IANOS

SUSTAINABLE SOLUTIONS
for islands' decarbonisation

D9.1 Lighthouse Islands Replication and Scalability Plan

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H2020-LC-SC3-2018-2019-2020 / H2020-LC-SC3-2020-EC-ES-SCC

EUROPEAN COMMISSION

Innovation and Networks Executive Agency

Grant agreement no. 957810

PROJECT CONTRACTUAL DETAILS

Project title	IntegrAted SolutioNs for the DecarbOnization and Smartification of Islands
Project acronym	IANOS
Grant agreement no.	957810
Project start date	01-10-2020
Project end date	30-09-2024
Duration	48 months
Project Coordinator	João Gonçalo Maciel (EDP) - JoaoGoncalo.Maciel@edp.com

DOCUMENT DETAILS

Deliverable no.	D9.1
Dissemination level	Public
Work package	Work Package 9
Task	Task 9.1
Due date	31/01/2023
Actual submission date	17/02/2023
Lead beneficiary	CERTH
Deliv. Reviewers	AME, REP

Version	*Date*	*Beneficiary*	*Changes*
0.1	8/7/2022	CERTH	Table of Contents (ToC)
0.2	26/7/2022	EDP	Starting of document
0.3	7/10/2022	CERTH	Writing – review and editing
0.4	16/11/2022	CERTH	ToC revision, Writing – review and editing
0.5	21/11/2022	TNO	Writing – review and editing
0.6	8/12/2022	ETRA, EDP	Writing - review and editing
0.7	29/12/2022	CERTH	Writing – review and editing
0.8	31/1/2023	CERTH	Draft sent for review
0.9	7/2/2023	AME, REP	Return of reviewed deliverable
1.0	10/2/2023	CERTH	Finalization of the deliverable

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 957810

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Executive Summary

This task deals with a thorough investigation of the replication potential of two decarbonisation scenarios on the IANOS LH Islands further exploiting the use cases and solutions demonstrated in the project, aiming to enable and facilitate their energy transition. A long-term plan for replication activities will be demonstrated by the two IANOS LH Islands of Ameland (NL), and Terceira (PT) taking into account their current policies, specific needs and implemented 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 formulated from the use cases and solutions deployed in the project and 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 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 pathways 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 LH island ecosystem, in order to evaluate the impact of the Master Use Cases (while taking also into account results from the CET-developed tool and T8.2). Results and outcomes aim to support IANOS LHs and 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 specific European islands that are characterised by typical EU challenges in terms of energy requirements, population, climatic conditions and topographic features. 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 will be explored. For this purpose, the set of the real-life operational Use Cases that will be demonstrated in the two LH Islands and their results and impact will then be studied in terms of replication potential. The replication studies will examine the envisioned outcomes that IANOS solutions could deliver at the island level. Replicability and scalability activities will be planned and examined also for the 3 IANOS Fellow Islands (FIs), of Bora-Bora, Lampedusa and Nisyros.

Deliverable *D9.1 – Lighthouse Islands Replication and Scalability Plan* is inserted in Task *T9.1 - Lighthouse 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 tools developed during the demonstration pilots of Terceira and Ameland and will present a detailed replication plan for the LH Islands. The deliverable will cover also all regulatory, technical, economic, and environmental aspects pertaining to the local ecosystem and the energy domain of both LH Islands as well as to describe the set of IANOS Use Cases, that will be examined in terms of replication and up-scaling potential. For this purpose, a “Master Use Case” (MUC) for each LH Island will be defined and presented, which will summarise the main actions to be taken for the decarbonisation of the islands’ energy system, a procedure that can later be easily replicated in other EU geographical islands.

To this end, this deliverable will also present the simulation results of the IEPT toolkit, introduced in Task T3.3, concerning the impact of the decarbonisation scenarios of the islands in the medium and long term, by examining the replication potential of the proposed use cases and technologies. The outcome and conclusions will be utilized in the further development and update of the

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Sustainability and Climate Action Plans (SECAP), which will be presented for each LH island by the end of the project. Task T9.1 and deliverable D9.1 will result in a clear, sustained and replicable plan for the decarbonization and sustainability of IANOS Lighthouse Islands. 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 between IANOS LHs, 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 D9.1 is structured as follows:

- Chapter 2 – Description of the replication framework is provided. Detailed description of the legal/regulatory context, economic, technological and environmental aspects for each LH Island is also provided.
- Chapter 3 – The methodology for the replication potential assessment under two decarbonisation scenarios (high and very high-RES penetration) is presented. The set of Use Cases (based on those described in WP2 and those implemented in WP5 and WP6, as well as the specific LH needs) and the technologies that will be selected to be used for the replication actions will be presented. A Master Use Case will be built and described for each LH island, Terceira and Ameland.
- Chapter 4 – The IEPT simulation results will be presented having in mind the replication goal of each Master Use Case. 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 two decarbonisation scenarios will be evaluated.
- Chapter 5 – Conclusions. Conclusions regarding the energy characteristics and transition opportunities of IANOS LH islands are presented.

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 *T9.1 – Lighthouse 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 LH 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 considered when elaborating a decarbonization plan, including social, economic, technical, regulatory and environmental aspects.

The social aspects that will be considered in the 2nd version of this deliverable will stem from 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 toolkit 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 into the Islands Master Plans being developed under *T2.4 – Islands Decarbonisation Master Plan* in *WP2 - Requirements Engineering & Decarbonization Road-mapping.*

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

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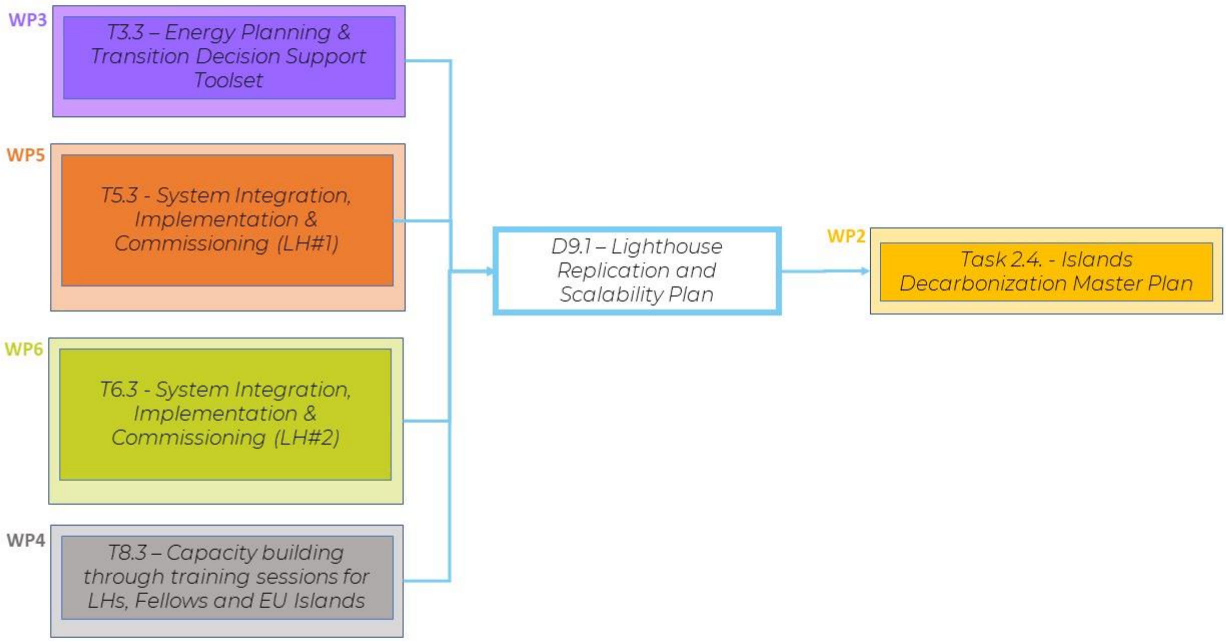

Figure 1 Relationship between Deliverable 9.1 and other Tasks in IANOS

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 decarbonisation 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 the specific use cases considering **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 situation of the islands' energy system** serves as a reference point (**baseline scenario**), against which the replication plans can be built, and the impact of the decarbonisation scenarios at island level be evaluated. Figure 2 depicts the IANOS approach for the replication studies.

