to a larger administrative and commercial centre. Obviously, the issue immediately has an impact on the price of moving goods and services.

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2.3.4 Environmental Aspects

Nisyros, being part of the Dodecanese complex of islands, follows the typical climatological pattern of the SE Aegean area, namely a mild Mediterranean, dry climate. Rain throughout the year is limited – height not exceeding 600mm/yr – while strong winds and fog (during winter) combine with persistent sunshine. The average annual temperature is 20°C, relatively higher to the mainland. The maximum temperature reaches 38°C in July, while the minimum is 4.5°C, observed in December. The average wind speed is 7.5-10 m/s (Figure 8 on the left), whereas the annual solar irradiance is 2,160 kWh/m2 (Figure 8 on the right). Nisyros, as a volcanic island, is well-known for its high geothermal capacity (geothermal potential estimated to be approximately 40MWe), the potential of which is enough to cover the energy needs of nine islands in Dodecanese, including Nisyros. There are three hot springs where the water temperature varies from 33 to 60° C (low enthalpy).

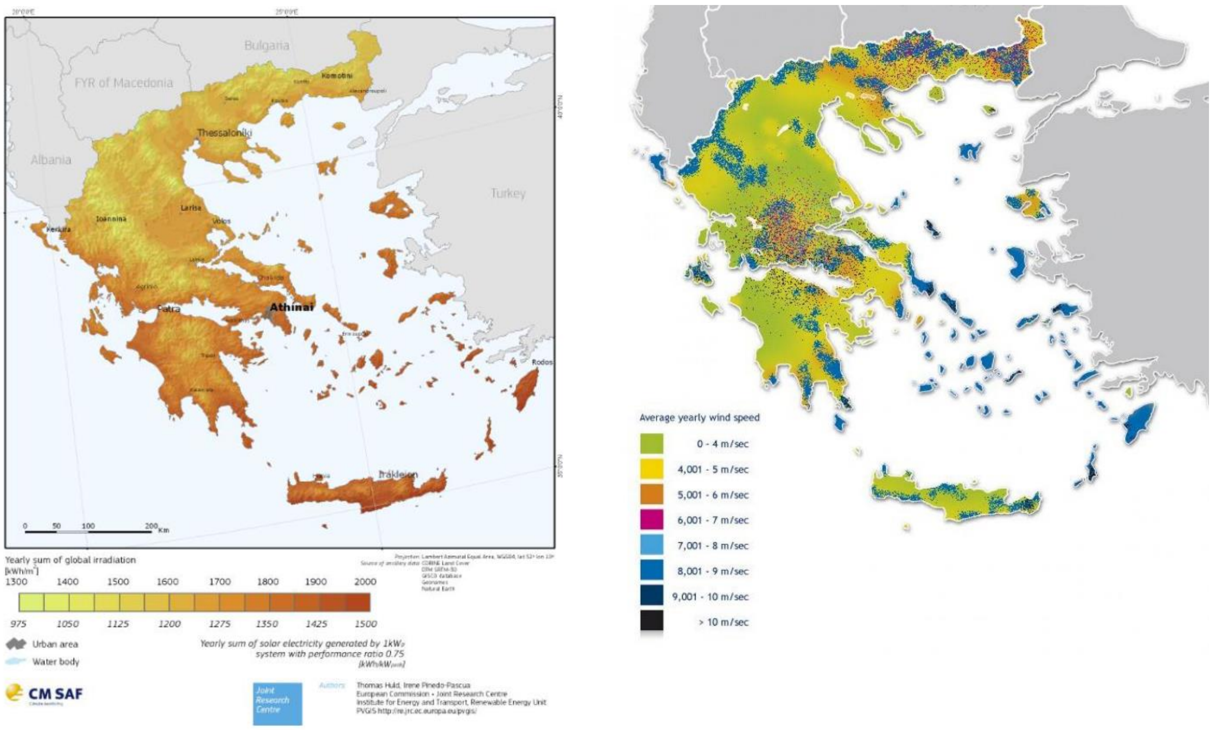

Figure 8: Global horizontal irradiation and wind speed

According to the above figures, Nisyros is located at an area of exceedingly high irradiation, while the wind potential is amongst the highest in the country.

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Water availability in some of the Aegean Sea islands is extremely low. During the summer and dry seasons, the water demand is higher than the water availability for household use and irrigation. The main reason for the increase in water consumption is the increase in the water consumed by the hospitality industry. The main ways to meet deficient water balance on the "semi-arid" islands is water transportation and desalination. In Nisyros island, desalination is mostly used with a total capacity of 1000 m^3/d of freshwater produced.

Main sectors' pollutants

The total **CO2 emissions for the municipality of Nisyros** are included in the **Sustainable Energy Action Plan (SECAP)**, where they are calculated for 2008, as reference year, following the methodology "Standard IPCC 2006" and Guidebook. The analysis has been carried out assuming only absolute CO2 emission reduction targets. Set in order to avoid overestimated per capita target that will be caused by the strong population variation in the different periods of the year.

In the following tables the equivalent CO2 emissions [t] per sector are presented.

Sectors	Electricity	Fossil Fuels			Total
		LPG	Oil	Gasoline	
Municipal sector	134	0	19	0	152
Tertiary sector	759	0	5	0	765
Residential	1623	14	56	0	1693
Municipal lighting	15	0	0	0	15
Total	2531	14	80	0	1625

Table 7 CO2 emissions buildings, equipment and infrastructures [t]

Emissions in this sector are increased due to the high consumption of electricity which, compared to fuel for movement and heating, has a higher emission factor. Almost all emissions are produced due to energy consumption in the tertiary and domestic sector, with the domestic sector being the largest and undisputed consumer. Municipal sector and municipal lighting emission are comparably a small part of the whole.

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Transport	Electricity	Fossil Fuels			Total
		LPG	Oil	Gasoline	
Municipal fleet	0	0	153	36	189
Public transport	0	0	0	0	0
Private and commercial transport	0	0	366	448	814
Total	0	0	519	483	1002

Table 8 CO2 emissions transport sector [t]

The **transport sector** contributes to a little more than a fourth of the total CO2 emissions of the municipality, this is due to the comparatively lower emission factor of the other energy carriers for transport compared to the electricity one. From the table is possible to notice that municipal fleet emissions are particularly high, compared to the usual amounts for small island municipalities. This fact is mainly due to the large number of heavy vehicles used by the Municipality in the area of the caldera, something that was also noted by the Municipality before the recording of the Municipality's energy consumption. However, the main volume of emissions is naturally produced by private individuals and entrepreneurs, in this category the contribution of tourism must also be taken into account.

CO2 Emissions	Electricity	Fossil Fuels			Total
		LPG	Oil	Gasoline	
Total	2531	14	599	483	3627

Table 9 Total CO2 emissions [t]

From the table of the total CO2 emissions four specific energy carriers can be observed along with their impact to the overall emissions. It is clear that electricity is the most polluting energy carrier, since it is a source of energy for activities that as a whole emit CO2 in a percentage greater than 2/3 of the total. Regarding fossil fuels, it is possible to distinguish three different fuels. LPG with a value of 14t is the lowest emitting one, due to the fact that it is rarely used, mainly for cooking and as a replacement for electric current. Oil, on the other hand, has a much bigger impact. The frequent use of oil as a fuel for space and water heating in the tertiary and domestic sectors and of course its consumption by vehicles, mainly municipal ones, makes it the second most common energy source. Lastly Gasoline,

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consumed exclusively by private and commercial vehicles, has a significant contribution to the total CO_2 emissions with 483 t.

Environmental strategies/policies (CO_2 emissions reduction goals)

The Sustainable Energy Action Plan includes environmental policies and areas of effort to reduce CO_2 emissions (SECAP). The Municipality's participation in many sectors with a direct or indirect contribution is necessary to meet its objectives and obligations to reduce CO_2 emissions through a more comprehensive sustainable development. Different **priority activity and thematic areas** have been identified taking into account the particularities of Nisyros Municipality.

Local production of electricity from RES:

Among all energy carriers, electricity accounts for the biggest share of energy consumption and CO_2 emissions. This finding is primarily attributable to the nation's typically high emission factors for energy production. The Municipality's highly considerable RES potential and land availability provide the ideal setting for the implementation of novel RES applications for electricity production that aim to lower a particular emission factor.

Saving electricity and oil consumption in the tertiary and domestic sector:

Beyond the activities in the power production sector, reducing the use of electricity and oil in the energy-intensive tertiary and domestic sectors is crucial and contributes to the reduction of emissions. While oil is primarily utilized in burners to provide space heating, electricity is used in similar industries for a variety of purposes, providing a multidimensional area of activity.

Saving CO_2 emissions with measures in the transport sector:

The Municipality's final energy consumption is significantly influenced by the transportation sector. Hence it is important to take steps to reduce emissions. The major goal of the Municipality of Nisyros' mobility management program is to accelerate the shift from private transportation (mostly motorbikes) to more energy- and environmentally-friendly modes of transportation like bicycles or E-vehicles.

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3. Replication Methodology

The replication framework described in Section 2 provided insights from a qualitative perspective on the islands' profile, stakeholder ecosystem and energy transition objectives and is a first stage for the definition of the Master Use Cases.

Following the description of the main aspects accounting for the energy transition replication framework in the Fellow Islands, this section presents the **methodology** for assessing the replication potential of the proposed use cases and solutions within the Fellow Islands energy network, as well as to other interested islands at national and EU level. More specifically, in this section, the following information is provided:

- Overview of replication analysis: background and process to conduct the replication assessment
- Review of existing projects and scientific studies (research)
- Description of the decarbonisation scenarios on which the replication of the technologies and the impact of the use cases will be tested
- Definition of the Master Use Cases that address the island needs and objectives and include the selected technologies

3.1 Brief Overview of Replication Analysis

The major goal of the IANOS project is to assist islands in achieving decarbonisation by maximizing the share of Renewable Energy Systems (RES) and providing flexibility in grid operation through innovative energy storage assets and other novel and promising clean technologies.

Apart from the actual implementation of specific solutions in the two LH islands itself, IANOS project aims to explore and analyse **the feasibility for the replication or large-scale deployment of specific use cases** (including IANOS solutions) in the energy networks of its Fellow Islands (FIs), in order to support their energy transition in the long term.

Each use case consists of innovative and conventional solutions/technologies focusing on a similar objective that increases impact. Table 10 summarizes the set

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of IANOS Use-Cases (UCs), as defined in the proposal stage, grouped under 3 axes called "Transition Tracks", according to the requirements each interdisciplinary Use-Case (UC) addresses. The three (3) complementary Transition Tracks (TT#1–TT#3) make up the Island Energy Transition Strategy adopted by IANOS, considering the challenges and enablers for the demonstration and replication of solutions in the IANOS Lighthouse and Fellow islands.

Table 10 IANOS Island Energy Transition Tracks and Use Cases

Island Energy Transition Tracks	IANOS Use Cases (UC)		LH Islands				FI Islands		
			AME		TERC		LAMP	BORA	NIS
#TT1: Energy efficiency and grid support for extremely high-RES penetration	UC1	Community demand-side driven self-consumption maximization	D	R	D	R	-	-	R
	UC2	Community supply-side optimal dispatch and intra-day services provision	D	R	D	R	-	R	-
	UC3	Island-wide, any-scale storage utilization for fast response ancillary services	D	R	D	R	R	R	-
	UC4	Demand Side Management and Smart Grid methods to support Power quality and congestion management services	D	R	D	R	-	-	R
TT#2: Decarbonization through electrification and support from non-emitting fuels	UC5	Decarbonisation of transport and the role of electric mobility in stabilizing the energy system	D	R	D	R	R	R	R
	UC6	Decarbonizing large industrial continuous loads through electrification and locally induced generation	D	R	-	R	-	-	R
	UC7	Circular economy, utilization of waste streams and gas grid decarbonization	D	R	-	R	R	R	R
	UC8	Decarbonisation of heating network	D	R	-	R	R	R	R
TT#3: Empowered LECs	UC9	Active Citizen and LEC Engagement into Decarbonization Transition	D	R	D	R	R	R	R

D: The solution will be Demonstrated during the course of the project // R: The solution is planned to be Replicated

In order to fully cover the IANOS-defined TTs, IANOS aims to enable and demonstrate the roll out of 9 UCs, as well as to explore the replication potential and impact of some of those specific UCs (including innovative solutions offered by IANOS) by defining a Master Use Case for each island, which will encapsulate all different UC levelized interventions in a single UC, named as MUC. This will be based on the island specific needs and energy transition aspects. The MUC will include conventional, but also innovative IANOS solutions selected in a way to increase the impact on the islands energy system. The specific capacities and areas for each of the selected technologies need to be defined, alongside the grid topology where the targeted IANOS innovative technologies will be included.

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Moreover, the economic figures of the MUCs will be given, including the CAPEX and OPEX for each operation unit, system and technology.

The replication studies will examine the feasibility of the Master Use Cases, based on the establishment of **two foreseen decarbonisation scenarios** which will be compared to the current state of the island energy networks and conditions (**baseline – business as usual operation**), and evaluated from the perspective of an **integrated energy, environmental impact and economic analysis**. The big advantage of this approach is the multi-vector, multi-scale and step-sequenced sustainability and feasibility evaluation provided by the different methods and tools.

The replicability analysis will be carried out via the conduction of simulations, computations and KPI calculations performed by the IEPT toolkit. Power flow simulations are required to evaluate the current energy system and the electrical grid state under the scenarios towards increasing RES penetration and network hosting capacity, while for the environmental impact assessment at the island level, a lifecycle assessment (LCA) approach is essential to be used. The overall cost effectiveness and techno-economic viability of the tested Master Use Cases will be investigated using the well-established lifecycle costing (LCC) and cost-benefit analysis (CBA) methodologies, specified for smart island and smart grid projects.

The energy networks of the Fellow Islands for all scenarios will be simulated and the techno-economic and environmental-oriented results obtained with the IEPT tools will be given. Both the **technical and economic feasibility** of the master use cases will be assessed. Results will help IANOS Fellow Islands redefine their climate strategy and update their sustainable action plans for achieving a fossil-free future, while delivering best practices and sharing knowledge and lessons learned from the particular context of each island to the EU island community.

The **2nd version** will include a detailed **techno-economic assessment** and **cost-benefit analysis** of the Master Use Cases. The aim is to identify the role of impacts, costs and benefits, in relation with replication and scalability characteristics.

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3.2 Review of related studies and projects

With the intention to explore the key features of the methodological approaches widely employed for assessing and enabling the replication potential of innovative solutions demonstrated in smart grid, smart island, smart city and island energy transition projects, a review of existing projects, initiatives and relevant scientific literature was conducted focusing mainly on EU contributions.

The following Table includes a list of projects whose topics are related to IANOS islands' replication objectives in the context of island energy transition and decarbonisation, as well as to the IANOS scope and methodology in terms of replicability and scalability analysis.

Table 11 Projects related to smart grids and islands energy transition

Project Name	Project Aim & Replication Analysis Approach
InterFlex-Interactions between automated energy systems and Flexibilities brought by energy market players Ref: [17]	InterFlex is a Horizon 2020 EU-funded project that aims to tackle the various challenges faced by DSOs when reshaping and modifying their systems and business models towards further integration of distributed renewable energy sources (DRES) into the energy mix. The project entails 6 real-scale demonstrators in 5 European countries. A scalability and replicability analysis (SRA) of the use cases was performed to assess the potential impacts of smart grid solutions when demonstrated at a larger scale within a similar or alternative environment, and also identify key barriers for large-scale deployment. Both a quantitative analysis considering various SRA scenarios simulated and compared to the baseline, and a qualitative analysis of the effect of the replication boundary conditions on the implementation of the use cases concerning technical, economic, regulatory, and social aspects, are followed.
SMILE SMart IsLand Energy systems Ref: [18]	The SMILE project dealt with the implementation and operation in real-life settings of a variety of technological and non-technological solutions intended to enable smart grid functionalities, demand response services, storage and energy systems integration, in three Lighthouse Islands, Madeira (PT), Orkneys (UK), and Samsø (DK), paving the way for their commercialization. Future scenarios of increased electrification and RES penetration in the LH islands were studied using power flow simulation and energy system analysis. Six European

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	islands from the participating countries in the project (Portugal, Scotland, Denmark, Italy, Greece, and the Netherlands) were chosen as potential replication sites of the SMILE solutions demonstrated in Madeira Island. Due to data gathering issues, the replication assessment was based on a qualitative analysis considering the technical, regulatory, and socio-economic boundary conditions in islands' ecosystems, and identifying the drivers and barriers for reproducing the use cases on those islands.
INSULAE Maximizing the impact of innovative energy approaches in the EU islands Ref: [19]	The primary objective of INSULAE is to support the deployment of innovative and cost-effective solutions (RES-based systems up to 70 % cheaper than diesel) aiming to the decarbonization of the EU islands, by demonstrating at three (3) LH Islands, Unice (HR), Bornholm (DK), Madeira (PT), a set of interventions linked to seven replicable use cases. In order to ensure larger project impact, project results will be used for the validation of an Investment Planning Tool in four (4) Follower Islands (Menorca (ES), Norderney (DE), Marie-Galante (FR), Chios (GR)), which will try to define their decarbonisation action plans using the tool and its outcomes, enabling the first step of INSULAE replication.
MAESHA deMonstration of smArt and flExible solutions for a decarboniSed energy future in Mayotte and other European islAnds Ref: [20]	MAESHA aims to decarbonize the energy systems of geographical islands via large-scale RES deployment and provision of innovative flexibility services building upon a thorough analysis and modelling of regional energy systems and stakeholders. The solutions demonstrated in the French overseas territory of Mayotte, will be used for examining their viability and replication potential in five more islands dispersed across Europe and other regions. The non-technical boundary conditions will be identified, the energy profile of the follower islands (baseline) and the replication scenarios will be defined to assist in the scalability and replicability analysis of the demonstrated use-cases via simulations. A replication guide for applying a community-based approach in energy transition projects will be developed.
GIFT Geographical Islands FlexibiliTy Ref: [21]	The GIFT project is deploying a number of novel solutions, including virtual power systems, energy management systems for factories, homes, and harbours, and novel storage systems that enable coordination between electrical, heating, and transportation networks, along with the provision of supply and demand forecasting and data visualization services via a GIS platform, with the aim to decarbonise the energy mix of European islands. Replication studies considering both the scaling-up and the potential replication to other similar islands in the context of Scalability and Replicability Analysis will be

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	conducted by two follower islands. A detailed replication methodology is followed including the description of the regulatory, socio-economic and technical factors contributing to a good replicability of GIFT solutions, the specification of the follower islands energy profiles in order to assess the replicability potential of the demonstration solutions, the definition of the scenarios and the data preparation for the simulation analysis of the replicability, the technical and design requirements for the replication and deployment of the full-scale use cases, and the analysis outcomes base on the simulation results.
REACT Renewable Energy for self-sustAinable island CommuniTies Ref: [22]	The REACT project focuses on combining RES systems, energy storage systems and a demand response platform in a local energy community to promote the energy independence in three pilot islands having similar size but different climate conditions and energy needs, La Graciosa, Canary Islands (ES), San Pietro, Sardinia (IT), and Inis Mór, Aran Islands (IE). Five follower islands will create large-scale replication plans to measure the project's socio-economic benefits and viability. An integrated energy planning approach is used by a developed platform for decarbonising the islands' electricity grids, in both the pilot and follower islands of the project, and select the best scenario based on life-cycle assessment and multi-criteria decision analysis.
RENAISSANCE RENewAble Integration and SuStainAbility iN energy CommunitiEs Ref: [23]	The main goal of RENAISSANCE project was to support and enable the establishment of energy communities across the globe, based on its four demo-sites acting as examples. A replication methodology has been developed to help the stakeholder ecosystem of ten (10) replication sites, design an optimal energy community scenario considering their specific objectives via employing a Multi-Actor Multi-Criteria Analysis (MAMCA) and the RENERGiSE multi-vector optimization tool [25]. The scalability and replicability of the RENAISSANCE approach was tested and validated in diverse geographic locations with different typologies, sizes and objectives.
POCITYF- A Positive Energy CITY Transformation Framework Ref: [24]	POCITYF is a smart city project that integrates a wide range of solutions and activities towards facilitating energy transition and the creation of positive energy districts (PEDs) in its Lighthouse cities (LHs), Evora (PT) and Alkmaar (NL), while also supporting the planning and implementation of replication actions in six (6) Fellow Cities (FCs). POCITYF assisted its FCs in the development of their replication strategy, the selection of the replication areas and innovative solutions for the replication activities, taking into account each specific city's features. The activities were organised in four phases: a) state of the FCs

	at the beginning of the project, b) stakeholders' ecosystem and feasibility analysis, c) business modelling and action planning and d) implementation. A replication methodology was established, i) highlighting all the technical, economic, legal and social factors to be considered for each city ecosystem for the replication activities, ii) evaluating through the conduction of feasibility studies the replication potential of the proposed solutions (MCDM, PESTEL, SWOT, CBA analysis used), iii) providing guidelines for shaping their replication plans and roadmaps towards achieving their 2050 city vision.
ISLANDER Accelerating the decarbonisation of islands' energy systems Ref: [26]	The ISLANDER project deals with the development of a roadmap for a complete island decarbonisation by 2030, by deploying smart grid solutions in Borkum Island (DK), aiming to aggregate the distributed energy resources. The project builds upon a replication strategy of its solutions that entails 3 replication axes: i) Follower islands located in four different geographical regions, ii) the related archipelagos, as well as iii) further replication to other EU islands. ISLANDER Follower Islands plan to replicate specific project activities as well as conduct feasibility studies for replication across all EU islands.
COMPILE Integrating community power in energy islands Ref: [27]	The key aim of COMPILE was to empower local energy systems in the transition from centralized to flexible, secure and decentralized energy supply networks via optimal integration of all energy vectors and community energy, based on a set of innovative developed tools tested at 5 locations, while exploring market potential in India and China; 3 demo sites, Luče (SI), Crevillent (ES) and Križevci (HR) deployed the complete COMPILE toolkit, and 2 replication sites in Lisbon (PT) and Rafina (GR) attempted to replicate the project results.

In addition, various scientific research papers examine the suitability, feasibility and effectiveness of decarbonisation scenarios for insular energy transition on multiple levels. A short number of **representative works in the literature** is selected. The specific study of [28] presented the key energy transition aspects in different Greek islands, through a comparative analysis of exemplar cases focusing on RES projects and the model of energy communities, whose solutions can be considered for replication by other Greek and/or European islands along with the support of the Clean Energy for EU Islands Secretariat.

The work of [29] focuses on an integrated energy and economic assessment with a developed platform to evaluate different decarbonisation scenarios for

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islands' electricity grids, in the eight islands of REACT project, previously mentioned, using life-cycle assessment and multi-criteria decision analysis considering technical, environmental, economic and social criteria.

The research of [30] tried to evaluate the impact of specific options in electricity, heating and transport sectors for three foreseen decarbonisation scenarios using as a case study Sardinia Island of Italy, considering the dynamics of energy transition and optimization modelling in EnergyPLAN software. In another study, a number of prospective decarbonisation scenarios for the Faroe Islands (DK), including a variety of energy technologies, are examined using the EnergyPLAN software. These systems are then evaluated by a set of environmental, social, technological, and economic characteristics.

The authors of [31] followed a multicriteria decision analysis (MCDA) approach, considering economic, technical, environmental and social factors, to evaluate the suitability of alternative energy mix scenarios for the Greek Island of Lesvos, using different energy technologies, conventional and RES.

The study of [32] followed a foresight interviewing approach to identify potential energy transition pathways for the Canary Islands, capitalizing on the various stakeholder viewpoints, and highlighting the main challenges and opportunities for the islands energy system towards the adoption of cutting-edge technologies and business models.

Lastly, the study of [33] looked into the FLEXITRANSTORE smart grid technology innovations' scalability and replication potential using a method adapted from BRIDGE methodology [34]. For this reason, scalability and replication-related project factors have been investigated and identified. These factors, which take into account technological, economic, governmental, and stakeholder criteria, were selected after performing in-depth literature research, to determine whether project's solution scaling up or replication is technologically feasible, commercially viable, legally supported and socially acceptable.

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3.3 Scenarios definition for IANOS Islands

As already stated, IANOS project aims at fostering the wide replication and upscaling of innovative solutions in EU islands. This section aims to define the examined decarbonisation scenarios for the replication studies of the IANOS Fellow Islands, in order to provide an assessment of the related use cases results, which will be compared to current operation of the island energy systems (baseline) and evaluated from the perspective of an integrated energy, environmental impact and cost-benefit analysis. This information will provide the blueprint for the feasibility assessment of the proposed solutions in the Fellow Islands, in order to design an overall replication plan.

The scenarios will focus on maximising RES exploitation and enabling power grid flexibility in the islands by considering use cases testing innovative IANOS technologies such as energy storage technologies e.g., environmentally friendly batteries, flywheels, etc., as well as conventional technologies, which will be defined for each island in the MUCs of the next section. The decarbonisation scenarios include one high-RES penetration scenario and one very high-RES penetration scenario aiming to help the IANOS islands achieve their energy transition objectives. A short description of the scenarios follows:

- a) Baseline scenario: current situation of energy mix and grid operation. As a first step, the baseline scenario models the islands network and its features at current state. In the IANOS project, the baseline depends on the energy data and information collected from the islands considered to define the grid baseline conditions and simulate the grid models.
- b) High-RES penetration scenario (towards 2030): increasing RES penetration in the range of 30%-50% in the energy mixture of the islands towards achieving 55% GHG emissions reduction, compared to 1999 levels.
- c) Very high-RES penetration scenario (2050): Maximum RES penetration levels up to 100% in the energy mixture of the islands (Fossil Free Scenario) towards achieving climate neutrality by 2050.

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3.4 Definition of Master Use Cases of IANOS Fellow Islands

The definition of the Master Use Case for each island entails the following tasks blended together towards a plan of the island's replication activities and goals:

- Description of Use Cases: the set of specific use cases which when combined, form the MUC which includes all technologies considered for replicability and scalability analysis towards enabling high-RES share and energy flexibility in island grid operation. The selection is associated with the island replication framework features and the specific goals that the island aims to address in the context of energy transition (given in Section 2).
- Specification of technologies: the list of the main conventional technologies (e.g., PV etc.) as well as IANOS innovative technologies included in the MUC of each island to be considered for replication and scale-up study and analysis. The main design and dimensioning characteristics e.g., capacity, size etc. as well as key environmental & economic figures (inventories, CAPEX etc.) for each technology should be given.
- Definition of Replication areas/sites: the targeted areas in which the innovative IANOS technologies will be included for assessing the MUC envisioned impact and examining the replication feasibility via the use of IEPT, by specifying the locations in the grid topology (e.g., grid substation X), and the energy units and communities benefited on the island scale.

In order to facilitate the definition of the Master Use Case for each island, a template was developed, aiming to provide very briefly a general overview of the island's replication goals. The template has been distributed to IANOS FIs representatives to be filled in by the island ecosystem, asking for the above information. The definition of the Master Use Case for each Fellow Island along with its key objectives and the selected technologies are presented below.

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3.4.1 Master Use Case (MUC) of Bora-Bora Fellow Island

The main objective of Bora-Bora Island is to increase its energy self-sufficiency for both the supply and demand side by local resources and the proposed replicated solutions by the project. By 2030, Bora-Bora wants to accomplish essential decarbonisation setting the goal of generating 75% of its electricity from RES. IANOS will assist in the deployment of 2 MW_p PV agricultural greenhouses and 2 MW_p PV shading structures integrated with an energy storage system. The creation of a desalination unit, the installation of solar panels and onshore maritime thermal energy (2 MWth) to support the renovation of the airport's air conditioning, and the building of an electric boat charging station are also in the plan. Relevant UCs to be replicated are UCs 2,3,5 and 8. The Master Use Case, supported by a more detailed dimensioning of envisioned interventions, on the level of systems, will be defined in the 2^{nd} version.

3.4.2 Master Use Case (MUC) of Lampedusa Fellow Island

Despite Lampedusa and Linosa programmed several actions to foster RES in the framework of the Sustainable Energy and Climate Action Plan (SECAP), the situation has changed due to the implementation of a new plan to use the funds provided for the Green Island project promoted in the framework of Italian PNRR. In fact, through the PNRR, Lampedusa and Linosa have received funding in the order of 41 million euros to be spent on the island's green transition no later than 2026. The municipality of Lampedusa is currently analysing solutions to be implemented with these funds. In addition, solutions are being studied to use these funds as leverage for potential private investments that can exponentially increase RES production on the two islands.

Therefore, an overview of potential solutions to be implemented through Italian PNRR funds include for Lampedusa the:

- installation of 300 photovoltaic modules on public rooftops on the island of Lampedusa for a total of 92.4 kW_p with an estimated production of 153.2 MWh/year;
- installation of a floating wind system for a total of 1500/3000 kW_p and a production of more than 5150 MWh/year at a distance of about 10km from the north coast of the island of Lampedusa;

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- installation of a photovoltaic system on the island of Lampedusa for a total of about 2.3 MW_p with an estimated production of 3800.0 MWh/year;
- installation of a 2300kWh electrochemical storage system;
- installation of 15 electric vehicle charging infrastructure on the island of Lampedusa;

The foreseen interventions for Linosa, are respectively:

- installation of 78 photovoltaic modules on public roofs on the island of Linosa for an overall total of 40 kW_p with an estimated production of 72.1 MWh/year;
- installation of a photovoltaic system on the island of Linosa for an overall total of 450 kW_p and a production of 765 MWh/year;
- purchase of 1 electric-powered bus, 3 electric-powered mini-buses and 3 electric-powered vans to be divided in the two islands;
- installation of 5 electric vehicle charging infrastructures on the island of Linosa.

The municipality aims to conduct techno-economic and feasibility studies with the aim to provide better grid stability through defining effective RES penetration models into the island's grid and addressing critical grid challenges as of congestion, curtailment, and voltage variations, facilitating the island energy transition. IANOS will assist Lampedusa during those studies and the potential implementation of those solutions. The goal for Lampedusa and Linosa is to figure out how to replicate the results achieved by UC 3, 5, 8 and 9. The Master Use Case will be defined in the 2nd version.

3.4.3 Master Use Case (MUC) of Nisyros Fellow Island

Nisyros envisions to benefit from the grid stability provided by the Kos electricity network, which is expected to be interconnected to the mainland grid with DC underwater cables by 2027. It is also necessary to conduct feasibility and techno-economic studies to determine the optimal decarbonisation and flexibility measures to the electric grid e.g., the installation of PV and wind parks accompanied by grid scale storage systems that will make it easier to operate the regional electrical grid in the South Aegean. Nisyros has 200 residential and 11 public buildings. Nisyros aims to boost RES penetration and decarbonize its energy grid via the construction of both a PV park and a wind farm with a total capacity of 570kW and 1.7MW respectively. The existing municipal fleet (32

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vehicles) will be replaced by electric vehicles (EVs) powered by 12 PV-based charging stations that will be coupled with innovative grid scale storage systems. The Master Use Case will include the innovative technologies of Saline Battery (SuWoTec) and Flywheel (Terraloop) that are demonstrated in IANOS project. UCs 1, 4, and 8 are expected to be taken into account for the formulation of the MUC. The following system assets and interventions will be considered:

- PV park (570kW)
- Wind farm (1.7MW)
- 12 EV charging stations: (AC 22kW each)
- Energy storage systems (240kWh)
  (2 bio-based saline batteries in the 120-kWh variant, developed by SuWoTec)
- A Flywheel (with a capacity of 250 kW) (developed by Terraloop)

The Master Use Case will be further elaborated in the 2nd version.

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4. Replication Assessment

4.1 Brief presentation of the IEPT tools

This sub-section presents briefly the IANOS Island Energy Planning and Transition (IEPT) suite and its components which focus on the energy modelling, environmental analysis and techno-economic assessment of the energy systems and their operation in IANOS islands. The IEPT components can provide results for a variety of indicators pertaining to energy systems and technologies analysis. The outputs of this task will be based on the metrics (KPIs) defined in WP2. D2.9 includes all the KPIs descriptions and formulas for the assessment of the IANOS project, explaining in detail their application and calculation methods [35]. In this context, a short description about the data, KPI metrics integrated in IANOS IEPT suite, and main outputs are also provided.

4.1.1 INTEMA.grid (INTegrated Energy MAnagement tool)

The grid simulation is the first evaluation step of island's energy system. INTEMA.grid is a component of the Island Energy Planning and Transition Suite (IEPT) of IANOS. It is a grid modelling and simulation tool which can analyse various energy management and operational strategies, taking into consideration various RES and storage integration scenarios as well as promoting the decarbonization of the current energy mix. It can also support long-term planning. It may also encourage the synergistic operation of energy networks. For any grid architecture, including electrical, heating/cooling, gas networks, and storage systems, the program can do the following calculations:

a) Power flow calculation at each grid node

b) Optimal power flow calculation, minimising generation cost at each timestep

c) Frequency stability study, which requires the comprehensive electromagnetic transient (EMT) modelling of each asset

d)Contingency plans analysis (N-1 criterion, short-circuit etc.), accounting also for forecasting algorithms (in real-time, if needed)

e) Renewables power generation and load

Besides plots of the grid response, the tool is also able to calculate specific aggregated energy-related KPIs, as defined in D2.9.

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4.1.2 VERIFY-D (Virtual intEgRated platform on LIFe cycle analYsis)

The deployed and replicated technologies in the islands will undergo a life cycle environmental and economic assessment. The Island Energy Planning and Transition Suite (IEPT) of IANOS includes the VERIFY-D platform tool, which will be used for this purpose. The use cases' and technologies' evaluation will be based on the list of the KPIs defined in D2.9. VERIFY-D consists of two modules, the Lifecycle Assessment (LCA) and the Lifecycle Cost (LCC) module. The LCA module is able to measure indicators regarding energy savings, fossil fuel consumption and greenhouse gas emissions, as well as primary energy demand and consumption. The LCC module is designed to assess the direct, indirect, internal, and external costs of selected technologies at every point during the course of a project and during lifetime i.e., the capital, operation and maintenance (O&M) and end-of-life costs in terms of LCC.

4.1.3 CBA Component (Cost Benefit Analysis tool)

Cost Benefit Analysis (CBA) is the most widely known method for techno-economic viability assessment. The last part of IANOS IEPT is the CBA component. The goal of this tool is to evaluate the overall advantages anticipated from the green energy/smart grid interventions in the IANOS demonstrators. The CBA tool will be based on the CBA techniques developed by the JRC and ENTSO-E and will give stakeholders and investors with an analytical approach that offers quantified insight into whether a smart grid intervention exceeds the current baseline scenario in terms of costs and benefits. To do that, the factors of interest will be chosen, and the corresponding KPIs will be calculated, to help them develop goals based on the actions and vision of the various stakeholders, but also in alignment with the priorities set by the EU Green Deal. The tool is based on the CBA methodology proposed by the European Network for System Operators (ENTSO-e). This technique aims to systematically, impartially, and consistently evaluate smart grid projects by taking into account not only the benefits on an economic basis but also the environmental and social implications. Benefits, Costs, and Residual Impacts are the three pillars on which the CBA is built. The tool is also able to takes the inputs by the complementary components INTEMA.grid and VERIFY-D of IANOS IEPT to calculate specific indicators considering also the KPIs defined in T2.3.

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From the perspective of system's planning, both JRC's and ENTSO-approaches E's provide thorough frameworks for evaluating the costs and advantages of smart grid interventions and electrical infrastructure. The analysis accounts at same time for technical, economic, reliability, environmental, and security benefits.

4.1.4 Evaluation Metrics by the IEPT toolkit

For the purpose of the replication studies, the baseline scenario will be used for later comparison with the decarbonisation scenarios via the calculation of KPIs. The IEPT is able to provide results for a complete set of indicators obtained from the specific methods adopted in each tool as well as indicators included in IANOS KPIs and evaluation metrics (D2.9). The KPIs calculated by the IEPT components, are based on the technology needs and the functionalities each tool offers. Table 12 shows the relevant IANOS KPIs and their links with each of the IEPT tools.

Table 12 *IANOS KPIs calculated by IEPT Suite*

Domain	ID	KPI Name	INTEMA.grid	VERIFY-D
Technical	T-1	RES Generation	✓	✓
Technical	T-2	Energy Savings	✓	✓
Technical	T-5	Increase of degree of energetic self-supply by RES	✓	✓
Technical	T-7	Storage capacity of the energy grid per total island energy consumption	✓	
Technical	T-8	Reduced energy curtailment of RES and DER	✓	
Technical	T-9	Peak load reduction	✓	
Technical	T12	kWp photovoltaic installed per 100 inhabitants	✓	
Environmental	EN-1	Reduced Greenhouse Gas Emissions		✓
Environmental	EN-2	Reduced Fossil Fuels consumption		✓
Environmental	EN-4	Air quality index (Air pollution)		✓
Environmental	EN-6	Primary Energy Demand and Consumption		✓
Economic	EC-1	Total investments		✓
Economic	EC-2	ROI		✓
Economic	EC-3	Total annual cost		✓
Economic	EC-4	Payback period		✓
Economic	EC-5	Total annual revenues		✓
Economic	EC-8	Internal Rate of Return (IRR)		✓
Economic	EC-10	Load purchasing from mainland	✓	
ICT	I-4	Increased hosting capacity for RES, electric vehicles and other new loads	✓	

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4.2 Fellow Islands Grid Energy Modelling and Analysis

The electrical system of the islands was developed with the utilization of INTEMA.grid tools and PowerSystems library [36]. Details regarding the modelling process and results obtained with the simulations are presented.

4.2.1 Bora-Bora Fellow Island

4.2.1.1 Energy system description – Current situation (Baseline)

The electric system of French Polynesia is very fragmented, since intended for 280,000 inhabitants spread over 76 islands (out of a total of 118) for an area close to that of Europe. **Bora Bora** as part of the French Polynesia archipelago, is not interconnected and has an **autonomous electric system** (Figure 9) of low installed power, with **no possibility of backup by a neighbouring island**. The concession for the production and public distribution of electrical energy in Bora Bora has been entrusted by the municipality of Bora Bora to **ELECTRICITE DE TAHITI (EDT).**

Figure 9: Bora Bora's network

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The island's **average annual energy production** was around **41 GWh up to the year of 2019**, but for the years of **2020 and 2021** the average energy production dropped to **~33 GWh**. **Peak power demands** were around **~7.5 MW** and **~7 MW**, respectively, for the two periods in question [37].

Bora Bora's distribution network consists of 4 HTA **14.4 kV feeders** with a **total length of 70.66 km** at the end of 2020, mainly underground (11.36% overhead MV lines). The low voltage network comes up to 90.08 km in length, 29% of which is overhead. The electric network of Bora Bora operates at **60 Hz frequency**. At the end of 2020, 3,213 customers were connected to the public electricity distribution network, including 31 HV customers.