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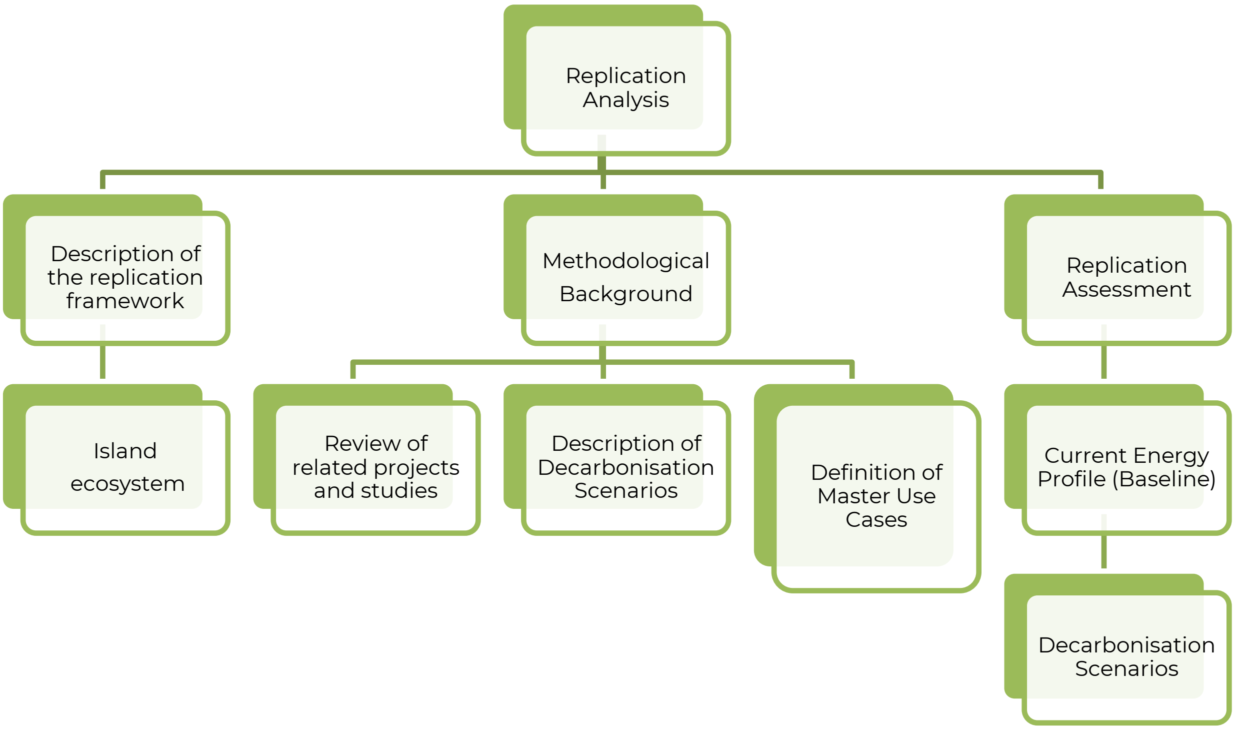

Figure 2 Replication Analysis in IANOS

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 the approach of other relevant **projects and studies applicable in the island context**. 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 via an **energy, environmental and cost-benefit analysis**, taking into account the two **decarbonisation scenarios** (medium- and long-term), aligned with the **EU Climate Law** and **Fit for 55 package** decarbonisation strategy. The 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 Lighthouse Islands (LHs), comprehensively summarizing the main aspects regarding the island ecosystem and related replicable and sustainable solutions for clean energy transition. The island dynamics and the local conditions in terms of sustainable development are outlined, 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 situation of the islands' energy system, which serves as a starting point (baseline scenario) from which the climate and energy strategy can be defined, the replication plans be built, and the impact of the envisioned results be evaluated.

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 LH island is presented below.

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2.1 Terceira Lighthouse Island

2.1.1 Political & Social Aspects

POLITICAL ASPECTS

Demography

Terceira is a volcanic island in the Azores archipelago, in the middle of the North Atlantic Ocean 1,600 km West of Portugal. It is the second most inhabited island in the Azores, with 55,300 inhabitants, 401.9 km^2 of surface, 30.1 km in length and 17.6 km in maximum width. It is the easternmost island of the five that make up the Central Group of the archipelago and the closest island is São Jorge, 37.9 km away. The island's highest point, at 1021 m altitude, is in the Serra de Santa Bárbara, at 38°43’47’’ north latitude and 27°19’11’’ west longitude. There are two municipalities on Terceira Island – Angra do Heroísmo and Praia da Vitória – with a total of 30 parishes and about 53.000 inhabitants. Overall, the population’s average age is younger relative to the whole country, but also less qualified. Angra do Heroísmo, the historical capital of the archipelago and part of Terceira, is classified as UNESCO World Heritage Site. Terceira has a subtropical climate with mild annual oscillations. Given its volcanic origin, geothermal surfaces allow the use of geothermal resources for power generation.

Brief overview of the political system

The archipelago of the Azores is an Autonomous Region of the Portuguese Republic, with legal personality under public law. The political, legislative, administrative, financial and patrimonial autonomy of the Region is exercised within the framework of the Portuguese Constitution and the Political and Administrative Statute of the Autonomous Region of the Azores.

The Political-Administrative Statute of the Autonomous Region of the Azores (EPARAA) is a legal document that frames the constitutional autonomy regime of the Azores, defining the powers of the autonomous regional administration and the structure and functioning of the self-government bodies. The EPARAA is in essence a Regional Constitution embodying the autonomous

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regime established in the Constitution of the Portuguese Republic (CRP) for the Azores archipelago.

Each Azorean Island constitutes a constituency, designated by its name. Each island constituency elects two deputies to the Regional Parliament, and also deputies in proportion to the number of registered voters. The electoral law also provides for the existence of a regional compensation circle, reinforcing the overall proportionality of the system.

Government policies regarding clean energy transition and decarbonisation

Currently, there are several policy documents that focus and support the importance of clean energy (i.e.: Medium-Term Orientations 2021-2024 [1], the Strategy for the Implementation of Electric Mobility [2] and the XIII Azorean Government Program [3]).

Energy is recognised as one of the sectors with the greatest potential for contributing to the mitigation of climate change, through the improvement of energy efficiency, the use of renewable energy sources and the increase in energy storage capacity.

These goals are included in the Azorean Energy Strategy 2030 (EAE2030). Although still in its draft phase, this document will be defining an energy policy for the Azores based on the objectives of guaranteeing security of supply, reducing energy costs and reducing emissions of greenhouse gases, based on the application of the guiding principles of energy efficiency, electrification and decarbonisation.

Thus, taking advantage of natural and endogenous wealth, the energy policy of the Regional Government of the Azores will favour investments – both public and private – involving renewable energy sources, such as hydro, solar, wind and especially geothermal, contributing to the reduction of imports and the dependence on fossil fuels, protecting the regional economy from the variation of oil in international markets. Projects based on intelligent energy storage and management solutions will be promoted, with the goal of, by 2025, achieving 65% of clean energy for producing electricity.

It will also boost the access of citizens and several economic agents to equipment and systems that allow them to obtain and store energy for self-consumption, encouraging private investment in technological solutions with high energy efficiency, enhanced by instruments of monitoring of consumption that can stimulate the rational use of energy, with an impact on household costs and on the competitiveness of companies. To this end, the Regional Government implemented ProEnergia, an incentives system for the production and storage of energy from renewable energy sources, initiated in 2010. The Strategy for the Implementation of Electric Mobility (Regional Legislative Decree 21/2019/A) (Estratégia para a implementação da mobilidade elétrica nos Açores) establishes the strategy for the implementation of e-mobility in the Azores, taking into account its geographic, physiographic and environmental characteristics. The implementation of the electric mobility policy in the Azorean archipelago implies the existence of regional and municipal planning instruments, namely: Plan for Electric Mobility in the Azores (PMEA) and Municipal Electric Mobility Plans (PMEM). The Plan for Electric Mobility in the Azores (Plano para a Mobilidade Elétrica nos Açores) [4] was developed by the Government of the Azores between 2018 and 2024. It is a guide for the implementation of electric mobility that includes the diagnoses of several activity sectors. In addition to that, PMEA is validated by diagnoses and simulations that support the proposed measures. For its part, the Municipal Electric Mobility Plans are being prepared with the support of the Regional Directorate for Energy. In total, there will be 19 different plans, one for each municipality in the Azores.

As has been mentioned previously, the Municipality of **Angra do Heroísmo** has been working towards creating a renewable energy community. The goal is to suppress the need for gas cylinders, at least at residential level, through supporting the acquisition of DHW equipment, such as heat pumps and solar panels. Separating public lighting networks from scenic lighting is already mandatory and has been possible through the introduction of equipment that allows for network intelligence. The acquisition of this type of equipment is mandatory for local/regional administration.

The Municipality of **Praia da Vitória** has also been working towards reaching a significant reduction on energy consumption. At the Environmental Interpretation Centre in Cabo da Praia, all lighting has been replaced by LED technology, resulting in a 69.4% reduction in consumption. As the Municipality of

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Praia da Vitória is responsible for the maintenance of public buildings, they have been replacing damaged equipment with more efficient ones and, in some cases, reducing the building's contracted power.