The single line diagram of Bora Bora's electrical grid is shown below, in Figure 10.

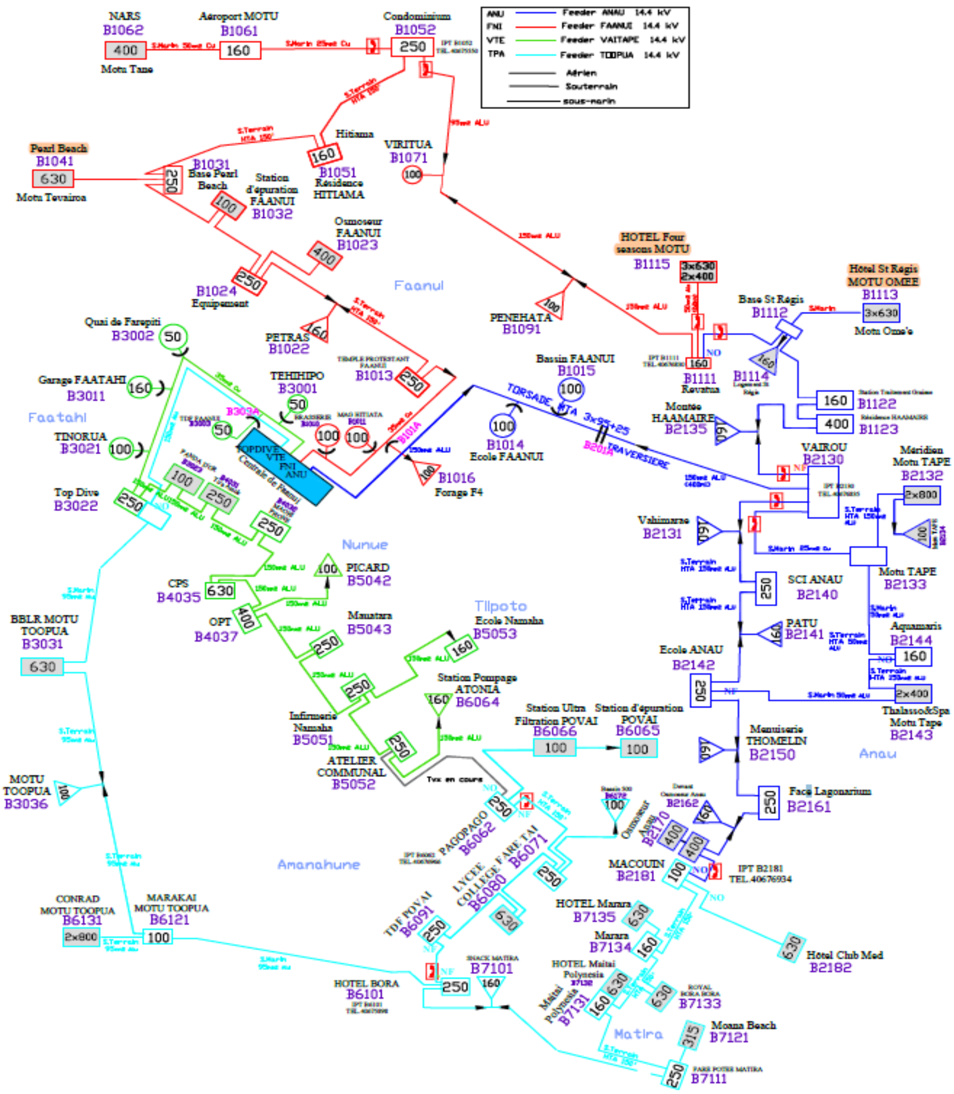

Figure 10: Single line diagram of Bora Bora's electrical grid

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The network is of radial form and consists of 4 different areas. The feeders are displayed with different colors —Vaitape (in green), Faanui (in red), Anau (in blue) and Toopua (in light blue).

Fossil-based power production plants

The energy supply derives from the island's **only thermal production plant**, consisting of diesel generation units (medium speed engines), totalling up to **21.36MW of installed power**.

The fleet is made up of 8 diesel groups:

- 1 fast Cummins 16V-KTA50 group with a useful power of 640 kW (installed in 1996),
- 3 Wärtsilä 12V-W200 semi-fast groups with useful power of 1800 kW (installed in 2001 and 2002),
- 1 Wärtsilä 6L-Vasa32 semi-fast generator with useful power of 2000 kW (installed in 1998),
- 1 Wärtsilä 8L-Vasa32 semi-fast generator with useful power of 2850 kW (installed in 1997), and lastly
- 2 Wärtsilä 9L-W32 semi-fast generating sets with a useful power of 3880 kW (installed in 2011).

In 2020, the share of plant auxiliaries represented only 2.73% of the gross energy produced by the generator sets of the Faanui thermal power plant.

RES-based power production plants

Furthermore, there are **several solar installations** owned by independent producers across the island with a total capacity of **1.922MW**. Such installation exists at the Four Seasons Resort where there is a 600 kW (1884 x Benq 327W) rooftop PV plant with IP65 protected Delta inverters. The optimal tilt of the panels is approximately same as the latitude, at ~16.5°. The optimal orientation (azimuth) is true North for the outer islands, but the shading from the mountain should be taken under consideration, as well. The Four Seasons solar system, (Figure 11) generates around 930 MWh of electricity per year and partly substitutes diesel power.

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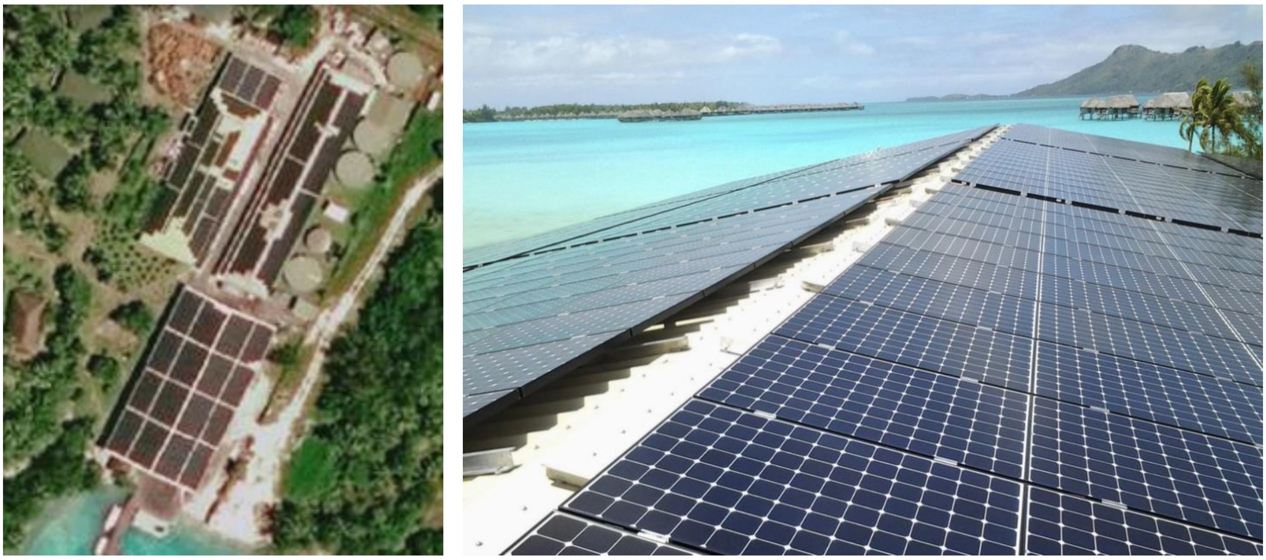

Figure 11: Four Seasons Resort PV installation

Other installations include the 641kW PV panel at Saint Régis hotel, the 98kW panel at Supermarket Toa Amok, the 306 kWp panel at Intercontinental Thalasso Spa, as well as smaller solar installations (including private households). **All photovoltaic systems combined** injected 169MWh in the network in the year of 2021 (excluding self-consumption), and 223MWh in 2020 which amounts **to ~0.5% and ~0.7% of the total production** respectively. Wind conditions in French Polynesia are generally not very favourable (not enough wind), hence no units are installed in Bora Bora [38].

4.2.1.2 Baseline Scenario - Results and discussion

MODEL SETUP

Data regarding the topology and main aspects of the Bora Bora network were acquired through Akuo Energy. The **model** development was implemented, as shown in Figure 12, and **includes the main diesel generation power plant** of the island, the Faanui power station, controlled by Bora Bora's DSO, EDT and the **4 main photovoltaic installations** (Four Seasons, Saint Regis, Toa Amok and Thalasso Spa) at different locations.

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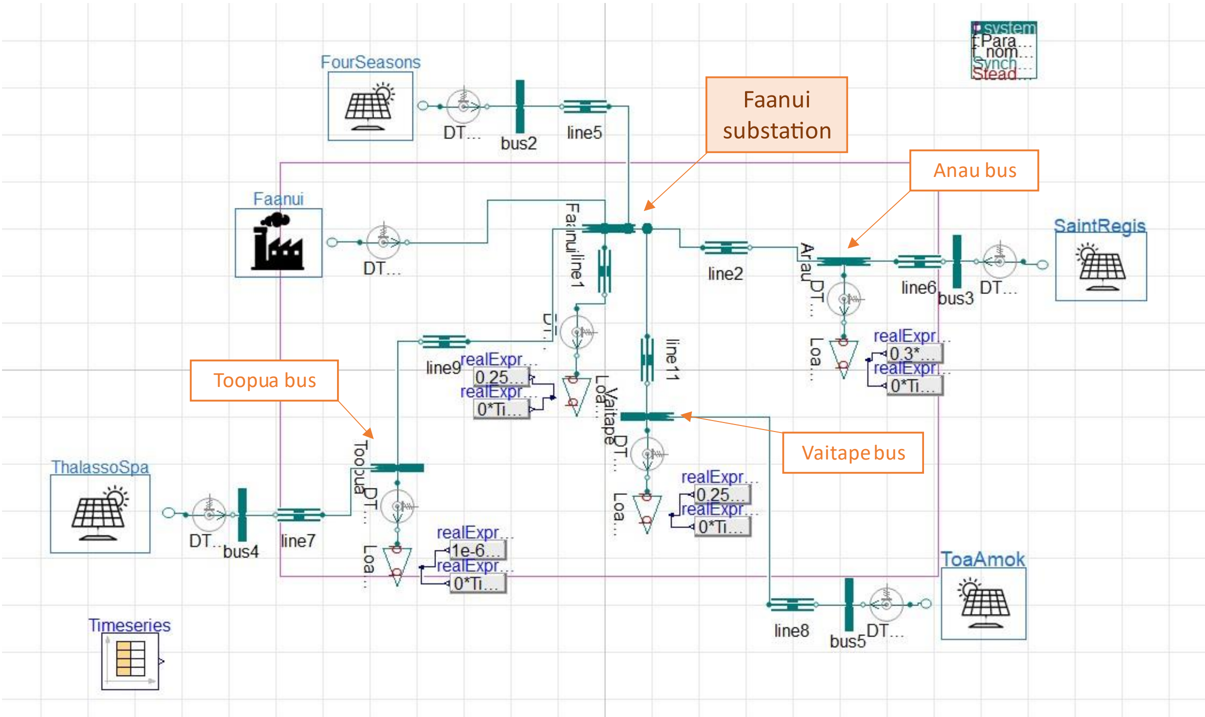

Figure 12: Developed model of Bora Bora network

The **4 solar plants** have a **total capacity of 1922kW**. Due to lack of information for the specific panel technology of each installation, Benq panel type of different installed capacity was chosen. For the modelling of the **Four Seasons** the installation consisted of **1884 Benq 327W,** with a **tilt angle** at **15°** and **0°** azimuth orientation. For the **Saint Regis** installation, there were **2200 of 290W Benq** panels with a **15° tilt**, and different **azimuths at 90° east, 90° west and at full North**. Similarly, for **Toa Amok and Thalasso Spa 300 of 330W and 850 of 360W Benq** were chosen with a **tilt angle at 15° and orientation at 40° Northwest and 50° Southeast for the former and a 15° tilt with East, West and North orientation for the latter**. Weather data, regarding temperature and solar radiation, were acquired from the photovoltaic geographical information system [39].

The aggregated loads are represented in the model network as PQ loads, that are connected to of the 4 main PQ buses (Faanui, Vaitape, Anau and Toopua bus). All transmission lines were modelled as HTA 150mm^2 aluminium cables and the lengths were approximately estimated using the island maps (combined length – 70.66km).

The low voltage distribution network is not part of the developed model, due to the lack of adequate information regarding its topology. Furthermore, it was

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assessed that its incorporation to the modelled network would not enhance the accuracy of the results, but on the contrary, would add on unnecessary difficulties to the development process.

Input Data

In order to proceed with the preliminary powerflow simulations, demand and generation timeseries for a typical year were required. Data with such granularity were not available, thus a **methodology** was chosen in order to **produce representative profiles for the demand and generation** of the particular network. The data acquired through EDT contained a graph with information about the typical daily energy consumption, as presented in Figure 13.

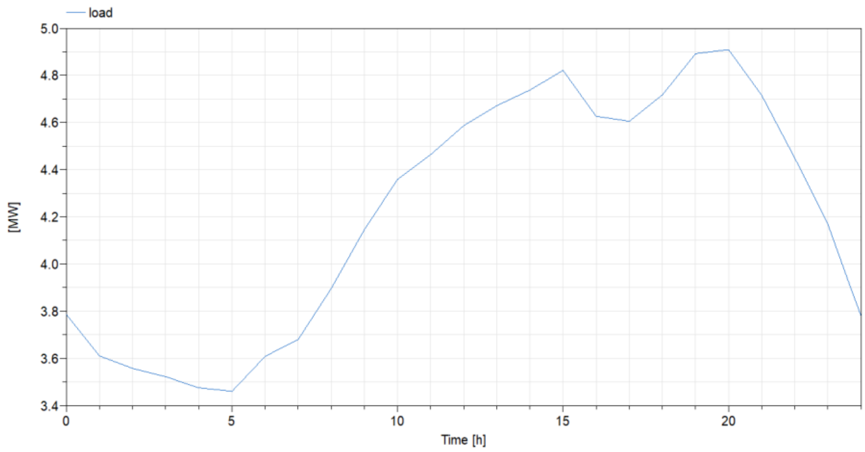

Figure 13: Typical daily load

For the load to be appropriately estimated on a annual basis, an assumption was made, supporting that **the energy consumption of Bora Bora is highly dependent on the tourism levels** throughout each year. The rationale was to express the **population deviation on the island** throughout different months of the year and therefore, the profile of the energy demand. Online statistics [40] , in Figure 14, show the quarterly number of Bora bora visitors for the periof of 2015 up to 2018.

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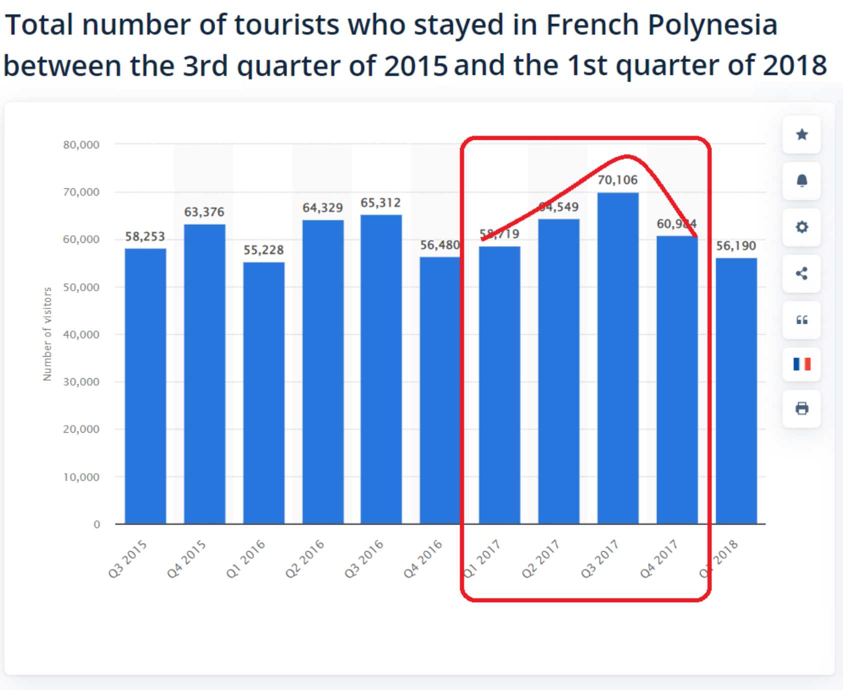
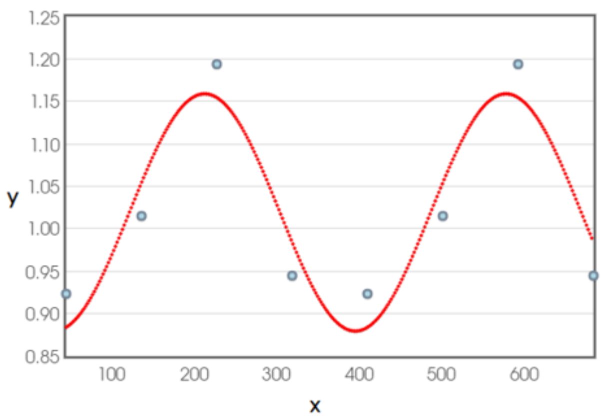


Figure 14: Number of visitors from 2015-2018

The next step was to **express the deviation in the tourism levels of the year 2017** and inculded the **normalization** of the corresponding values for this specific year, with the application of division by mean. The result was **a set of values around 1** that could be interpreted as **a factor of the deviation in the island population**. Afterwards, a sinusoidal regression (Figure 15) calculation fitting was performed to obtain a vector of **365 points** that represented **the variation of the daily energy consumption for a complete year.**



Regression Equation: $y = 0.1398 \cdot \sin(0.0172x - 2.0911) + 1.0193$

Figure 15: Sinusoidal regression calculation

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The last step involved the scaling of the typical daily load according to a coresponding scaling factor. By assuming that the total energy consmuption on a typical (mean) day corresponds to factor 1, the consumption on the rest of the days thourghtout the year can be caclulated accordingly. The resulted yearly demand profile is presented in Figure 16.

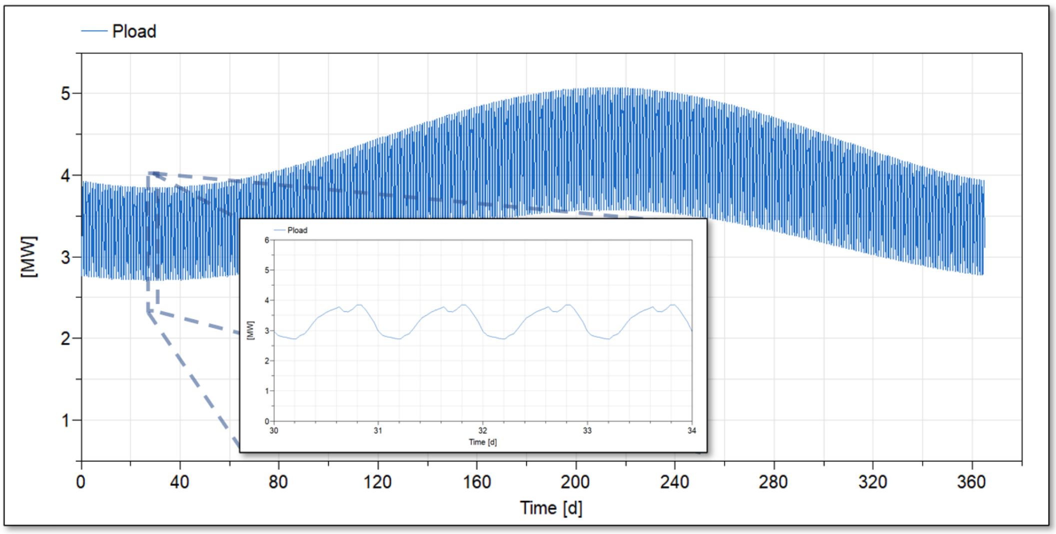

Figure 16: Active power demand based on the annual load profile

SIMULATIONS

The data produced following the aforementioned methodology were used for the powerflow simulations. The simulation interval time was set equal to 365 days, and ran with a constant **60 min timestep**. The actual duration of the power flow lasts for about 25 seconds, representing one year of simulation. **The total power produced by the fossil fuel and RES based plants annually and on a typical day**, are shown if Figure 17.

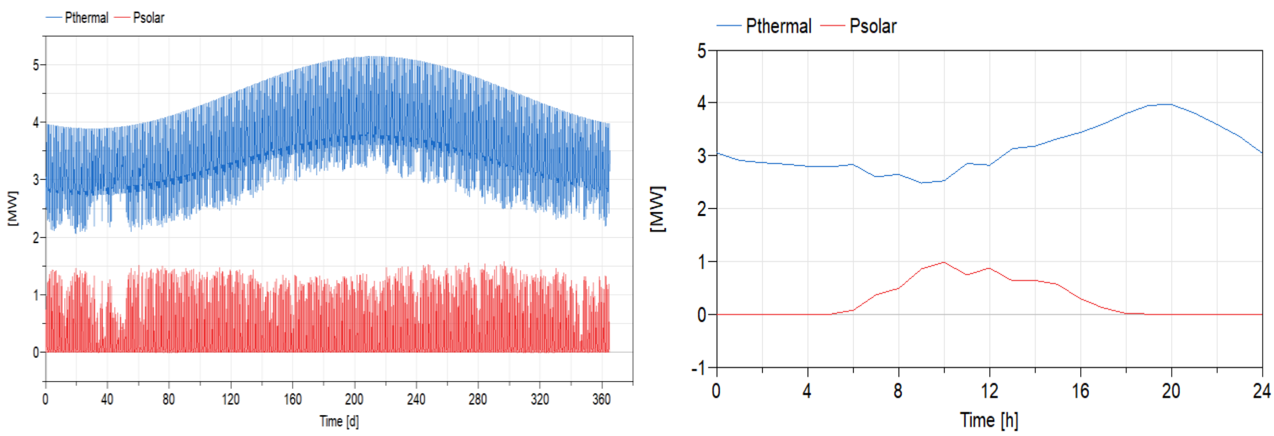

Figure 17: Thermal and solar power generation annually (left) and on a "typical" Jan 1st (right)

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For a typical day, the energy demands are shared amongst the fossil fuel and RES based plants, as follows: the Faanui power station serves as a base generation plant which stays continuously in operation, whereas the photovoltaics cover a small part of the energy demand (up to 30-35%) during the day.

From the annual powerflow simulations the energy consumption estimations amounted to 33.9 GWh and production was up to 34.3 GWh considering the technical losses in the transmission lines (0.4 GWh). The losses can be seen as the gap between the graphs of generated and demanded power (Figure 18), which contitutes a varying difference in the range of 0.04 – 0.07 MW.

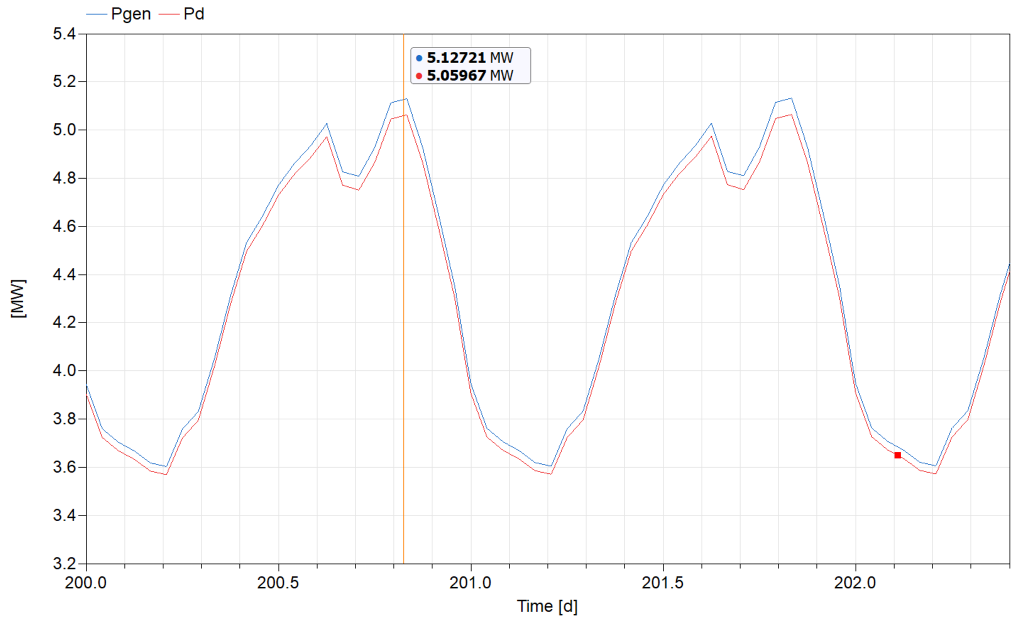

Figure 18: Demanded and generated power for 200-202 day of the year

On an anual basis the losses are kept relatively low, reaching up to 1.2% of the energy production.

An approximate 10% *(3.56 GWh)* of the annual power production was generated by photovoltaic panels. The island's RES penetration in the energy mix is limited and solely consists of photovoltaic systems. However, there are times when solar generated energy can cover over 50% of the load demands. Such occasions occur frequently throughout the year, but less often during the summer months, which can be easily noticed in the graph of Figure 19.

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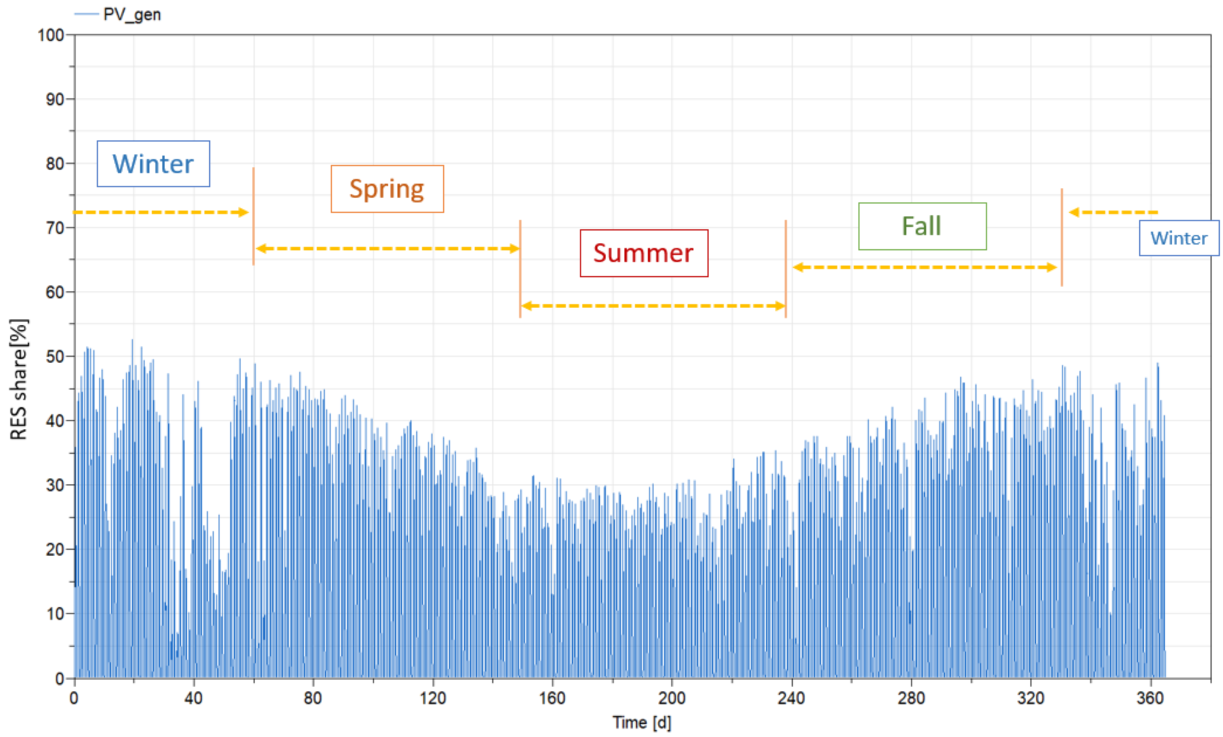

Figure 19: Power generated by photovoltaics compared to throughout the year

The share of RES based generation is shown below, in Figure 20 and the photovoltaic installation at Saint Regis hotel seems to be the prime producer of solar energy (Psg). Following next are the Four Seasons photovoltaic (Pfs), the Thalasso Spa (Pts) and lastly, the Toa Amok installation (Pta).

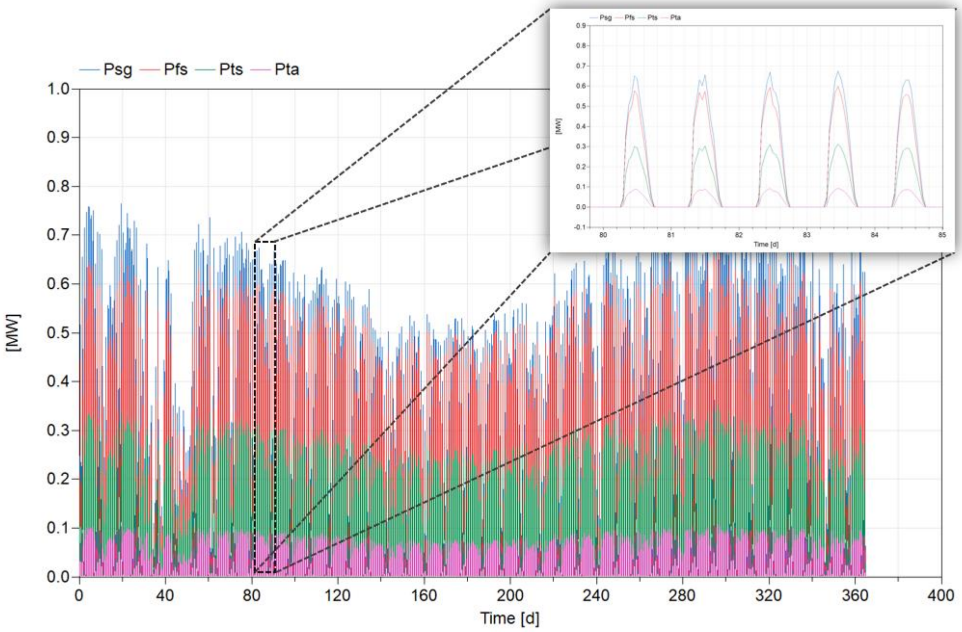

Figure 20: Annual power emitted by solar installations

Since the LV distribution network is not a part of the currently developed model, the system's energy demand is represented by the 4 aforementioned aggregated loads, one at each province connected to a 14.4kV bus. As the loads change by the hour, the voltage magnitudes of the buses are affected, except for the one that connects to the Faanui power station. In Figure 21 the voltage graphs of Faanui and Vaitape buses are displayed. The voltage drop is kept at acceptable levels, barely reaching 0.5%. At this point, it is important to note that the voltage setpoint in the Faanui power station is considered to be 1 p.u. and that no other voltage regulation device has been included in the model, e.g., on-load tap changer transformer, voltage regulators etc.

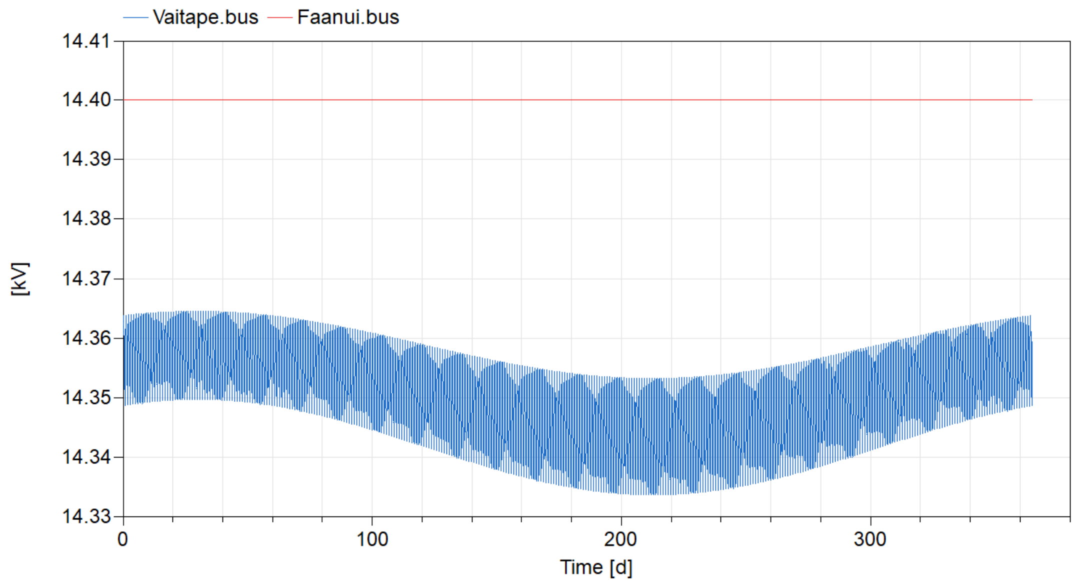

Figure 21: Voltage magnitude at the Faanui and Vaitape bus

The generation plants are responsible for providing reactive power to the system and ensuring voltage stability at the buses they connect to. Due to the lack of adequate data regarding the reactive power flow at various points of the network, the plants' reactive power supply cannot be accurately portrayed at this stage. The voltage levels of the 3 other buses connected to aggregated loads follow a similar oscillation profile to the voltage graph of Vaitape bus.

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4.2.2 Lampedusa Fellow Island

4.2.2.1 Energy system description – Current situation (Baseline)

The island of Lampedusa, due to its position at the Archipelago of the Pelagie, is not interconnected with the Italian electricity grid. All utilities, including desalination plants, are powered by a single power plant owned by S.EL.I.S Lampedusa Spa. The island's electricity distribution network has only two voltage levels: 10 kV for MV distribution and 0.4 kV for LV distribution. The 10 kV public MV distribution network originates from the Cala Pisana power station. The network, presented in Figure 22, has a structure of the radial type, classically used for MV networks in rural areas or, more generally, in territories with low electrical load density.

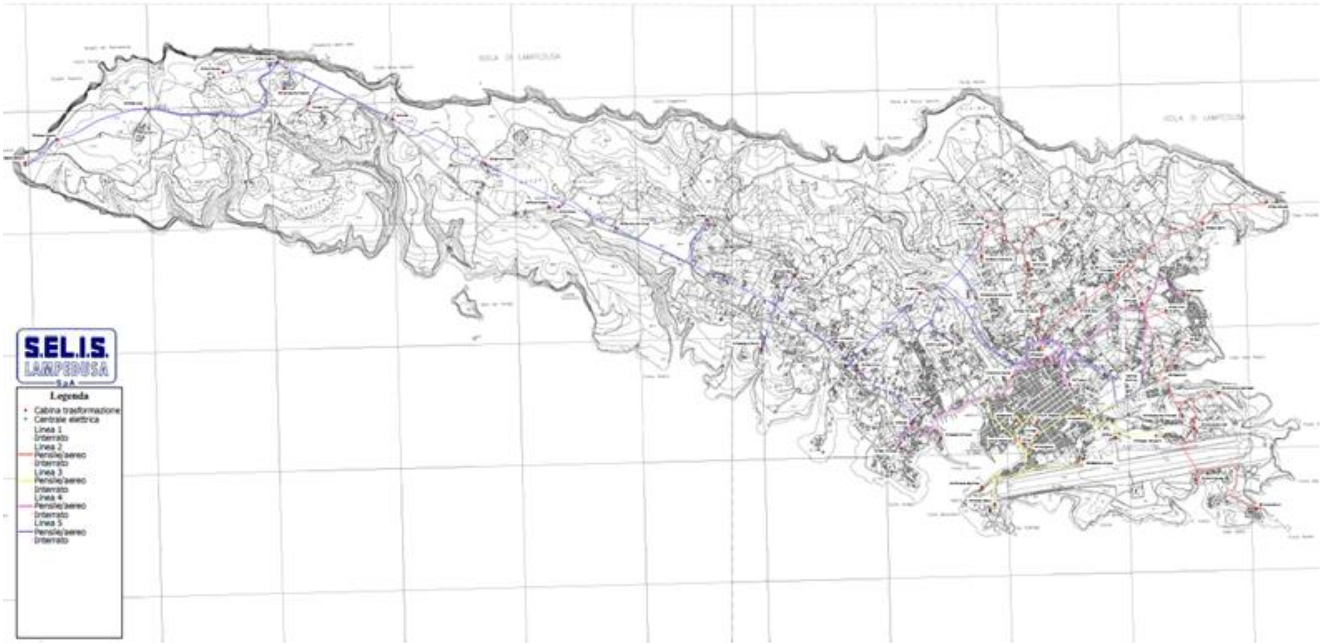

Figure 22: Diagram of the MV network of the Lampedusa Island

The MV network is operated with isolated neutral in radial mode with 5 feeders. Feeder 1 is exclusively used to cover the energy needs for the water supply. The remaining nodes are split between feeders 2, 3, 4 and 5. Feeders 1, 3 and 4 consist of underground cable and run mainly through the inhabited center. Feeder 2 runs through the center of the island and extends to Capo Grecale and Terranova. Feeder 5 reaches the peripheral areas of the island, covering the entire territory

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from East to West and as a result has the greatest overall length. Feeders 4 and 5 combine **underground cable and overhead lines.** The cables are of the RG7H1RX 12/20 kV type with a 95 mm^2 section and less frequently a section of 50mm^2 and 25mm^2 (mainly for short lines). The overhead lines are made with 35mm^2 section braided copper conductors**.**

The island's LV distribution network, at 400 V, is entirely **in cable** and supplies power to all active and passive users of the LV electrical utilities in accordance with the same requirements and technical rules as for the Italian network. It has the classic radial structure with road sectioning boxes. The distribution network supplies single-phase and three-phase users with maximum available withdrawal power up to 100 kW (generally not exceeding 80kW). Domestic users are powered with single-phase supply up to 6 kW or, in some cases, 10 kW.

Fossil-based power production plants

The island's only power plant is of **thermoelectric type** and is located **in Contrada Cala Pisana**. Until the early 2000s, the total installed power was around 11 MVA. Since then, 3 new generation sets have been added by S.EL.IS resulting in over **50% increase in the network's installed power**. In the current state, the power station accommodates **8 diesel generation groups** of different sizes and with different output voltage, **for a total power of 22.5 MW**. Each group is calibrated to operate generally around 65%-80% of the rated electrical power. The cooling system of the generating sets makes use of evaporative towers. The **generation groups operate in rotation** depending on the load demands and the scheduled stops for maintenance.