SOCIAL ASPECTS

There are two municipalities on Terceira Island - Angra do Heroísmo and Praia da Vitória – with a total of 30 parishes and about 53.000 inhabitants. Overall, the population's average age is younger relative to the whole country, but also less qualified.

Local Energy demand

Data from 2020 states that the production of electricity in the Azores reached 769.226.767 kWh. Of these, 184.609.162 kWh on Terceira Island [5].

From January to December 2020, there was a decrease in energy emission of 3.1% relative to the same period in 2019. Normalising the number of days in this period, the evolution rate was -3.3%.

In 2020, 40.4% of electric energy production was obtained from renewable energy sources, with the two largest shares corresponding to geothermal (25.1%) and wind (9.3%).

In terms of consumption, in 2020 the Azores registered a total of 719.411.153 kWh, while Terceira Island registered 170.719.763 kWh. From January to December 2020, there was a decrease in energy consumption of 3.2% relative to the same period in 2019. The largest portion was consumed by the domestic sector, with 36.4%, followed by the trade and services sector, with 31.8%, the industrial sector, 18.3%, public services, 9.6%, public lighting, 3.6%, and self-consumption, 0.3%.

In terms of production, in 2020 the Azores registered a total of 769.172.773 kWh, while Terceira Island registered 184.609.162 kWh. The accumulated production of electricity on Terceira Island from RES in 2020 was 69.841.130 kWh, from the following two sources: wind – 16.7%; geothermal – 12.9%. An increase in the emission of geothermal energy is expected to take place between 2021-2025, as a result of the increase in installed power on the islands of São Miguel and Terceira.

As for demand, it is estimated that the average annual growth rate of electricity demand between 2021 and 2025 will be 0.7% in Terceira [6]. In 2021, the emission of electric energy should reach 779.1 GWh, with the island of São Miguel being responsible for 55.3% of total and the islands of Terceira, Pico and Faial, together, for about 35.2%. Terceira Island is expected to be responsible for the emission of 185.4 GWh in 2021, having been 184.6 GWh in 2020. Figure 6 presents a perspective on the evolution, by island, of the thermal and renewable emission between 2004 and 2019. The structure of the electricity supply continues to undergo important changes, mainly resulting from the growth of emissions originating from endogenous energy resources. [7]

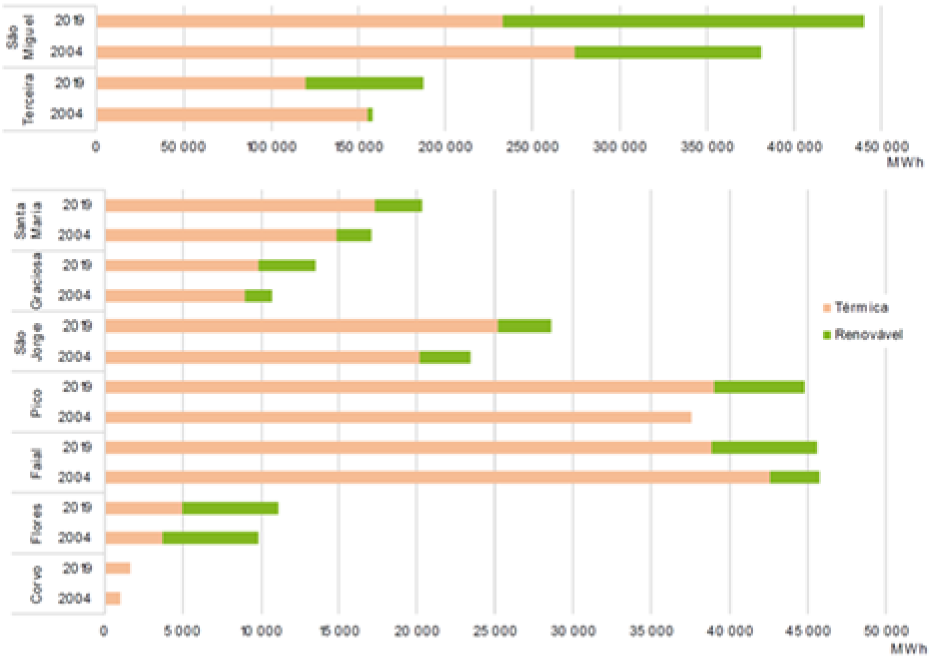

Figure 3 Evolution of thermal and renewable/endogenous production per island (2004 to 2019).

Wind energy, which represented 1.7% in 2004, should come to represent 10,1% in 2021. In 2004, hydro, geothermal and wind energy amounted to 18.4% of the total, and it is estimated that in 2021 they will be representing about 38.1%.

Engagement of islanders in the energy transition movement

The Government of the Azores has pursued an energy policy that aims to bring attention to energy related matters, creating awareness regarding the importance and the advantages that come with the correct management of

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energy. The goal is to promote energy sustainability as one of the sectors that greatly affects the emission of greenhouse gases in the Azores.

Nevertheless, challenges in the Azores in general and in Terceira in particular must be taken into account, based essentially on:

- Specific local context. All actions to be carried out in the Azores must be adapted to the specific context of each of the nine islands. An example of this is the implementation of energy production for self-consumption. This initiative has not been widely adopted on the smaller islands, as revealed by the data provided by the regional incentives system. In 2020, around 27% of equipment investments under this system took place on Terceira Island.
- Structural poverty. This problem persists in the Azores, conditioning the development of the archipelago as it affects the growth of various sectors. In regards to Terceira Island, it is worth mentioning the unemployment rate, aggravated by the reduction of US soldiers at Base das Lajes, which has resulted in hundreds of redundancies and has had an impact of around 15% on Terceira's GDP. In terms of energy, this is particularly relevant as it affects the role of the population as an active consumer, considering that the initial investment on energy efficiency (buildings, equipment and systems) is usually quite large.
- Low level of education. The Autonomous Region of the Azores continues to register, since 2017, the lowest percentage of population that has finished secondary school in Portugal (18.2%). This is directly related to how aware and open the population is to energy related issues, affecting the usefulness of national and regional incentive systems for the aforementioned investments.
- Reduced diversity in local economy. This especially impacts agriculture and livestock, as well as dairy related industries, which results in a lacking internal market in terms of the exploration of renewable energy sources, given the low investment in this sector Reduced diversity in local economy. This especially impacts agriculture and livestock, as well as dairy related industries, which results in a lacking internal market in terms of the exploration of renewable energy sources, given the low investment in this sector.

Specific island initiatives regarding energy efficiency and mobility

In order to overcome these challenges, a number of good practices have been implemented regarding energy efficiency and e-mobility in order to boost energy transition, such as:

- Energy efficiency: PROENERGIA is a system of incentives for the production and storage of energy from renewable sources in the Azores. In 2020, this system of incentives supported the purchase of about 900 pieces of equipment in the Azores, a private investment of over two million euros. Around 27% of this amount refers to Terceira Island.
- Electric mobility: The system of financial incentives for the purchase of electric vehicles and charging points, available since 2020 and improved in 2021, contributes with 10% to the purchase and leasing of electric vehicles. Taking into account all of the available bonuses, the incentive can reach 4,550 euros. In 2020, the Regional Government granted incentives for the purchase of 117 electric vehicles. There were 42 applications on Terceira Island, 39% of the total in the Azores, resulting in more than 112 thousand euros. In all, applicants invested over one million euros in electric vehicles.

A system of incentives has recently become available for the acquisition of photovoltaic solar systems for the production of electricity for self-consumption, called SOLENERGE. This system supports 100% of eligible expenses up to a maximum of €1,500 per installed kW. It aims to increase installed capacity by 12.6 MW and is committed to electrification, decentralized production and distributed storage, and this investment will allow the end user to move from a final consumer to an active agent in the energy system, with the possibility of consuming, storing and produce, helping the network.

This incentive program also aims to reduce the energy bill for families and organizations that opt for this alternative for producing electricity, contributing to increased regional competitiveness and the development of a low-carbon economy. Funds are used from the Recovery and Resilience Plan.

With the ambitious goal of becoming a reference island for all EU volcanic islands as a renewable energy island, Terceira has engaged itself in an array of national and international projects. These aim to increase economic, social growth

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while promoting an environmentally friendly energy sector. With plans to implement geothermal energy, a solar PV plant, a battery storage facility, and smart metering infrastructure, Terceira aim to become 67% powered by renewable energy by 2024. A high focus on electric cars and charging stations are bringing the volcanic island's mobility sector to the forefront of its development.