RES-based power production plants

The island's RES penetration in the energy mix is limited and solely consists of photovoltaic systems. Data acquired from the work portfolio of independent investors (Figure 23) revealed **4 photovoltaic installations** with a **total capacity of 206kW** (The Dammusi of Cala Creta-70 kW, Guitgia tourist service-50 kW, Cupola Bianca Resort-50kW and Hotel Guitgia Tommasimo-36kW).

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Figure 23: Photovoltaic installations of The Dammusi of Cala Creta (top left), the Guitgia tourist service (top right), the Cupola Bianca Resort (bottom left) and the Hotel Guitgia Tommasimo (bottom right) [41]

Furthermore, data from the 2021 report of the Sustainable Islands Observatory project [42] show that the cumulative capacity of the **distributed solar generation totals up to 605.12 kW**.

The annual electricity production in Lampedusa is **around 36.2 GWh**, characterized by a significant **variability due to tourist flows**, hence the **production peak** is concentrated **mainly in the summer season**. The monthly energy production for the year 2015 is shown below, in Figure 24.

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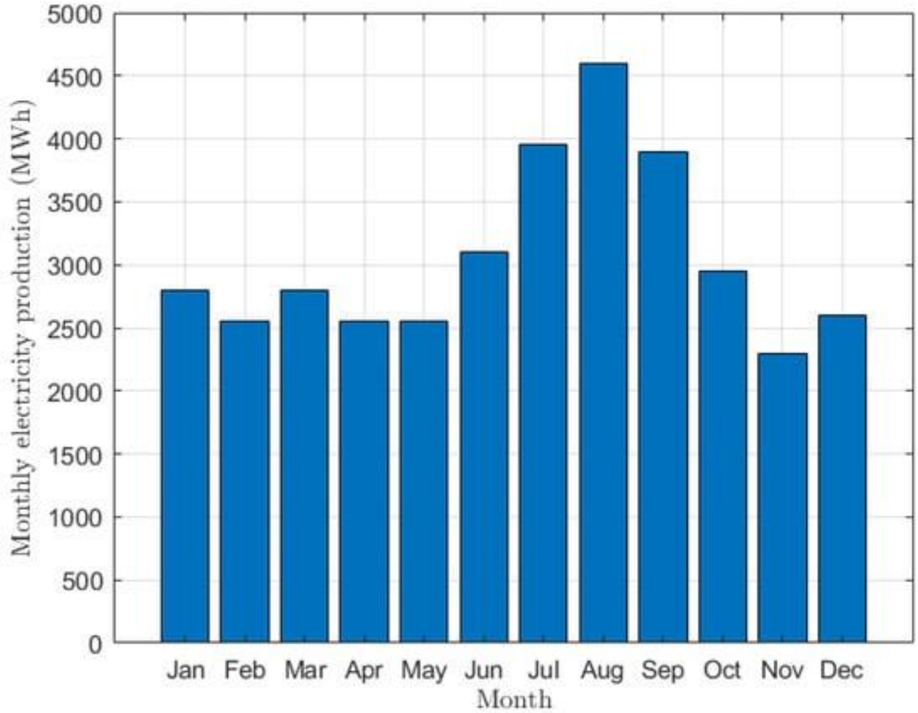

Figure 24: Monthly energy consumption for 2015 [43]

RES based installations cover only a small part (around %5) of the energy produced on annual basis, whereas the most significant part of the energy is generated by the thermal power station.

4.2.2.2 Baseline Scenario - Results and discussion

MODEL SETUP

The model development was implemented, with the aid of INTEMA.grid, which mainly utilizes the open-source PowerSystems (PS) library. For the purposes of the baseline scenario a simplified version of the 10 kV MV distribution network has been modeled. The topology and main aspects of Lampedusa's developed model network are displayed in Figure 25 and include the main diesel generation power plant of the island (Diesel Plant) with a 22.5 MW capacity, the aggregated solar energy-based generation (PV installations) of 605,12 kW capacity, the central bus, the 5 feeders, the distribution lines and the aggregated loads. Feeder 1 exclusively covers the desalination load. Feeders 2, 3 and 4 cover mainly the energy demands in the inhabited areas, including the airport and harbor. Feeder 5 reaches areas all across the island covering the "ponente" (west side) energy demands. The LV distribution system was excluded from the developed model, as it would

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introduce many difficulties in the process and would not result in any significant improvement on the outcomes of the load flow simulations.

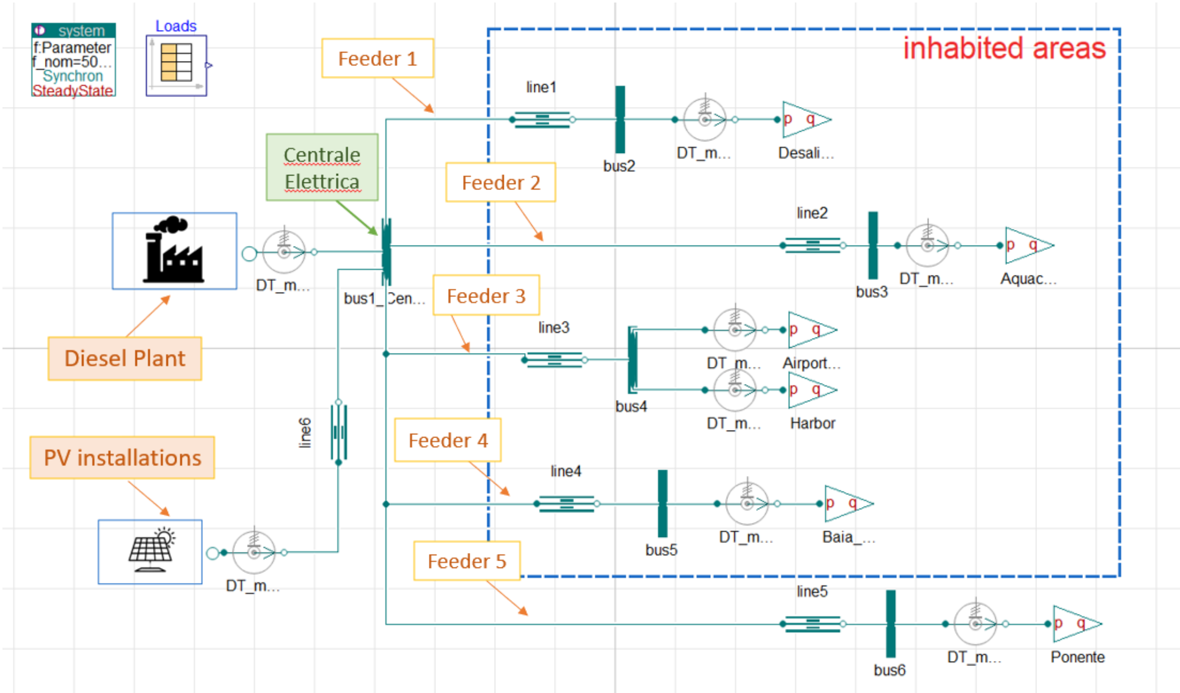

Figure 25: Developed model of Lampedusa's network

Due to lack of adequate information for each installation on the island of Lampedusa, the modelling of **solar energy plants** was implemented as a **sole aggregated plant**, consisting of **1850** panels of the **327W Benq** type. The **tilt angle** was chosen at **35°** and the panel **orientation at 0° pointing South**. Weather data, regarding temperature and solar radiation, were acquired from the photovoltaic geographical information system [39].

Input Data

The verification of the developed model required the supply of accurate data for the energy production and consumption of Terceira. Such precise data (of hourly granularity) for the generation and demand were not available. Thus, a **methodology** was followed, in order to **produce representative profiles** for the particular network operation. Data acquired from an official document of the Economic Development Ministry [44] contained a graph with information about the average daily energy consumption (2015 as the year of reference) in summer

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and winter, Figure 26. The **nadirs of energy demand** on a **typical summer and winter day** respectively are **4.17 MW and 2.74 MW**, whereas **the peaks reach 7.34 MW and 4.27 MW**.

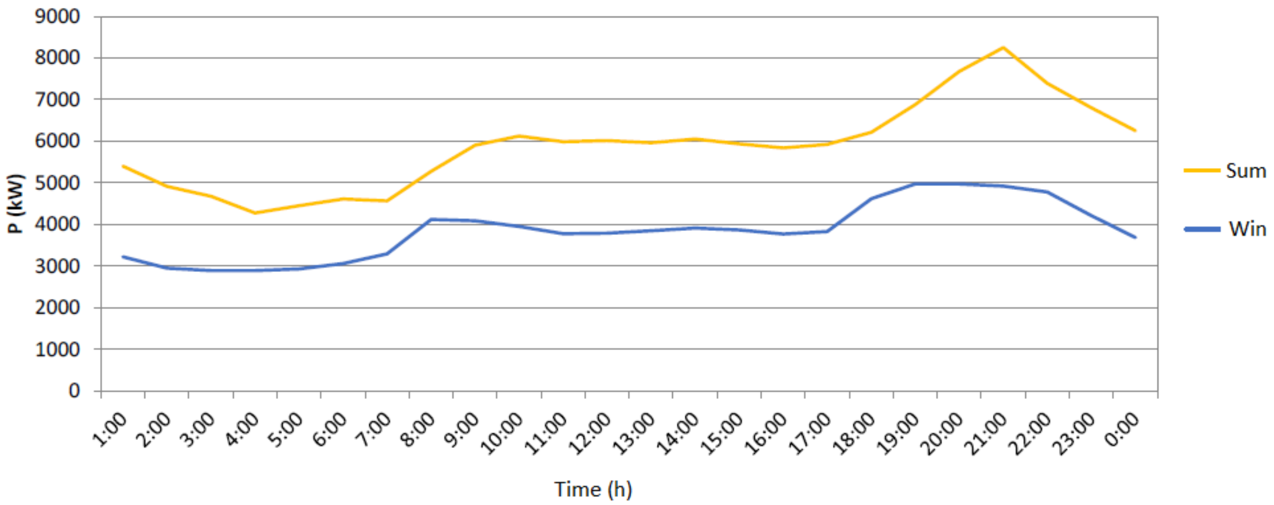

Figure 26: Average daily load diagrams for summer and winter days [X]

The first step of the followed methodology included the calculation of **the typical daily load as a mean average of the 2 diagrams** shown in the graphs. Moreover, an asssumption was made regarding the actual daily load, supporting that it varies accordingly to the monthly energy consumption. Therefore, the next step inculded the normalization of the corresponding monthly values for the year 2015 (Figure 24), with the application of division by mean. The result was **a set of values around 1** that could be interpreted as **a factor of the deviation in the monthly energy consumption**. Afterwards, a sinusoidal regression (Figure 27) calculation fitting was performed to obtain a vector of **365 points** that represented **the variation of the daily energy consumption for a complete year.**

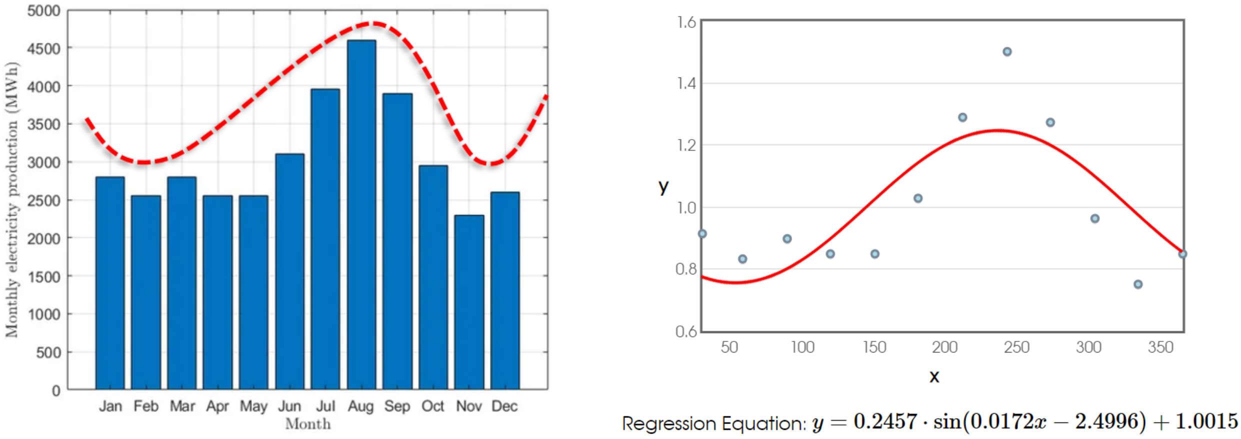

Figure 27: Sinusoidal regression of monthly energy consumption

As a last step, the scaling of the typical daily load according to a coresponding scaling factor was performed. By assuming that the total energy consmuption on a typical (mean) day corresponds to factor 1, the consumption on the rest of the days thourghtout the year can be caclulated accordingly. The resulted profile is presented in Figure 28.

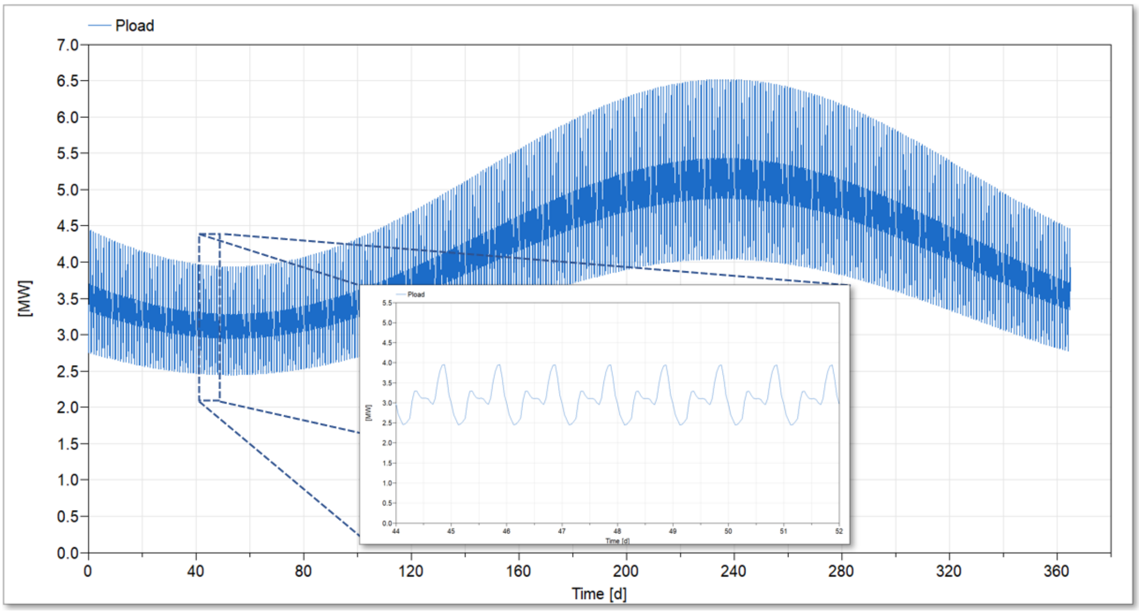

Figure 28: Active power demand based on the annual load profile

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The powerflow simulations were performed using the data produced following the aforementioned methodology. The simulation interval time was set equal to 365 days and ran with a constant **60 min timestep**. The actual duration of the power flow lasts for about 0.2 seconds, representing one year of operation. **The total power produced by the thermal power station and RES based plants annually and on a typical day**, are shown in Figure 29.

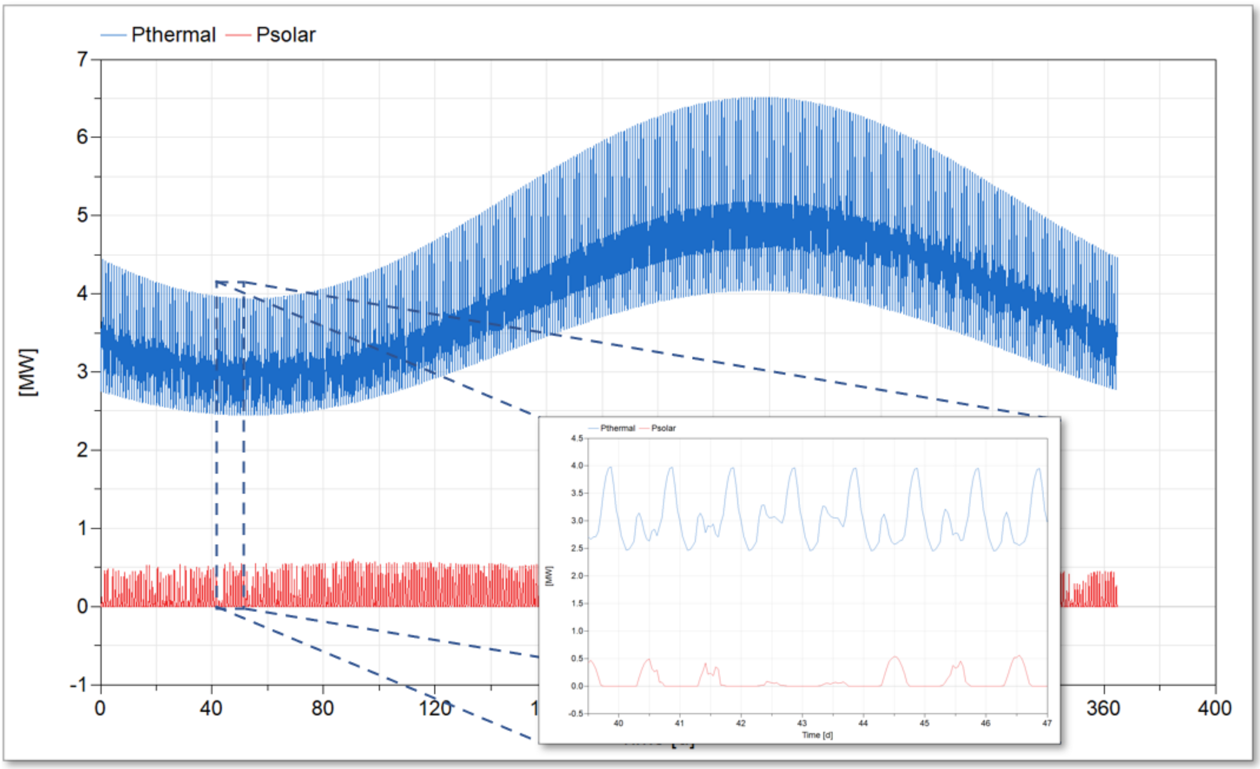

Figure 29: Thermal and solar power generation for a typical year

The **energy consumption** calculated from the powerflow simulations amounted to **36.51GWh** annually and **production** was up to **36.67GWh** considering the **technical losses** in the transmission lines which totaled up to **160 MWh.** The RES contribution to the energy production is small but significant. Almost **4% (1.44 GWh)** of the annual power was generated **by photovoltaic panels**. As displayed in Figure 30, the transmission losses appear constantly as a noticeable **difference between the graphs of generated and demanded power**.

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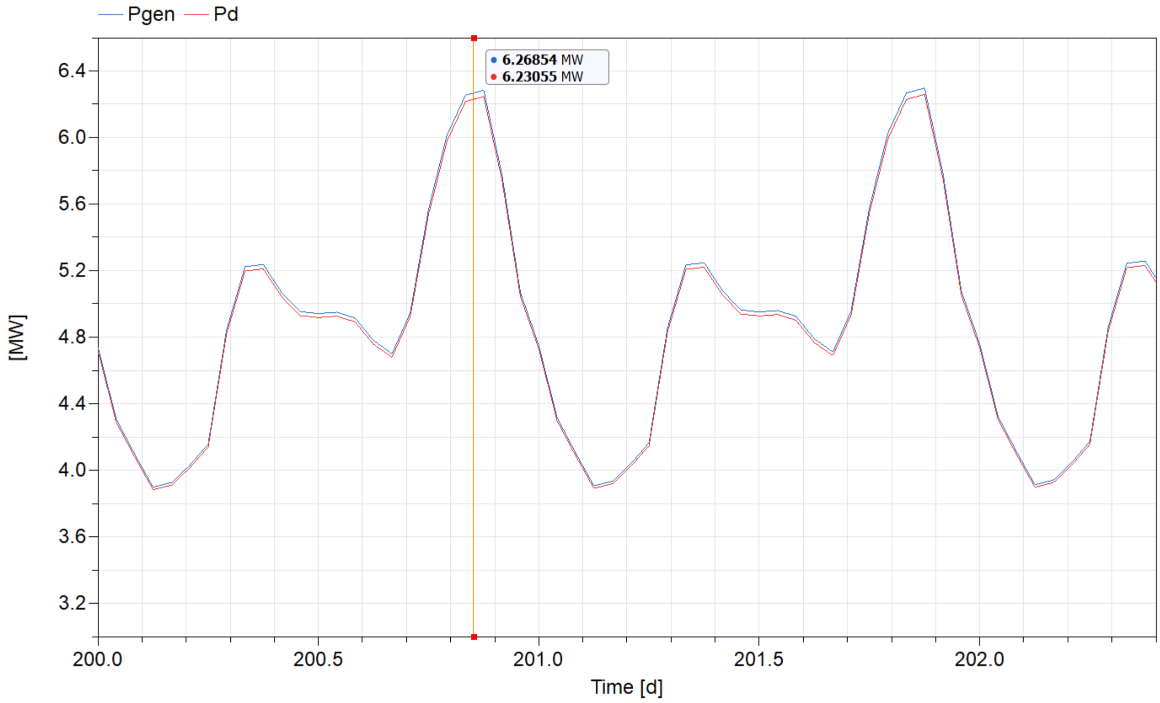

Figure 30: Demanded and generated power for 200-202 day of the year

The **minimum and maximum rated values** of the technical losses on an annual basis are **6 kW and 41 kW** respectively. On an anual basis **the losses are kept relatively low**, reaching up to **0.4% of the energy production.**

Since the LV distribution network is not a part of the currently developed model, the system's energy demand is represented by **aggregated loads** connected to the 5 feeders at 10 kV buses. As the loads change by the hour, the **voltage magnitudes of the buses** are affected, except for the Elettrica Centrale, where the thermal power station is connected to and thus, the voltage is regulated. In Figure 33, the voltage graphs of the central bus and the bus connected to the desalination plant (bus 2) are displayed, indicatively.

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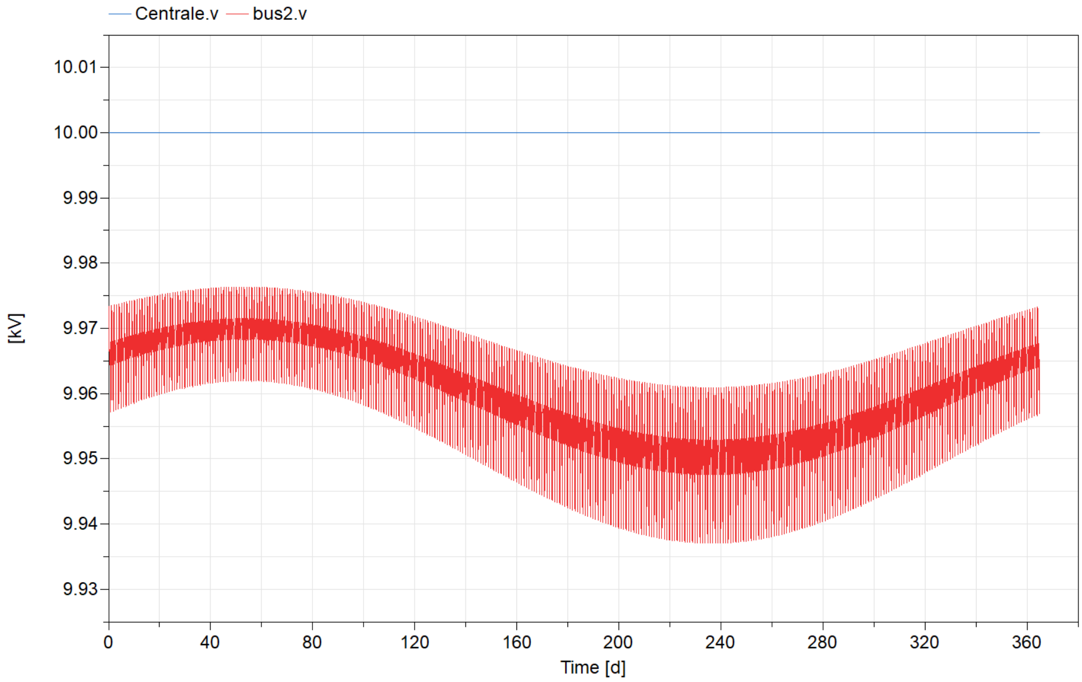

Figure 31: Voltage magnitude at the central bus and at a random PQ bus

The voltage drop of bus 2 is kept relatively low at an acceptable 0.65%. The rest of the load buses that are connected to the feeders follow similar voltage profiles. The voltage of the central bus remains constant at 10 kV. It is important to note that the voltage setpoint in the thermal power station is considered to be 1 p.u. and that no other voltage regulation device has been included in the model, e.g., on-load tap changer transformer, voltage regulators etc.

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4.2.3 Nisyros Fellow Island

4.2.3.1 Energy system description – Current situation (Baseline)

Dodecanese group of islands are not interconnected to the mainland. They are part of several **autonomous electric systems,** some of which appear in Table 13 . More precisely, the system at issue is the **Kos-Kalymnos electric network operating at 50 Hz**, which is responsible for the energy supply of 9 islands in total—Kos, Kalymnos, Leipsoi, Leros, Telendos, Pserimos, Gyali, Nisyros, and Tilos—as displayed in Figure 32.

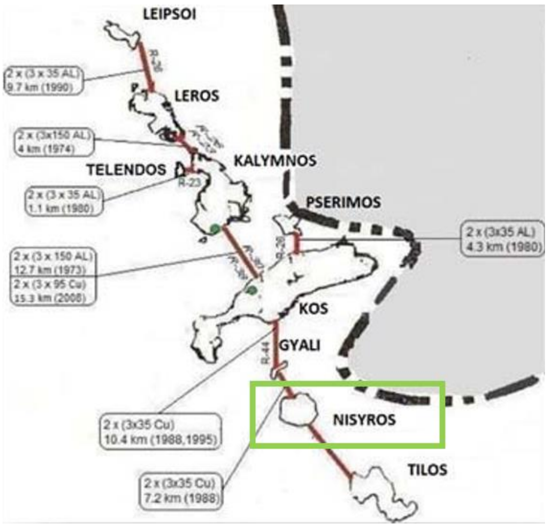

Figure 32: Kos-Kalymnos transmission network

The local islandic grid is managed by **HEDNO**, the main national DSO of Greece, offering as well TSO services for the **non-interconnected Greek islands**. Energy requirements are fulfilled by **local, autonomous power stations (APS),** combusting primarily **fossil fuels (Diesel and Heavy Fuel Oil – HFO)**. The energy infrastructure of the Dodecanese is based on numerous thermal power stations, the majority of which is in service for more than 4 decades (Table 133) [7].

Table 13: List of the APS in the Dodecanese based on the installed capacity

Category	Installed Capacity / APS (MW)	Islands
Very Small	<1	Agathonisi, Megisti
Small	>1 & <9	Astypalaia, Symi
Small to Medium	>9 & <20	Karpathos, Patmos
Medium	>20 & <50	-
Big	**>50**	**Kos – Kalymnos**, Rhodes

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Currently, there are **no generation plants** on the island of Nisyros and the loads are solely covered by the energy production of Kos and Kalymnos. The energy generated is mainly based on the **thermal power stations** in **Kos** and **Kalymnos,** of total installed capacity of **119.07 MW and 19.66 MW** respectively. There are also **4 wind parks** of **15.2 MW** total, **92 photovoltaic installments** of **8.78 MW** and a **small hybrid station** of **0.4 MW, in those interconnected islands** [45]. Statistics for 2021[11] are presented in Figure 33, showing the progression of RES and thermal monthly generated energy throughout the year.

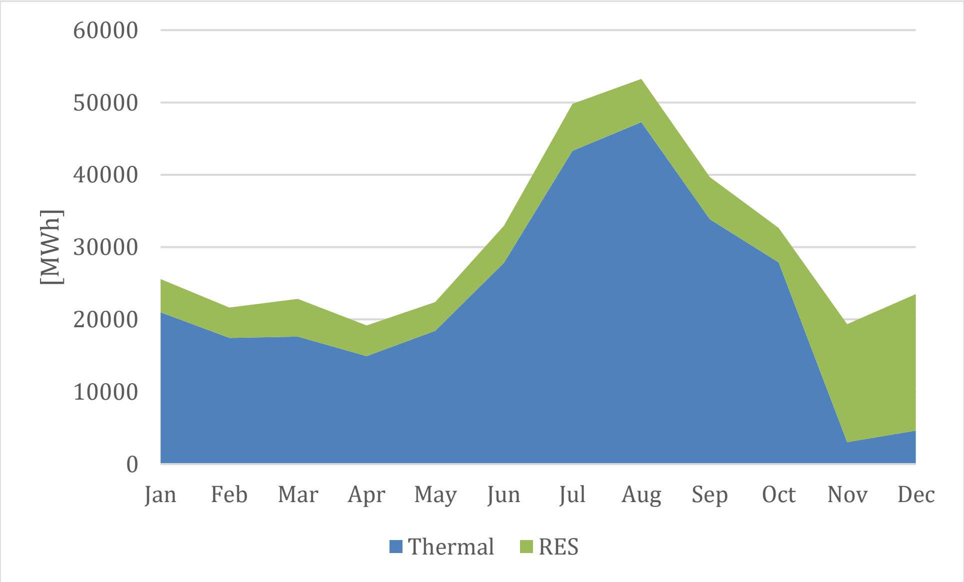

Figure 33: Thermal and RES production in 2021

In Figure 34 below, the percentage of RES penetration in the energy production of the Kos – Kalymnos electrical system for the months of 2021 is displayed.

[11] https://deddie.gr/el/themata-tou-diaxeiristi-mi-diasundedemenwn-nisiwn/agora-mdn/stoixeia-ekkathariseon-kai-minaion-deltion-mdn/miniaia-deltia-ape-thermikis-paragogis/minaia-pliroforiaka-deltia-paragogis-2021/

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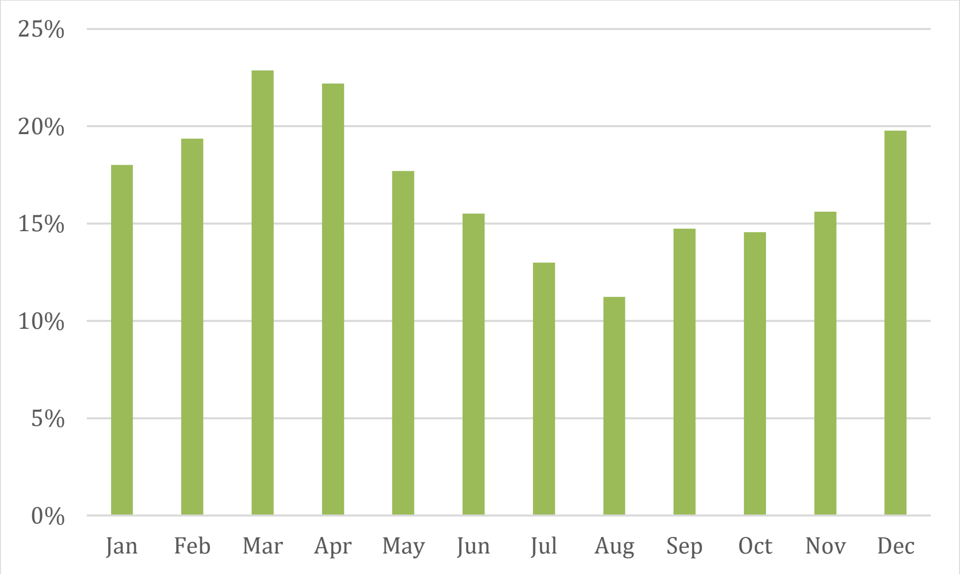

Figure 34: RES penetration in the energy production of the Kos-Kalymnos network for 2021

Although, Nisyros is not autonomously powered, in the local small power station, a **generation set with a total capacity of 1MW** is housed and **used to operate in the past**, but it is now in cold lay-up and serves as a backup source in emergencies (in case of local blackout) during the busy summer months.

The island is powered by two undersea power cables (22kV, 3x35 Cu, length: 17.6km)[12] that come from Kos (Kardamena) and end up surfacing on the north coast of Nisyros (close to Mandraki), to a local Station (PQ Bus), via the island of Yali. The island's grid topology and power distribution are shown below in Figure 35.

[12] https://deddie.gr/media/7847 2021_2025-network-development-plan-2021-2025.pdf

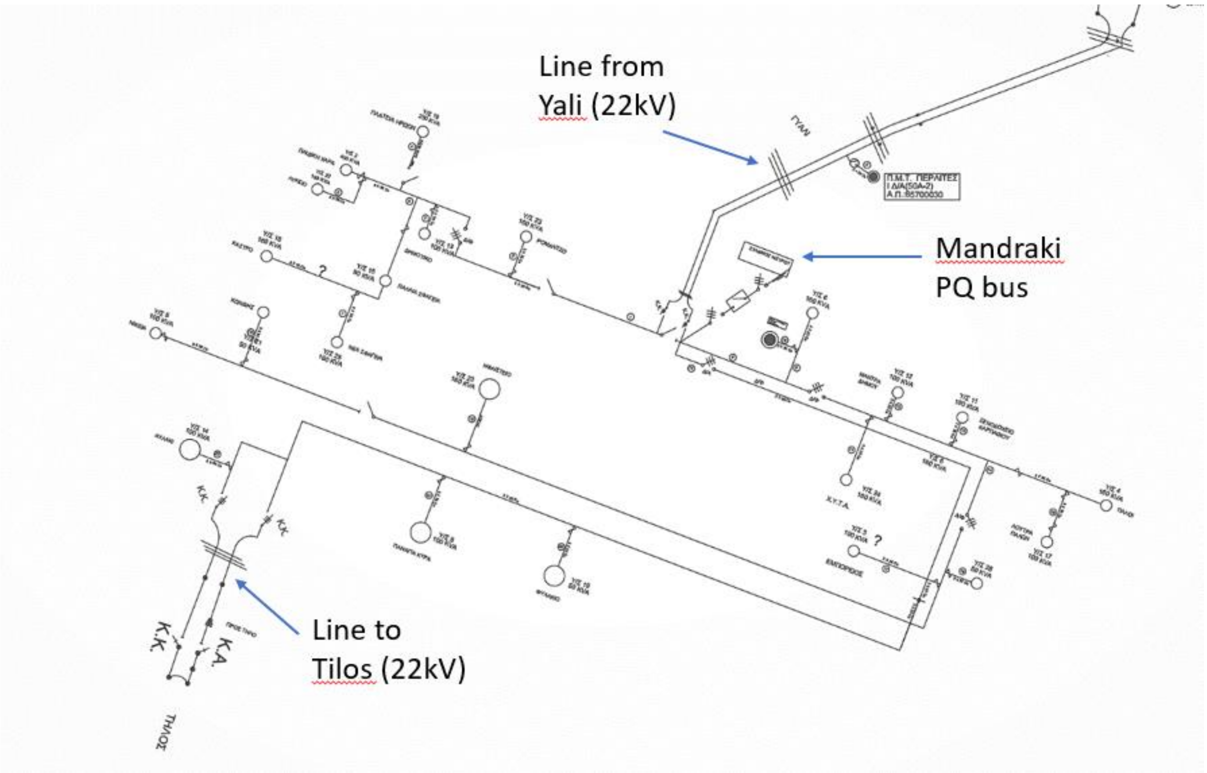

Figure 35: Single-line diagram of Nisyros transmission and distribution network[13]

Nisyros' internal **electricity transmission and distribution network**, consists of the main **Medium Voltage (MV) line at 22kV**, which originates from Kos, connects to Mandraki (PQ Bus) and runs through the island communities, where a series of local transformers **downgrade the voltage level to 400V** (single phase/3-phase) for home and commercial usage (low-voltage consumers at 230V phase to neutral). Industrial consumers (MV consumers), particularly the **desalination plant**, is powered directly from the MV line through an in-house transformer (400V/3-phase). Another MV transmission line runs from Mandraki (PQ Bus), directly to the south of the island (area of Avlaki), by aerial lines which connect to submarine cables that power Tilos island, the southernmost end of the grid.

The **installed capacity** of the Kos – Kalymnos autonomous network **marginally covers the load requirements**, especially **during the peak of the tourist season**. The extended nature and complexity of the grid affects the quality of supply, often resulting in instability (voltage/frequency fluctuations), **breakdowns** of the diesel generator sets and sometimes **blackouts,** leading to both increased insecurity of

[13] Information from Municipality of Nisyros (NIS)

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the islanders as they feel that **power supply is not guaranteed**, as well as posing barriers to economic growth in the area.

A graph in Figure 36, depicts the total energy consumption of Nisyros over the last decade and offers a visual representation of the load allocation to domestic, commercial, industrial, public and municipal.

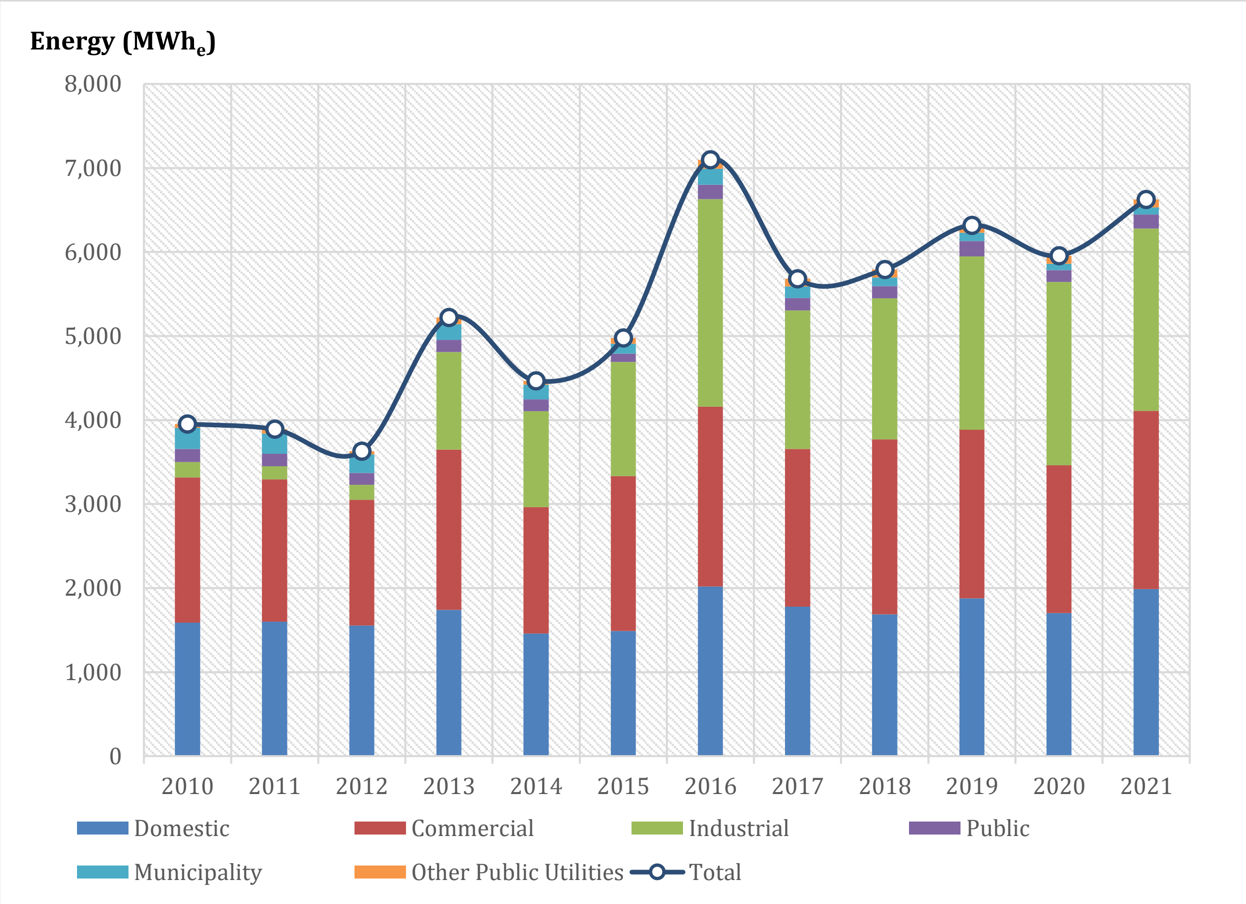

Figure 36: Breakdown of the energy consumption of Nisyros

As it appears, the energy consumption reaches a distinct peak around the year of 2016. The sudden 2 GWh spike seems to have smoothen over the last five years (2017-2021). Doubtless, during the period of 2010-2021, the energy demand has increased by 62.5%. The **annual energy consumption** of the island is estimated to be approximately **6.5 GWh** (for 2021).