Energy Poverty and Local Energy Communities and Cooperatives

1. The IANOS partners on Terceira have expressed that the awareness of energy efficiency measures and their impact on climate change goals and people's energy bills is limited among stakeholders on the island. This concerns schools, industry, companies, and the tourism sector. Thus, in order to get these stakeholders and the broad public onboard a renewable energy transition on Terceira, it is important to raise their awareness on the urgency and potential of such a transition.
2. Many stakeholders on the island seem to have intentions of participating in the local transition but may lack a connection to each other and a common direction. A need to create a network between the stakeholders could help accommodate their needs and raise awareness on the importance of developing renewable energy as a community. For example, involving the academic community could help increase awareness on climate goals and what the individual could do to save energy or produce their own clean energy.
3. There already exist energy cooperatives in Portugal. These may be highly valuable for inspiring Terceira to establishing a similar community on the island. Connecting stakeholders in the island with this existing Portuguese energy cooperatives has been expressed as a need from the island partners.
4. The local government has also expressed a wish to form a formal stakeholder and citizen engagement strategy, something that is yet to be undertaken.

Some groundwork for community engagement processes have already been undertaken on Terceira. For example, extensive information events have taken place in local schools, informing students of how implementing energy efficiency can save energy and impact the climate. Informing about energy efficiency is also

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the purpose of the Life project, where trainings are organised on different islands of the Azores. Below is an overview of the citizen engagement initiatives that have taken place or is currently taking place on Terceira, provided by the Regional Secretariat for Tourism, Mobility and Infrastructures, and the Regional Directorate for Energy:

- Rota da Energia ('Energy Route') – a partnership between the Regional Directorate for Energy and the Portuguese Energy Agency. The Energy Route includes in-person and/or distance information and training sessions, bringing knowledge to people, instigating the desire to know more about the world of energy and helping people better understand the role of citizens in building a more sustainable world.
- Dissemination of energy efficiency tips.
- Campaigns to promote energy efficiency have taken place, directed at schools, the industry, companies and tourism entities, contributing towards an increase in energy performance across the various sectors in the Azores.
- The cycle of conferences Encontros com a Eficiência Energética ('Meetings with Energy Efficiency') is a set of awareness-raising actions that are carried out with the goal of informing, discussing and disseminating the best practices regarding energy efficiency.
- The phone line Linha Poupa Energia ('Save Energy Line') was created in partnership with DECO as a support system to advise citizens on energy matters.
- A number of energy efficiency manuals are now available to different sectors in the archipelago, namely: agro-industrial, public administration, residential, hospitality and fishery.

The above-mentioned events form a great basis for organising more extensive engagement processes such as forming local energy cooperatives. The local government has expressed an interest in forming a strategy for engaging the public, something that is yet to be undertaken. A questionnaire has been distributed to local municipalities on the island probing their interest and ambitions to involve the public in climate mitigating and adaptive measures. The result of this questionnaire is still awaiting. The input of this questionnaire can inform the direction of the local governments and can be used to

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streamline a strategy of engaging the citizens more extensively. A great potential is residing in the decarbonisation projects taking place on Terceira. Based on the engagement plans from the local governments, a streamlined masterplan could be formulated providing a common vision for engaging the citizens in decarbonising Terceira.

2.1.2 Legal Aspects and Regulatory Framework

Regulation authority

In the Azores, the electricity distribution and commercialisation market are regulated by the ERSE, a national entity created for this purpose. Electricity tariffs to be charged to consumers are annually fixed by ERSE. Besides ascertaining the level of benefits to be allocated per tariff, they also characterise the method for calculating and structuring each tariff.

Electricity of the Azores (EDA) is responsible for the production, transport and distribution of energy in the Azores, while also being the only electricity supplier in the archipelago.

Regulatory Framework for Azores islands

The context for the production and distribution of energy in the Azores is quite specific in terms of legislation, considering that the Azores is composed of nine isolated energy grids. This is quite a challenge for the electric regional system and resulted in the need for some kind of control mechanism. Therefore, the Energy Services Regulatory Authority (ERSE) determines how the production and distribution of energy is managed in the Azores.

There is no regional legislation for the active involvement of energy communities, with the autonomous region of the Azores having adopted national laws with regard to self-consumption and energy communities. Because of this, local authorities are currently working on developing regional legislation that supports the existence of energy communities in the Azores, which so far are not in place.

Even so, there is a national diploma that regulates energy communities – Legislative Decree no. 162/2019 [8].

Even though the Azores do not currently have energy communities in place, their importance is acknowledged when increasing the integration of Renewable Energy Sources, through legislation. These communities allow for the promotion and the development of RES and will be a great opportunity for the Azores to further rely on clean energy. Regarding Terceira Island, the Municipality of Angra do Heroísmo has been working towards creating a renewable energy community.

The Autonomous Region of the Azores has the liberty to adapt both European and national legislation to the specific regional context with regards to energy, the following are noteworthy:

- Regional Legislative Decree No. 5/2010/A, of February 23, amended by Regional Legislative Decree No. 27/2012/A, of June 22, and by Regional Legislative Decree No. 14/2019/A, of June 12 - establishes ProEnergia, an incentives system to encourage the storage and production of electricity, essentially for self-consumption.
- Regional Legislative Decree No. 4/2016/A, of February 2 – adapts the Energy Certification System for Buildings (SCE) to the Azores context.
- Sustainable Urban Mobility Plan (PMUS) – contemplates a low-carbon strategy focused on promoting multimodal and sustainable urban mobility to reduce energy consumption and regional dependency on fossil fuels.
- Government Council Resolution No. 106/2019, of October 4 – approves the Plan for Electric Mobility in the Azores, the guideline for public policies to be implemented in the Azores to promote electric mobility.
- Government Council Resolution No. 92/2018, of August 7 – determines the preparation of the 2030 Azorean Strategy for Energy (EAE 2030), the guideline for public policies to meet the energy demands of the archipelago as an outermost region.
- Regional Legislative Decree No. 19/2019/A, of August 6 – approves the Energy Efficiency Program in Public Administration (ECO.AP).
- Regional Legislative Decree No. 21/2019/A, of August 8 – defines the strategy for the implementation of electric mobility in the Azores.
- Ordinance No. 13/2020, of February 7 – regulates the implementation of the charging station network for electric vehicles through urban planning operations.

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- Regional Regulatory Decree No. 4/2021/A, of April 26 – regulates the attribution of financial incentives for the purchase of new electric vehicles and charging stations.

2.1.3 Economic & Technological Aspects

The region's economy is mainly based on services, with public administration assuming an important role in terms of employment, followed by wholesale and retail trade, transport and accommodation and catering activities. The sectors of agriculture (with a strong focus on the production of milk and its derivatives) and fisheries are also very important for the Azorean economy. The insular, archipelagic nature and smaller market size add, however, to high transport costs that make the economic activity less competitive in terms of exports. In recent years, tourism has been gaining weight in the region: this applies both to the tourism sector itself and to a wide range of activities related to it.

The Azores have an energy system that is heavily dependent on the import of fossil fuels, with a smaller variety of energy sources compared to other regions, such as coal or natural gas. The insular, archipelagic nature and smaller market size also add to high transport costs. Around 60% of primary energy imports are channeled to two sectors of great importance: road transport, in the form of gasoline and diesel, and the electricity sector, in the form of fuel oil and diesel.

The consumption of fuel oil and diesel for the production of electricity is high, as a result of the natural thermodynamic performance of this activity where, again for reasons of economies of scale, production is carried out using fuel oil in the largest units and diesel in the smaller ones.

For the electricity sector in the Azores, strong investments in renewable energies are planned until 2026. Community funds will be used for storage systems (batteries), to be installed, in the first instance on the islands of Terceira and São Miguel, and later on for the remaining islands. These investments will make it possible to maximize the penetration of renewable production in the small and isolated electrical systems of the Azores.

One of the main barriers facing the electricity generation sector in the Azores is related to the fact that interconnection between the islands is technically not possible, making investment and greater penetration of renewable sources difficult. In this way, each of the islands is an isolated power generation system, with a reduced economy of scale.

ECONOMIC ASPECTS

Overall, the Azores is composed of 236.657 inhabitants meaning that 22,53% of the Azorean population lives in Terceira. The variation between 2011 and 2021 is negative in both municipalities on Terceira Island, having decreased in -4,4% for Angra do Heroísmo and -7,4% for Praia da Vitória. According to the Azores Regional Statistical Service (Serviço Regional de Estatística dos Açores – SREA), Terceira's Gross Domestic Product (GDP) in 2017 was €902.189.000, corresponding to 21,9% of the Azores. The provisional value for 2018 points to €935.404.000 (21,9% of the Azores) [9].

Terceira has been losing economic weight in the Azores since the early 1980s. The relative weight of the Terceira's GDP decreased from 24,2% in 1980 to 23,1% in 2009 and to 21,9% in 2017 (and 2018, according to estimates by SREA). Regarding the sectorial Gross Added Value, Terceira Island registered €69.693.000 (8,9%) in 2017, in relation to the primary sector; €58.729.000 (7,5%) to the secondary sector; and €652.455.000 (83,6%) to the tertiary sector. Terceira Island is predominantly composed of rural areas, enhancing the importance of agricultural activity.