The graphs in Figure 37, depict a breakdown of the demand for energy on the island of Nisyros per category of consumer for the period 2010-2021.

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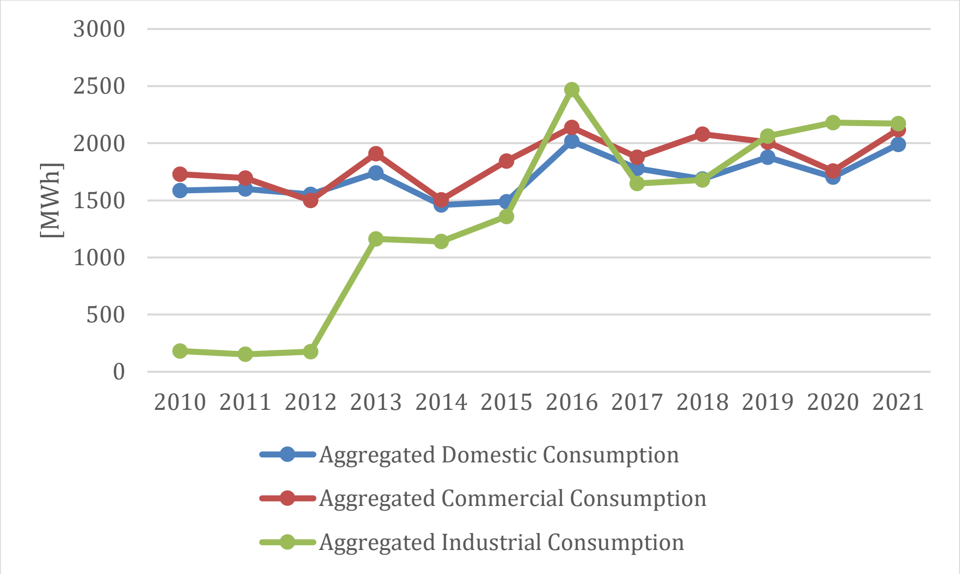

Figure 37: Pattern for aggregated domestic, commercial & industrial electricity consumption progression

Note that demand trends are not considered to have changed significantly (if at all) since the period under consideration. However, the advent of COVID quarantine had an impact in demand throughout 2020, however, for 2021, demand pattern closely matches that of 2019, with a slight increase. A small additional increase can be assumed for year 2022.

Based on these Figures, it is deducted that **the bulk demand is domestic and commercial.** However,

1. The operation of an **additional desalination unit in 2013**, posed a decisive increase in the demand for energy by **about 1GW$_e$.** The installation of a **second unit** in **2016 doubled the industrial demand**, while the following years, demand decreases, depending on the operational status of the units. In 2019, a third unit is installed as a replacement of the damaged/inoperable unit installed in 2013.

2. The energy allocated to public lighting is minimized twofold in the period under consideration, alongside the **energy demand of public buildings** of all kinds/uses and **now constitutes 6%-7% of the total energy consumption**. This is primarily due to the **use of solar panels to power public lighting**, the use of LED lamps throughout and better management altogether in their power use, especially in public buildings.

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4.2.3.2 *Baseline Scenario - Results and discussion*

The power system of Nisyros island is modeled representing the current state of the network, before high RES and very high-RES penetration scenarios are incorporated, in the short and long term.

MODEL SETUP

The model development of Nisyros' network was implemented with the aid of a fundamental part of the INTEMA suite of tools, INTEMA.grid, utilizing the open-source PowerSystems (PS) library.

In order to perform load flow simulations for the network of Nisyros island, both sides of the power system—the generation and the load demands—have been modeled. As there are no locally installed power plants in Nisyros currently, its network model includes mainly consumption loads. For that reason, the incorporation of the generation side of the power system entailed the consideration and basic modelling of the overall Kos-Kalymnos network, which is presented below, in Figure 38.

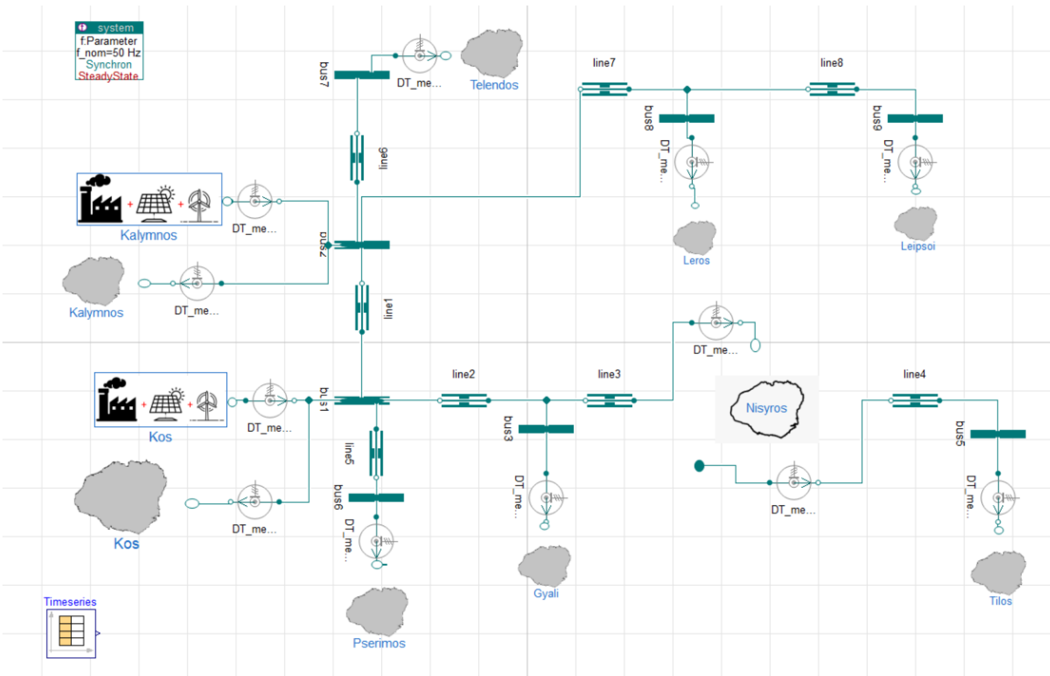

Figure 38: Developed model of the Kos – Kalymnos network

The **grey island icons**, in the figure above, represent the island **load demands**. **Nisyros icon is distinctive** comparing to the others, as its network has been **modeled in detail**, as shown in Figure 39. Furthermore, in the developed model of

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the Kos – Kalymnos network the **generation is exclusively attributed to Kos and Kalymnos**. For the modelling purposes, the **aggregated generation plant of Kos** combines its **thermal power plant and 50% of the total RES** installations (wind parks of 15.2 MW, photovoltaic installations of 8.78 MW, small hybrid station of 0.4 MW in total). Similarly, **Kalymnos' aggregated generation plant** includes the island's **thermal power station, as well as the remaining 50% of the RES** installations. Lastly, the rest of the components that appear in Figure 38 represent the main buses at each island's substations, the cables that connect them and several power sensors that are installed solely for the simulation purposes.

General information for the Kos-Kalymnos network was acquired from government official documents regarding the plans for the autonomous electricity grids of Greek islands [45].

It is obvious, that the Nisyros island constitutes only a small part of the Kos – Kalymnos autonomous network. In the aforementioned model, **every island is represented as an aggregated PQ load**, except for **Nisyros**, the network of which **was thoroughly studied, and its model was in more detail developed, as depicted** in Figure 39.

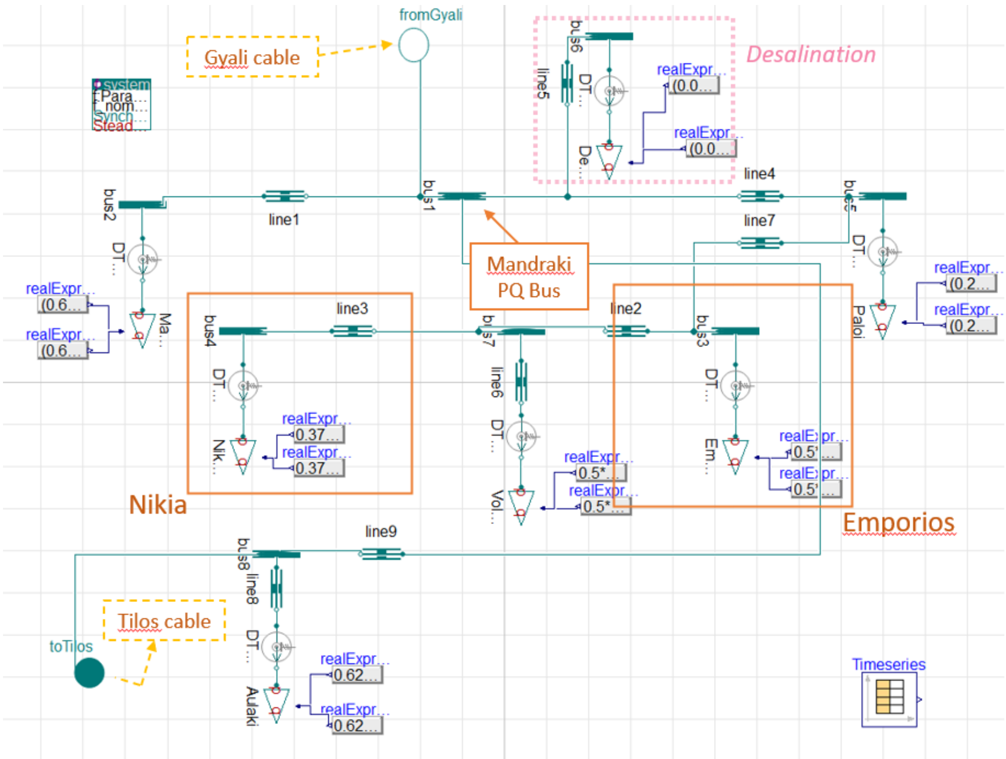

Figure 39: Developed model for Nisyros' network

The model development process of Nisyros' network lacked extreme complexity, mainly due to the fact there are no generation units on the island. In the simplified scheme of Figure 39 a small share of the load demands is allocated to the 2 main provinces of the island, **Emporios and Nikia**, while the **remaining and largest share of the load is appointed to Mandraki area (including Paloi)**. For the purposes of the **baseline scenario** all lines were modeled as **22 kV MV transmission copper cables**, as the incorporation of the LV distribution lines and transformers would introduce unnecessary difficulties to the model development process and would not enhance the accuracy of the load flow simulation results.

Input Data

Energy production time-series for the islands of Kos and Kalymnos were utilized in the simulations, that were in our possession. The time-series at issue refer to the generated energy in the year of 2018. Moreover, similar data were provided by **Municipality of Nisyros NIS** and contained **load time-series of the island for the year of 2020**. The simulations were implemented on the assumption that both aforementioned timeseries refer to the same year. In the entire Kos–Kalymnos network, only the energy consumption of Nisyros can be accurately portrayed. For the rest of the islands, the load demands were estimated using weighted factors (i.e., it was estimated that Kos' load demands represent the 59% of the total energy production) after taking into account several consumption aspects, such as the island's acreage, population, industrial activity and tourism levels. More specifically, **the load of Nisyros** amounted to only **a close 2% of the total network's production** (estimation based on given timeseries). Accordingly, **Kos and Kalymnos claimed 59% and 30%** of the energy production, respectively. The **remaining 9%** of the loads were **attributed to the rest of the islands.**

Simulations

The aforementioned pre-processed data were used to run annual **power flow simulations**. The simulation interval time was set equal to 365 days and ran with a constant **60min timestep**. The actual duration of the power flow lasts for ~1 second, representing one year of simulation. The graph in Figure 40 depicts the power consumption of Nisyros throughout the entire year.

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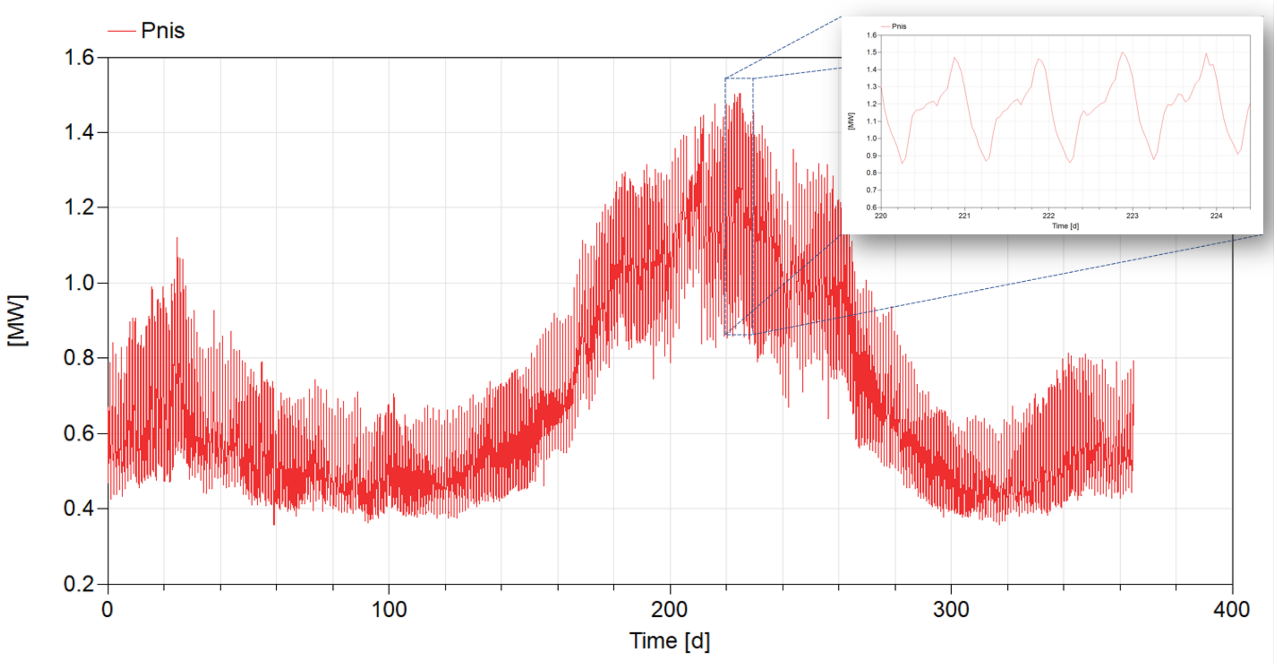

Figure 40: Annual power demand for Nisyros

The **peak in energy demand seems** to be **around 1.5 MW$_e$** and appears several times during the **August days**, when tourism levels are the highest. In addition, it can easily be said that the energy demand is at its **lowest, during the spring months** and the late fall months.

Accordingly, the below Figure 41 depicts the peaks and nadirs of the energy production and consumption for the entire Kos – Kalymnos network.

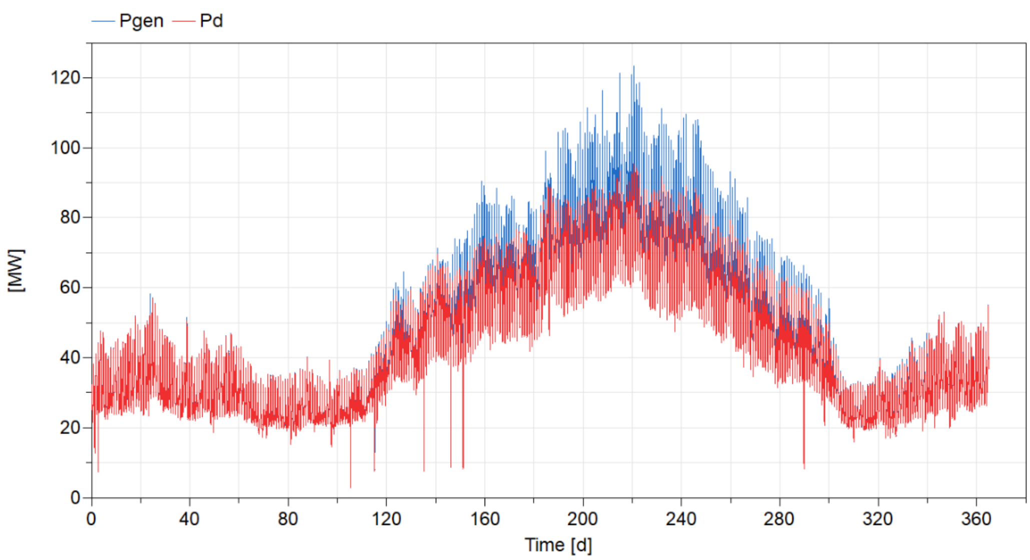

Figure 41: Generated power and demand for the Kos – Kalymnos network

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The noticeable spikes are outliers in the provided data and appear either due to false metering from the telecounting devices or due to short-period power-outages for generator maintenance (more unlikely). The **difference** between the two graphs **represents** the **power losses** and seem to peak during the summer season of high demand.

The powerflow simulations on an annual level, Figure 42, reveal the following interesting results for energy production, consumption and losses for Nisyros and the whole Kos-Kalymnos network.