The primary sector, along with tourism and services are the main economic activities on the island, especially since 2014. In 2019, the Employment and Professional Training Observatory (Observatório do Emprego e Formação Profissional) registered 1.116 companies headquartered in Terceira. [10] At the municipality level, Angra do Heroísmo registered higher business activity, with 788 registered companies (70,6%), while Praia da Vitória registered 328 (29,4%).

Inflation: According to information provided by SREA, between January and October 2021, the average inflation rate in the Azores was 0,19% [11]; and 0,59% [12] for the country.

As there is no data on the inflation rate by island, this analysis is based on the total of the Autonomous Region of the Azores [13].

Employment structure: According to the Regional Directorate for Vocational Training and Employment (Direção Regional da Qualificação Profissional e Emprego), Terceira Island registered around 1,408 unemployed residents in the first semester of 2021, corresponding to about 20,35% of the Azores. Specifically, the Municipality of Angra do Heroísmo registered 936 unemployed individuals, corresponding to about 13,52% of the Azorean municipalities, while Praia da Vitória registered about 473 unemployed individuals in the same period, corresponding to about 6,84% in the Azores [14].

On Terceira Island, in October 2019, the number of working residents was 11.901, with around 95% being dependent workers. Significant numbers are registered in wholesale and retail trade (2.708), in human health and social support activities (2.000) and in hospitality, restaurants and similar (1.337) [15]. Of these, 82,6% had qualifications between the first cycle of basic education and secondary education, while 15,4% had higher education. The average monthly base remuneration for working residents was €835,43 as of October 2019 [16].

The report "Challenges and opportunities for Terceira Island. Study on the impact of the reduction of personnel at Base das Lajes", developed by the Office for Strategy and Studies of the Ministry of Economy [17], indicates that Base das Lajes employed, in June 2012, 760 Americans and 823 Portuguese people, a total of 1.583 allocated jobs. With the US troops being reduced to 168 (a decrease of 592), it is important to assess not only the direct reduction at the Base das Lajes, but also the reduction of indirect jobs in the local economy, that is, jobs whose existence depended on the economic activity boosted by the Base das Lajes.

The reduction in the wage bill had implications for the expenditure in Terceira. Multiplying average wages by the impact on employment referred to above, the impact on the wage bill is estimated to be €31.7 million. Local and foreign investments in energy, renewable sources and technology

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Investments in RES and grid infrastructure

The investment in renewable energy sources (RES) makes it possible to reduce energy dependence from abroad and has a positive environmental effect. In 2019, renewable and endogenous energy sources secured around 38% of the total electricity produced in the archipelago. Terceira Island benefits from the following RES (2019 data) [18]:

- Geothermal: Pico Alto geothermal power plant, with an installed capacity of 4,7 MW, corresponding to approximately 12,5% of the total energy produced on the island.
- Wind: wind farm with an installed capacity of 12,6 MW, which corresponded to about 16% of the electricity produced on the island.
- Hydro: hydro plants with an installed capacity of 1,43 MW – 0,3% of the energy produced on the island. With regards to investments, the Multiannual Strategic Plan and Budget for 2021, developed by Eletricidade dos Açores, SA, estimates that, of the total investment planned for the period between 2021 and 2025 (around €239 million), 50% refers to work and actions at the level of the production centres, of which 26% are related to storage systems and battery network control on the islands of Santa Maria, São Miguel, Terceira and Corvo.

Thus, the following investments are planned for Terceira:

Revitalization of the fuel park and renovation of the command-and-control system in the Belo Jardim Thermoelectric Power Plant. Expansion of the Belo Jardim Thermoelectric Power Plant through completion of the installation of group 11 and the installation of group 12, which will be replacing groups 1, 2 and 4 of the same plant.

Completion of the construction of a battery energy storage system on Terceira Island: providing a power reserve and collaborating in the regulation of voltage and frequency – 15MW/10.5MWh BESS System.

The investments related to transport and distribution are also noteworthy and are grouped as follows:

Transmission Lines (TL) – construction of the 30 kV transmission line between the Vinha Brava Substation and the future Pico Alto switching substation, next to the

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Pico Alto Geothermal Power Station. Renovation of the transmission line to 30 kV between the Substations of Praia da Vitória and Lajes; Distribution Lines – renovation of the line and branches of Transforming Substation 30 – Serreta circuit.

Renovation of the TL underground network (15 kV) in the city of Angra do Heroísmo (3rd phase). Several expansions and renovations in the TL networks; Switching Substations – construction of the Pico Alto sectioning post; Transforming Substations (TS) – renovation of several TS and several power changes in TS;

Low-Voltage Distribution Networks – renovation of the Angra does Heroísmo underground low-voltage network and renovation of the low-voltage network on several transforming substations. The intervention on several distribution lines and the transmission line Praia da Vitória – Lajes is also worth mentioning. It aims to mitigate the action of Avifauna in the electric grid, namely in the high number of reconnections that occur for this reason;

Public lighting – Expansion of several public lighting networks and campaign to replace sodium vapor lamps with LEDs. In Terceira Island, regarding geothermal energy, EDA, S. A's goal is to maintain the initial contracted power of 3,5 MW and expand the plant with a power of more than 6,5 MW. This will depend on how the resource will meet demand expectations and on the success of the campaign to drill a maximum of three geothermal wells in the Pico Alto geothermal field [14]. EDA, S.A estimates that the investment between 2021 and 2025 on Terceira Island will reach €65.650.845. Around 65% of this investment will be related to production centres (production units and storage systems).

TECHNOLOGICAL ASPECTS

The Government of the Azores is drawing up strategies and plans with the goal of balancing the regional electricity system, while promoting energy efficiency and the growing adequate use of electric vehicles. The 2030 Azorean Energy Strategy (EAE 2030), a guiding document highlighting the specificities arising from specific context of the Azores reality, explores the potential of natural and endogenous

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resources, as well as that of new technologies currently available, in a constant search for balance between energy demand and supply.

Following EAE2030, the Regional Action Plan for Energy Efficiency (PRAEE) will be drawn up, so as to optimise and create cross-sector synergies to promote energy efficiency. In turn, the use of renewable and endogenous energy sources in the Azores will increase. Nine geothermal wells are currently being drilled in the Azores, namely on the islands of São Miguel (six) and Terceira (three).

On Terceira Island, the wells will be built on the Pico Alto geothermal field. The goal is to capture enough geothermal fluid so as to maintain production on the Pico Alto plant and allow for a future expansion of an extra 7 MW.

Island interconnection with the mainland grid

There is no electrical interconnection between the islands, nor between the islands and the mainland.

Heating network

There are no heating networks in the Azores.

Large industrial energy consumers

With a total electricity consumption of approximately 170,72 GWh in 2020 the industrial sector stands out, on Terceira Island, with 16,4% of the total consumption (over 28 GWh), surpassed only by the domestic sectors with 36,4% and by commerce/service with 28,4% [20].

Industrial activity is mainly directed towards the agrifood sector (cheese, milk, butter, wine and agroforestry processing). There is also an industrial slaughterhouse on Terceira Island, approved for the export of meat, as well as an industrial unit for cutting and packaging beef, where raw materials are collected from all of the Azores.

Transport sector

In 2019, the Automobile Fleet of the Azores consisted of around 161 thousand vehicles, of which 135.302 (84%) were light vehicles, 11.503 (7%) were motorcycles and mopeds and 9% belonged to other categories. Regarding the distribution of vehicles per island, São Miguel registered 84 thousand vehicles (50.9% of the total

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vehicle fleet in the region) and Terceira Island 37 thousand vehicles, meaning that these two islands together held 74.9% of the Region's total vehicle fleet. The average growth of the car fleet on Terceira Island was 2,5% in 2019, which represents a decrease relative to 2018 (4,6%). It appears that more than half of the car fleet in the Azores is more than 10 years old [21].

The analysis of the evolution of the number of passengers using regular public transport between 2017 and 2019 shows significant decrease. Passenger transport by sea in the Azores has shown a growth trend over the years, which has accelerated since 2014, having reached 562.993 passengers in 2019 [22]. The Government of the Azores has been consistently encouraging sustainable mobility, through the implementation of the Plan for Electric Mobility of the Azores (PMEA), which describes a number of measures and actions to promote the electrification of land transport in all the islands of the archipelago.

Implemented technologies

Smart meters: Currently, only medium voltage and special low voltage customers have smart meters. There is a working group in EDA, SA aiming at the massification of smart meters throughout the Azores for all low voltage customers. The services to be provided by the energy box are those specified by the Smart Grid Regulation published by ERSE.