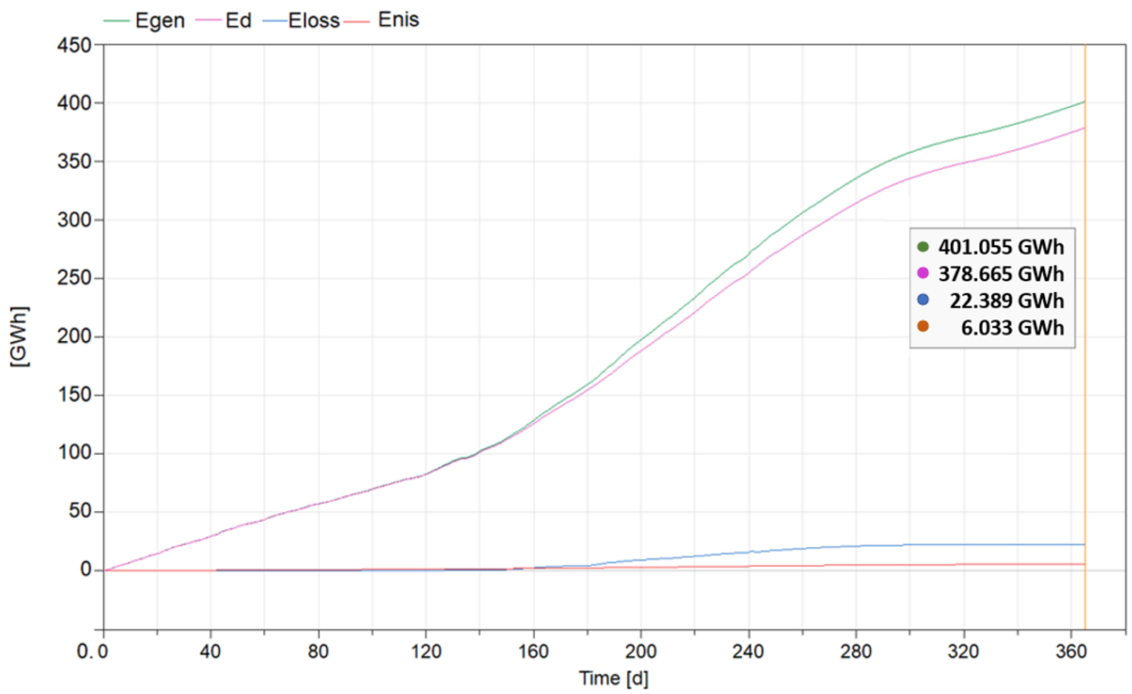

Figure 42: Powerflow simulation results- Annual energy production, consumption and losses for Nisyros and the Kos-Kalymnos network

Nisyros' annual energy consumption reaches up to **6.03 GWh.** The corresponding energy losses of the entire interconnected grid (Archipelagos) are calculated around to 22.3 GWh (5.1%), which is an acceptable percentage loss considering the lack of adequate data for the entire Kos-Kalymnos network (excluding Nisyros). The calculated **energy losses** appear mostly due to the impedance of the **transmission lines and cables**, adding to the **losses that occur at the distribution level.**

The **energy consumption of Nisyros barely overcomes the 1.5% of the total network's consumption.** Another thing to note, is that geographically, the **prime**

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consumer of energy **is the greater area of Mandraki**, given that the **consumption of the villages of Emporios and Nikia is very limited** (Figure 43).

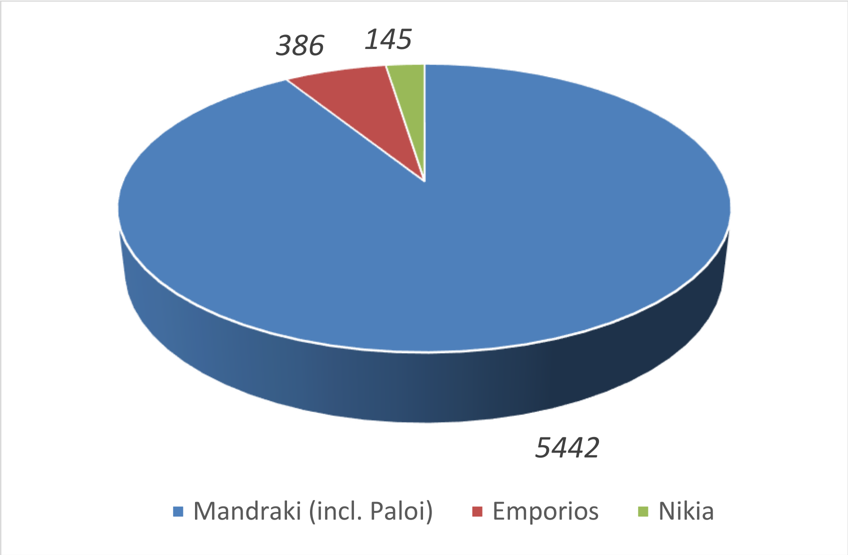

Figure 43: Geographical distribution of electricity consumption in MWh

It appears that **over 91% of the energy demands originate from Mandraki**, a **little over 6%** of the energy is **distributed to Emporios** village and lastly, **Nikia** is **responsible for the rest** of the consumption. Thus, the total demand for electric energy is in the range of 6 GWh attributed mainly to Mandraki. A noteworthy fact is that the desalination plant located near Mandraki – less than 1km from the centre of the village, is one of the biggest energy commercial consumers of the island, further explaining the high energy demands in the area.

The **voltage level of the buses** at the beginning and end of a transmission line or cable deviates, due to the impedance on the lines, as shown in Figure 44 for the main PQ bus of Nisyros, located in Mandraki.

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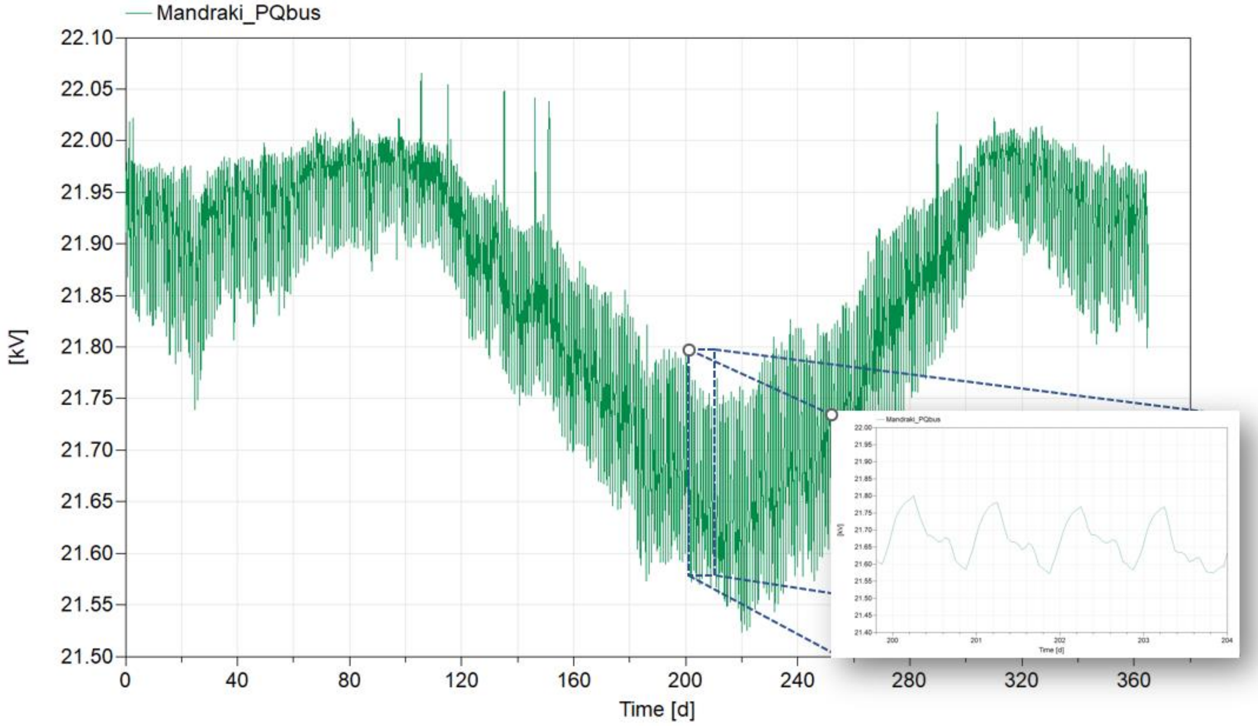

Figure 44: Voltage levels of Mandraki

The noticeable spikes can be disregarded, since they appear solely because of errors contained in the data from the metering devices. The **voltage drop appears in an acceptable range between 1.1%** for the time periods of January – April and October – December **and reaches up to 2.2%** for the rest of the months, peaking in August. Although the voltage graph above follows an evidently realistic pattern, there are reservations about the accuracy of these estimations, due to the lack of adequate data for the entire Kos-Kalymnos network and the necessary simplification of its model.

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4.3 Fellow Islands Grid Environmental & Costing Analysis

In this section the environmental and costing assessment will be performed taking into consideration the results of the energy simulations realized in INTEMA.grid. The analysis is conducted in VERIFY-D tool, which is an online platform for holistic lifecycle environmental and costing assessments in energy systems and fully described in D3.1 [46]. Only the current states of the island networks are examined (baseline scenarios), as they have been explicitly defined in the previous sections. In VERIFY-D all the significant stages of the lifecycle analysis are considered for the technologies/components, i.e., i) raw materials extraction, ii) manufacturing/installation, iii) operation phase.

The set-up of the scenarios in VERIFY-D are based on the models developed in previous sections and in INTEMA.grid. In Table 14 the main energy sources of the Fellow Islands along with their basic technical information are summarized.

Table 14 Fellow Islands Energy production input data

Nisyros	1. Thermal power plant (diesel) of 119.07 MW capacity
Bora Bora	1. Thermal power plant (diesel) of 21.36 MW capacity 2. Solar farm of 600 kW capacity 3. Solar farm of 641 kW capacity 4. Solar farm of 98 kW capacity 5. Solar farm of 306 kW capacity
Lampedusa	1. Thermal power plant (diesel) of 22.5MW capacity 2. Solar farm of 605.12 kW capacity

The information of Table 14 is inserted by the user in VERIFY platform through a friendly User Interface (UI). The main menu is divided in five sectors (Building, Energy Production, Energy Storage, Transport and Public Infrastructure sector) in order to be clearer and more convenient to the end user. Given that, in the three demo cases only power plants are participating, the Energy Production sector is under consideration.

It is worth mentioning that VERIFY-D offers a set of input that it is fully modular and can be changed in the future based on the latest information that fellow islands will provide.

The following paragraphs focus on some remarks that should be mentioned before proceeding to LCA and LCC analysis of the three demo cases. Three major points are examined, regarding i) the energy grid topology of Nisyros,

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ii) the fuel and the energy prices in each Fellow Island and iii) the inventory of the technologies used in VERIFY-D for the LCA and LCC analysis.

In the case of Nisyros, where no power plants exist in its physical system but there is an interconnection with Kos island by a Medium Voltage line, it is assumed that it is electrified entirely by the thermal power plant of Kos and not by the power plants of the Kos-Kalymnos autonomous network (Table 14). Of course, the size of the thermal power plant of Kos is enormous comparing with the electrical peak demand of Nisyros (around 1.5 MW). Although this assumption is not completely true (as Nisyros is supplied by the energy mix of Kos-Kalymnos network), the results would not be significantly affected. On one hand, it can be assumed that the energy of the RES in Kos-Kalymnos network is consumed internally. On the other hand, the cost and the environmental footprint of the power plant construction is negligible in a lifecycle analysis of 25 years where the use phase dominates (fuel costs and CO2 emissions due to fossil fuel consumption) [47].

Table 15 presents the pricing data used for the analysis in each demo case which can be modified by the platform user. The electricity prices (the selling prices or the price for the end user) were selected after an extensive market research for the three islands. Regarding Nisyros and Lampedusa, the electricity prices are the same with the respective average prices of Greece and Italy, whereas for Bora Bora the price is not identical with the respective of France. In addition, in the case of Bora Bora where the currency is the Pacific Franc (xpf), an exchange rate of 0.0084 euros for 1 xpf has been chosen. Considering the diesel price for the power plants (heavy fuel oil), they were retrieved from the official government websites in cases of Nisyros and Lampedusa, whereas in case of Bora Bora from the national institute of statistics (France). In the three demos the prices of the refinery are provided and not any transport costs are not included. Regarding the Bora Bora demo, a difficulty in the data research has been arisen, and hence the selected diesel price is the price in France increased by 30 %. Finally, in order to convert the price from €/ton or €/m3 to €/kWh, the density and the energy content of the heavy fuel oil were set 850 kg/m3 and 11.17 kWh/kg respectively.

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Table 15 Pricing input data

	Diesel for power plants (€/kWh)	Electricity (€/kWh)
Nisyros	0.06 [48]	0.15 [49]
Bora Bora	0.044 [50]	0.27 [49]
Lampedusa	0.282 [51]	0.19 [49]

For the purposes of the LCA and the LCC analysis an integrated private database with specific environmental and costing initial information for a large set of innovative and conventional technologies/materials. This database contains environmental/costing/technical data, e.g., solar farm manufacturing cost per kW, CO2 emissions due to the manufacturing of a solar farm, solar farm lifetime. In Table 16, part of the costing and environmental data for the installed components in the three demos are presented. All the values are provided per the selected functional unit, which is kW regarding the electric generators. Specifically, in Table 16 the Capital Expenditures (CAPEX), the Operational Expenditures (OPEX), the Embodied CO2 emissions and the Embodied Primary Energy are presented. These values were obtained mainly from literature and market research. Wherever a strong difficulty was appeared regarding the data acquisition, assumptions were made.

Table 16 VERIFY-D database information

Technology	CAPEX (€/kW)	OPEX (€/kW/year)	Embodied CO2 emissions (kgCO2/kW)	Embodied Primary Energy (GJ/kW)
Thermal power plant	1.000	50	20.000	300
Solar farm	1.312	39,3	2.400	24,39

VERIFY-D utilizes the user input data, the timeseries from INTEMA.grid along with the information from the integrated database and calculates the desired environmental and economic KPIs. The timeseries retrieved from INTEMA.grid are in hourly basis for the period of one year (8760 values) and consider the energy production of the power plants. In Table 16 and Table 17 a generic formulation for the most important economic and environmental KPIs is

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presented. In the cases of the economic KPIs, an inflation of 5% and a discount rate of 7% are considered for the calculations.

Table 17 Economic KPIs description

KPIs	Generic Formula
Lifecycle Fuel Costs (k€)	$NPV(\sum_{Generators}(Annual\ fuel\ consumption)_{Generator} * Fuel\frac{price}{1000})$ *where,* • *Annual Fuel consumption is in kWh* • *Fuel price in €/kWh*
Lifecycle Income (k€)	$NPV(\sum_{Generators}(Annual\ energy\ production)_{Generator} * Electricity\ price/1000)$ *where,* • *Annual energy production is in kWh* • *Electricity price in €/kWh*
Lifecycle O&M Costs (k€)	$NPV(\sum_{Generators}\frac{(O\&M\ costs)_{Generator}}{1000})$ *where,* • *O&M costs is the OPEX in €*
Lifetime Capital Costs (k€)	$\sum_{Generators}(CAPEX * Capacity)_{Generator}/1000$ where, • *CAPEX is the capital cost of the generator in €/kW* • *Capacity is the nominal power of the generator in kW*
Lifecycle Cost of (produced) Energy (€/kWh)	$\sum_{Years}\frac{Lifetime\ capital\ Costs + Lifecycle\ Fuel\ Costs + Lifecycle\ O\&M\ costs}{\sum_{Generators}(Annual\ energy\ production)_{Generator}}$

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Table 18 Environmental KPIs description

KPIs	Generic Formula
Lifetime Primary Energy (MWh)	$$\sum_{Years}\sum_{Generators}(Annual\ fuel\ consumption)_{Generator} * PEF + (Embodied\ PE * Capacity)/1000$$ *where,* • *Annual Fuel consumption is in kWh* • *PEF is the primary energy factor of each type of fuel* • *Embodied PE is the embodied energy of the component in kWh/kW* • *Capacity is the nominal power of the generator in kW*
Lifetime CO2 Emissions (tons CO2)	$$\sum_{Years}\sum_{Generators}(Annual\ fuel\ consumption)_{Generator} * EF + (Embodied\ CO2\ emissions * Capacity)$$ *where,* • *Annual Fuel consumption is in MWh* • *EF is the emission factor of each type of fuel in kgCO2/kWh* • *Embodied PE is the embodied energy of the component in MWh/kW* *Capacity is the nominal power of the generator in kW*
Annual Renewable Generation (GWh)	$$\sum_{Generators}(Annual\ renewable\ energy\ production)_{Generator}$$
Annual Conventional Generation (GWh)	$$\sum_{Generators}(Annual\ conventional\ energy\ production)_{Generator}$$

The environmental and costing analysis is performed for a period of 25 years. In *Table 19* and *Table 20* the environmental and economic results are presented for the three demo cases. Lampedusa is the island with the highest lifecycle fuel costs, while Nisyros has significantly lower fuel costs mainly due to the levels of tourism. The Lifecycle Cost of produced Energy is higher than the selling price in Nisyros pilot and hence a loss is being appeared. This happens because across Greece the electricity price for the end users is the same, regardless of the location or the real cost of production. In general, the environmental KPIs follow the same

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trend for each demo case. In the three pilots so the primary energy needs and so the CO2 emissions are significant, of course because of the fuel oil consumption.

Table 19 Costing KPIs

KPI / Demo	Lifecycle Fuel Costs (k€)	Lifecycle Income (k€)	Lifecycle O&M Costs (k€)	Lifetime Capital Costs (k€)	Lifecycle Cost of (produced) Energy (€/kWh)
Nisyros	25,249.7	22,492	85.2	52.2	0.1624
Lampedusa	131,626.5	161,372	1,069.1	1,174	0.1512
Bora Bora	88,736	216,060.9	2,811.4	3,165.9	0.1135

Table 20 Environmental KPIs

KPI / Demo	Lifetime Primary Energy (MWh)	Lifetime CO2 Emissions (tons CO2)	Annual Renewable Generation (GWh)	Annual Conventional Generation (GWh)
Nisyros	467,259.6	43,719.2	0	6.4
Lampedusa	2,549,707.1	236,729.6	1,1	34.9
Bora Bora	2,236,374.2	209,539.8	3,5	30.5

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5. Conclusions

The opportunities for the energy transition of IANOS Fellow Islands (FIs) are described in this deliverable. Critical aspects of the islands' ecosystem and energy system are highlighted via a non-technical analysis, to understand the various issues encountered and their particular needs and characteristics, to assist in establishing replication activities adopted in the islands. The report continues by explaining the methodology for the replication assessment within the local context of IANOS Fellow Islands and the presentation and technical analysis of the current energy profile of the island networks (business-as-usual grid operation (BaU)). These are the main focus areas of the 1st version.

Specific solutions implemented in the LHs will be of interest to be either replicated or deployed at a larger scale by the FIs in order to achieve their sustainability goals. A tailored Master Use Case for each FI, including both innovative and traditional solutions towards increasing RES penetration and grid flexibility, will be defined and examined in terms of replication potential. The outcomes will be based on a detailed feasibility and sustainability analysis compared to the baseline situation, performed with the IEPT toolkit. For the purpose of the replication assessment, grid power flow simulations are employed. In this version, power flow simulations were used to determine the baseline situation. A lifecycle analysis followed showcasing the environmental performance of the current grid infrastructure.

In the next version, simulation models will account for the Master Use Cases to calculate the energy flows and explore the effects of increased RES penetration on the islands' energy systems based on the foreseen decarbonisation scenarios, and corresponding lifecycle models will assist in the environmental impact assessment. The replication assessment will be concluded with a cost-benefit analysis monetizing all impacts. Upon the completion of the project, FIs will be able to gain an in-depth understanding of the use cases' feasibility, interpret data and results, and transform outcomes regarding replication potential into specific decarbonisation management strategies and best practices for the establishment of their SECAPs.

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