Distributed generation: The Azores energy policy aims to achieve decarbonisation and decentralisation of energy use, through the integration of renewable energy sources and energy storage systems. In terms of decentralisation, the Azores have been relying on Regional Legislative Decree No. 162/2019, of October 25, as well as on the legal regime of renewable energy communities, considering the partial transposition of Directive 2018 /2001, of the European Parliament and of the Council, of December 11, 2018.

Smart grid/Microgrid: The concept of smart grid, as defined by the Council of European Energy Regulators, encompasses the implementation of smart meters, automation systems, remote control, IoT (Internet of Things), and adequate information systems, which will allow for coordination and automatic control of the network, therefore optimising consumption through energy production.

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The Tariff Regulation, approved by the Energy Services Regulatory Authority (ERSE), aims to "encourage distribution system operators to carry out pilot projects and investments on distribution systems involving smart grids".

Special demands of energy supply on Islands:

In general, the continuity of electricity supply in the Azores is defined by quality service zones, stipulated as follows:

- Quality Service Zone A: locations with more than 25 thousand inhabitants;
- Quality Service Zone B: Locations with more than 2500 customers and less than 25 thousand inhabitants;
- Quality Service Zone C: Locations with less than 2500 customers.
- There are customers with special/priority needs whose typology is identified in the Quality-of-Service Regulation [19], namely between articles 101 to 106.

New technology trends

The growing integration of renewable energy sources, especially those of an intermittent nature, such as wind and solar, and the gap between consumption and renewable energy production, are the current challenges arising from modern power generation systems, which require support from systems that increase flexibility and stability, such as energy storage systems.

The cost of batteries as energy storage devices is increasingly more accessible. It is also worth noting that they bring advantages such as swift installation and the current wide range of large-scale applications (Utility-Scale): commercial, residential and even electric vehicles (EV).

With all of this in mind, the Azores Distribution System Operator – EDA, S.A – has an ongoing Utility-Scale energy storage project on Terceira Island, consisting on the acquisition of an innovative 24 MW battery system. The system comprises 24 battery modules and a storage capacity of 16 MWh, enough to cover the average daily consumption of more than 2600 families.

The main purposes of introducing an Energy Storage System on Terceira Island's electricity production system are to increase the stability and quality of

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service of the system, as well as to enhance the island's endogenous resources and, consequently, reduce CO_2 emissions.

It should also be noted that the introduction of this Energy Storage System will allow for a power expansion on the Pico Alto Geothermal Power Plant of up to 10 MW, ensuring the stability and safety of the island's electrical system during off-peak hours. Within this scenario, it will be possible to reach an integration of renewable energy of around 60.9% to 67.3%

2.1.4 Environmental Aspects

Energy contributes to 52.5% of total greenhouse gas emissions, followed by agriculture, mostly through of enteric fermentation processes, with 41%. Within the energy sector, the transport subsector corresponds to 24% of total emissions and electricity production to 20%. In terms of emitted gases, carbon dioxide (CO_2) comes first with 52%, followed by methane (CH_4) with 36% and nitrous oxide (N_2O) with 11%.

The Regional Plan for Climate Change (PRAC) defines low-carbon mitigation guidelines that can contribute to reducing GHG emissions:

- Reduce the carbon intensity of public transport through strategic technological planning;
- Reduce fossil fuel consumption and GHG emissions by increasing the use of soft transport modes, restricting the use of private transport;
- Promote the decarbonisation of the energy mix through the use of electric vehicles and other alternative fuel vehicles;
- Reduce GHG emissions through electrification in service, domestic and public buildings;

Climate Change

The Government of the Azores has focused on developing policies in order to counter climate change, through legislative and strategic documents, such as:

– Government Council Resolution No. 123/2011, of 19 October [22], which approved the Regional Strategy for Climate Change (ERAC), a document focused both on mitigation and adaptation strategies.

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– Regional Program for Climate Change (PRAC), through Government Council Resolution No. 93/2014, of 28 May [23], approved by Regional Legislative Decree No. 30/2019/A, of November 28 [24], a sectoral plan that binds all public entities. Land-use special, inter-municipal and municipal plans are responsible for developing and implementing their own defined strategic policies and goals.

Natural resources

The Azores archipelago is composed of nine islands of volcanic origin and a few coastal and oceanic islets, with a total surface area of approximately 2.344 km2. Within the Exclusive Economic Zone of Portugal (EEZ), the Azores comprises a marine surface of approximately 1 million km2 (948 439 km2), which represents about 30% of the European EEZ, one of the largest in the European Union.

The strategy for the rational management of natural resources in the Azores is based on safeguarding the existing marine biodiversity within the surrounding maritime area, while also appropriately taking advantage of the naturally available resources.

Water

In island regions, such as the Azores archipelago, water is a relevant resource due to the scarcity of alternative sources. So as to act accordingly with regional, national and European legislation, it is now essential to focus on the optimisation of use and management of water resources. It is important to consider its various ends, while also reconciling technical, economic, social and environmental aspects. The management of water in the Azores necessarily calls for specific actions and accountability on the part of various regional entities.

Forest resources

In the Azores, forest areas are protected and regulated through legislative and strategic documents, such as:

– Regional Legislative Decree No. 6/98/A, of April 13 [25], regulated by Regional Regulatory Decree 13/99/A, of September 3 [26].

– "Estratégia Florestal Regional". The Regional Forestry Strategy promotes the multifunctionality of forest resources through appropriate policies regarding environmental, social and economic aspects.

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Natural resources management

So as to properly manage the archipelago's natural resources, a number of protected areas have been established. The Network of Protected Areas of the Azores integrates all the protected areas within the archipelago through the system established by the International Union for the Conservation of Nature (IUCN). The management units of the Protected Areas Network are composed of nine Natural Island Parks (one per island) and the Marine Park of the Azores Archipelago.

Natural disasters

Due to its geographical location and the increase in the occurrence of extreme weather events, the Azores are subject to the constant risk of flooding, contributing to coastal erosion. Water erosion that affects the soil also implies loss of productive land, nutrients and organic matter. Terceira Island has been one of the most affected islands in the region, suffering from natural disasters such as earthquakes, major storms and floods that have deeply affected both the environment and the population.

Circular economy

In the Azores, the Regional Legislative Decree No. 6/2016/A, of 29 March [27] which approves the current Strategic Plan for the Prevention and Management of Waste in the Azores (PEPGRA), provides strategic guidelines to increase recycling and prevent the loss of valuable materials. The Circular Economy proposes new goals for recycling urban waste by 2030, as well as for the total deposition of waste in landfills.

Environmental situation on Terceira Island

The contamination of water resources in the municipality of Praia da Vitória, resulting from the use of fuel storage structures used by the US detachment based at Base das Lajes, has led regional authorities to focus on the environmental situation on Terceira Island, looking to guarantee the safety of the quality of water for public consumption.

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2.2 Ameland Lighthouse Island

2.2.1 Political & Social Aspects

POLITICAL ASPECTS

Demography

Ameland is one of the 5 inhabited Waddeneilanden (Wadden sea islands). The islands' total size is 58,83 km^2 and consists mostly of sand dunes. It is the fourth major island of the West Frisians. Ameland is connected to the mainland electrical grid and to the mainland natural gas grid. There are four villages in Ameland: Hollum, Ballum, Nes and Buren with a total population of 3.673. The Wadden sea islands is the largest unbroken system of intertidal sand and mud flats in the world and is recognized as a UNESCO world heritage site. The Wadden sea islands as a part of the UNESCO world heritage site collaborate on several issues and sustainability is one of them.

Brief overview of the political system

The Dutch political system is a parliamentary democracy, with the monarch (constitutional monarchy) as the head of the state (Firm, n.d.). The Netherlands is also sometimes described as a consociational State. A consociational state can be described as a politically stable country that is deeply divided along distinct religious, regional, ethnic, or racial lines. In these countries the destabilizing effects of subcultural segmentation are neutralized at the elite level by embracing non-majoritarian mechanisms for conflict.

The Netherlands is administered politically on three levels: 1) Nationally, by the central government, 2) Regionally, by the provincial authorities, 3) Locally, by the municipal authorities. The municipalities are dependent on the central and the provincial government. Over the past decades the central government has delegated more and more duties and responsibilities to the municipalities. The central government provides guidelines and the provincial and municipalities are allowed some degree of freedom in how they operationalize / implement the guidelines (Rankema, 2008). The Dutch Island of Ameland falls under a single municipality also known as the Municipality of Ameland. Ameland is a part of the province of Friesland.

One of the focus areas for the Dutch government is to fight climate change. The Netherlands has signed the Paris agreement. To achieve goals set in the Paris Agreement, the Dutch government has passed a law "Klimaatwet" (Climate Law in English) and has signed agreement with a broad group of stakeholders called the "energieakoord" which states that the CO_2 emissions in the Netherlands should be reduced by 49% by 2030 and by 95% by 2050 compared to the emissions levels of 1990 [29].

To achieve the Paris agreement, the provinces and the municipalities have developed the Regional Energy transition Strategy (RES). The RES is a regional partnership for the spatial integration of the energy transition with the following functions: regional translation of the national agreement for climate agreement; it describes the decision-making process for the spatial integration of sustainable energy infrastructure; and organizing interaction and cohesion between regional stakeholders (VNG, n.d.). The RES is in turn an aggregation of the ambitions of several municipalities within the province. The RES stipulates that the province of Friesland aims to generate 3TWh of sustainable electricity on land [30]. Furthermore, the specific contribution of Ameland is expected to be 0,023 TWh, or 23 GWh. Additionally, the island of Ameland wants to reduce it CO_2 emissions in 2035 by 95% compared to the CO_2 emissions in the year 1990. That is 15 years ahead of the rest of The Netherlands. The electricity will be primarily generated via solar energy, but the municipality of Ameland will also experiment with innovations, such as Tidal kites.

In March 2022, municipal elections were held in the Netherlands. The outcome of these elections on Ameland has led to the coalition of parties AmelandÉén and Algemeen Belang Ameland also continuing after the 2022 elections. This has formed the basis for a coalition agreement in outline. Quality of life and sustainability run like a red thread through all topics for the future of Ameland and the islanders.

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SOCIAL ASPECTS

Local Energy demand

IANOS is focused on the self-sustainability of islands with regards to energy. In some contexts, it is critical for their energy provision to be self-sustainable. If the energy supply does not meet the energy demand, energy poverty will occur on the island. The Dutch context does not have this criticality. Energy poverty therefore has a different meaning in Dutch context than in other contexts. In Dutch (and other West-European) contexts, energy poverty occurs in a household if the energy expenditure exceeds more than 10% of their income. In the case of Ameland, the average household spends €2054,10 per year on energy, which is 10,06% of their average yearly household income. This means that, following the widely accepted standard of energy poverty of 10% of the household income. Ameland is exposed to energy poverty. Due to the iVPP in IANOS, energy can be bought more efficiently, which means that the expenses should go down after IANOS. The minimum value of energy poverty is near the index that Ameland has, so it could be the case that after the IANOS project, energy poverty is solved.

To relate the social aspect of the island to the IANOS project, it is best to discuss the acceptance, or rather participation, to the sustainability goals of the island by inhabitants of Ameland.

Engagement of islanders in the energy transition movement

Ameland has an initiative that gives an indication of how citizens are engaged to the sustainability program on Ameland called "Duurzaam Ameland' [32] (in English: "Sustainable Ameland"). This program is aiming to make the energy system on the island constructively more sustainable. This is done through experiments and projects, of which IANOS is one.

In other projects, Duurzaam Ameland is incorporating citizens in projects. A good example of such a project is EnergieNet Ameland, where Duurzaam Ameland is aiming to make the energy grid of gas and electricity more sustainable, without making energy too expensive. They do this together with citizens on the island itself. In this respect it is relevant to mention that the subject of energy poverty is a theme that will be included in the development of further plans arising from the Sustainable Ameland convenant.

Another good example of active engagement from firms and organisations towards citizens is a project that the Amelander Energy Cooperation (AEC) is preparing. A new solar farm that is going to be implemented during IANOS has a new concept, where citizen can financially participate in the development of a solar farm and get a share of the green electricity in return. This shows that organisations, apart from the municipality, see that citizens should be engaged in order to create success. Households themselves are also acting towards the goals of Duurzaam Ameland. With the help of the municipality and partners of the Duurzaam Ameland Cooperation, 136 hybrid heat pumps are installed in households throughout Ameland. Next to that, in 2020, 378 PV-panel installations are done on the island, with a total capacity of 7,991 kW [31]. Throughout the island, even some households try to have a storage of energy, in case of overproduction. This shows that inhabitants themselves are quite willing to invest in creating a more sustainable energy system for the island.

Nonetheless, in the past the engagement from project groups towards local communities has not been as good as it is at present. According to research of TNO, past projects that have not been as successful as the ones stated here caused friction. From interviews with local citizens and entrepreneurs on Ameland was gathered that local communities felt that more engagement from the project groups towards the community should be sought. Work Package 8 of the IANOS project should focus on this. So, overall Ameland has quite an engaged community that is willing to take measures to become more self-sustainable, even though some friction is caused due to a top-down approach and lack of incorporation of local communities in the process. This makes the chances of succeeding and reaching the goals of IANOS more likely.

Local Energy Communities and Cooperatives

Ameland has its own Energy Community: Amelander Energie Coöperatie (AEC) which delivers clean energy to its customers. Currently, AEC has 286 members and 993 customers being the main organization to participate in Renewable Energy projects as well as in Energy Savings projects.

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The island has the ambition to be self-sustainable in terms of sustainable energy and water supply [33]. In 2006, Ameland also started an initiative called "convenant Duurzaam Ameland". The initiative is a collaboration between public and private parties. The collaboration involves jointly and individually investing in projects that contribute to the energy transition and that stimulates sustainable economic growth and entrepreneurship. Furthermore, there are grass root level initiatives, for example the AEC was setup in 2009 by the islanders. Their goal is to provide a platform to the energy transition ambitions for the citizens of the island. The energy cooperative actively engages with the energy transition related issues on the island. To conclude, the political landscape in Ameland is very favourable for energy transition. Energy transition is one among the central themes in the Ameland political landscape. Several top-down and bottom-up initiatives on the island focus on the energy transition process.

Grid capacity to support energy transition projects

Next to the municipality of Ameland, NAM, Eneco, Philips, TNO, EnTranCe (part of the Hanze University of Applied Sciences), and Amelander Energie Coöperatie, network operator Liander is one of the parties that has signed the Sustainable Ameland covenant. Liander thus endorses the sustainability ambitions and objectives for Ameland and helps to realize them by, among other things, expanding the capacity of Ameland's current electricity cables with two new cables. In this way, the network can meet the rapidly growing demand for capacity and space is created for new sustainable initiatives

2.2.2 Legal Aspects and Regulatory Framework

Regulatory Framework

The laws and regulations on Ameland are the same as those on the Netherlands' mainland. The following national laws are the most relevant to the energy transition process: (1) Klimaatwet (climate law), (2) de Elektriciteitswet 1998, (3) de Gaswet, (4) de Warmtewet, (5) de Windenergie op zee wet, (6) de Mijnbouwwet, and (7) de Omgevingswet, which is yet to be enacted. Moreover, the following

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European Directives are most relevant to the energy transition process: (8) the energy efficiency directive, (9) the renewable energy directive.

The Klimaatwet provides a framework for the cabinet to draft policies that will help reduce greenhouse gas emissions by 95% by 2050 and by 49% by 2030 when compared to the emissions in the year 1990 [34]. Furthermore, all the other laws in essence help achieve the above overarching goals.

The Dutch Elektriciteitswet 1998 (Electricity Act) aims at gradually giving individual consumers and suppliers in the electricity market more freedom of choice within a framework of rules aimed at reliable, sustainable and efficient functioning of the electricity supply.

The Gaswet governs the process of transport and supply of gas. Recently, the Gaswet has been changed to facilitate the energy transition process. The Gaswet has been modified to not allow realisation of new natural gas connections [34]. This is in a bid to step away from natural gas to cleaner sources of fuel. Also, because of the earthquakes caused by natural gas mining in the province of Groningen.

Currently, the Dutch government is reforming the regulatory framework surrounding energy by implementing the so-called Energiewet (Energy Act). This Energy Act will replace the Electricity Act and Gas Act currently in force. This future Energy Act aims at clarifying and simplifying electricity and gas legislation, and removing unnecessary differences between electricity and gas legislation.

The Warmtewet was enacted in 2014 and governs the heat networks and mainly focuses on small scale users i.e., 100 kilowatts. The law was mainly enacted to protect the consumer and lays certain ground rules such as how the price should be determined, supply guarantees, etc. [34]

The 'Windenergie op zee wet' was enacted in 2015 and provides an integrated legal framework for realizing large scale offshore wind energy. The law focuses on zoning sites for wind farms and licensing and subsidy related issues. The law is currently being modified to reduce/eliminate the inflow of government subsidies and to introduce auction mechanisms for predetermined sites for offshore wind parks. As of October 2002, the first Mining Act started to regulate the exploration and extraction of minerals. From July 2021, the regulatory body considered that it is necessary to replace the existing laws and set up a new regulation which meets the requirements to be imposed for mining-related activities [34].

De Mijnbouwwet regulates the permits for exploration and production of minerals and geothermal energy, as well as the detection of substances and the detection of CO2 storage. De Omgevingswet, which is due to come into effect on 1 July 2023, aims to provide a collection of rules for spatial development which are easy to implement. For example, it provides a regulatory framework to start the construction of housing, infrastructure, the living environment, nature and water [37]. Moreover, it also regulates the construction of spatial projects on old industrial estate or the construction of wind farms. Therefore, it aims to provide a balanced regulation between utilizing and protecting the living environment. Next to this, the Omgevingswet aims to stimulate construction work in existing buildings and neighbourhoods to be beneficial for the environment.

Next to the abovementioned laws, there are also different network codes which legislate the energy market (electricity and gas) and apply to the network operators and energy suppliers. The different types of network codes: tarrif codes, technical codes and information codes.

In addition, the international Energy Efficiency Directive obliges the EU Member States to achieve 1,5% yearly efficiency cumulative improvements during the period 2014-2020. The Member countries have the freedom to establish their own objectives on how to achieve the aforementioned target. The Netherlands intends to meet this target by achieving cumulative savings of at least 482 PJ on final energy consumption (Energy Efficiency Directive, 2013). Finally, the Netherlands is represented in the Global Bio-Energy Partnership by the Ministry of Infrastructure and Water Management, in order to establish international agreements that support the use of sustainably produced biofuels. In 2011, the Dutch parliament incorporated the EU Directive on Renewable Energy, which aims to increase the use of energy from renewable sources, such as biofuels to 20% by 2020 [36].

Main challenges experienced

The main challenge, currently experienced within the legal framework on Ameland, lies mainly with the national applicable netcodes (adopted by the

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Dutch regulatory authority, the ACM) in the Netherlands, specifically the Netcode Electricity. Currently, statistical calculations are used in order to e.g. determine whether there is congestion on the grid or not. This could lead to situations where the calculations through this method suggest that the grid capacity is full, while in practice this is not the case. This leads to cases of so-called "administrative congestion" instead of real congestion. Changing this calculation system to that of dynamic calculation would possibly lead to a (legal) larger capacity of the grid, which would give more opportunities for developing projects.

Next to that, there was also a challenge concerning state aid regulation. Some proposed RES on Ameland are dependent on joint investments between government and private investors or government subsidies on development of the technology. Both constructs are susceptible to state aid challenges, as the investments have to fall under specific state aid exemptions mentioned in the "Guidelines on State aid for climate, environmental protection and energy ". During and before the development of IANOS, however, these challenges have been mapped and were deemed not applicable to IANOS. Specifically, for the deployment of the SeaQurrent tidal kite (partially funded through the Wadden Fund) an extensive state aid analysis was required as part of the subsidy.

2.2.3 Economic & Technological Aspects

<u>ECONOMIC ASPECTS</u>

The economic analysis is done in two parts. Firstly, an overview of the current status of Ameland is presented. After this, the analysis will focus on aspects relevant to IANOS, mainly on the energy-related economy on Ameland; What causes the current energy demand profile, what are the challenges here, what is being done to innovate in these focus areas?

Ameland is an island situated in the northern part of the Netherlands and officially part of the province of Fryslân. This island is around 270km^2 and has 3747 inhabitants [3] of which around 3100 are of working age (CBS, 2021), and around 3000 are in the working population. This means that the unemployment rate is quite low on the island. The average household income of the Island is €1700,- /month. The Wadden Islands of the Netherlands are performing quite diverse when it comes to average household income; Texel has an average household income of €6300,-/month, but Vlieland has an average household income of 'just' €600,-/month

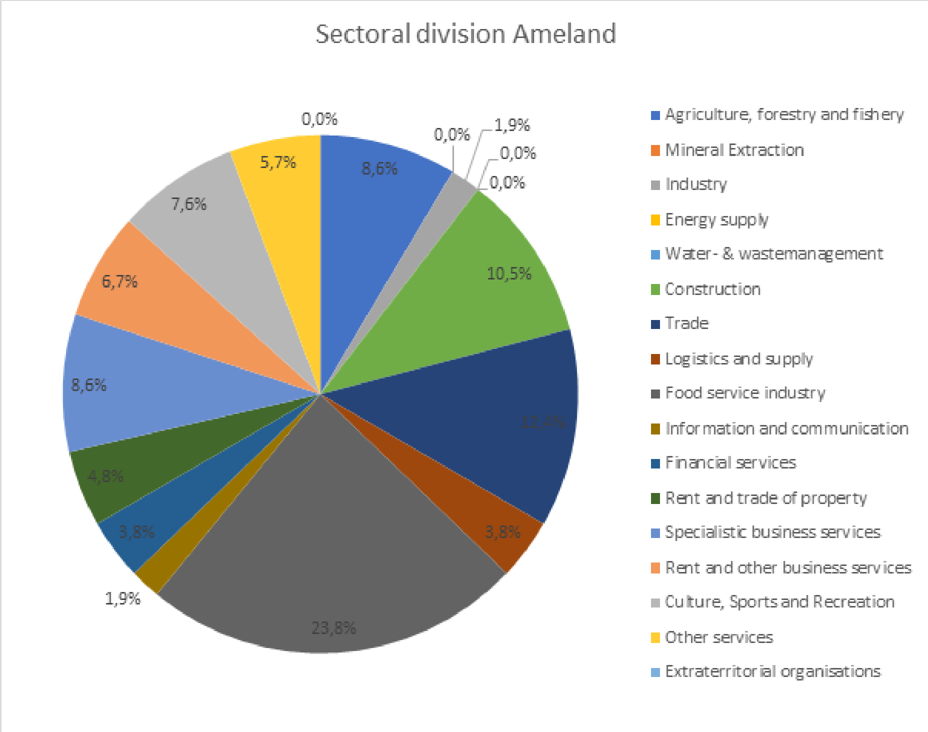

Figure 4 Table of sectoral division of Ameland (CBS, 2021)

As can be seen figure 4, the biggest sector on Ameland is "Food service industry". Other big sectors are rent and trade of property, rent and other business services & Culture, sports and recreation. These sectors are all related to the tourism sector, of which Ameland is quite dependent for their economic development. According to LISA (2020)[1], 44,7% of all jobs on Ameland are related to the tourism & recreational sector, and around a third of total businesses is related to this sector. The other sectors are quite underrepresented on the island; only construction work is a substantial sector, whereas industry is 'just' 1,9% of the total economy of Ameland. This is in line when looking at the geographical characteristics of the island. Industry-related economies are space-intensive, something Ameland does not have. Most of the industry that is present on the island is the NAM platform, where gas is being extracted from the bottom of the sea.

The challenge IANOS is facing is the decarbonisation and smartification on the island. The energy demand of Ameland was 486 TJ in 2018 and 492TJ in 2019

[1] https://www.lisa2020.org/

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(excluding transport). Most of this energy is used in the built environment, mainly heating. Figure 5 shows that gas and fossil fuel are most used, whereas electricity is not yet used as much as needed to decarbonise the island.

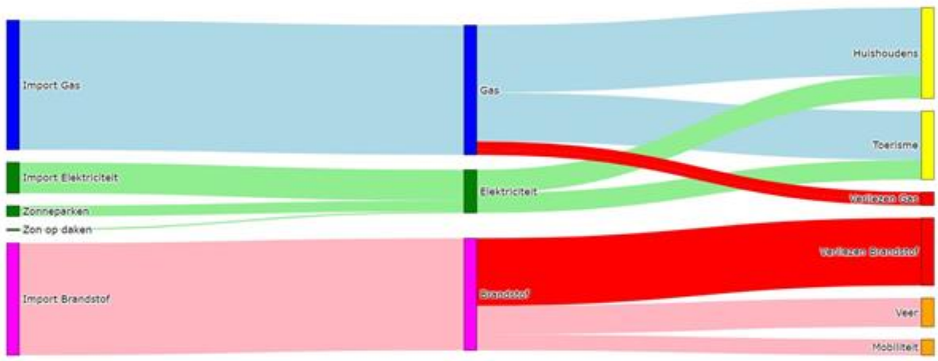

Figure 5 (In Dutch) Left: Energy resources used. Right: application of that particular energy source

To decarbonise the island, households and the tourism sector should make the transition from gas to electricity/biogas, which is done partly within the IANOS project by implementing domestic PV-panels. As can be seen, a substantial portion of the energy demand (200 TJ) comes from the biggest economic sector on the island: tourism. This implicitly says something regarding the fluctuation of energy demand on the island. The demand for tourism itself is relatively low in the winter and autumn. During summer and spring, the demand for tourism increases. In other words, the demand for energy for tourism fluctuates with the demand for tourism itself.

So, the economy of Ameland has an impact on the current energy system and its peak demand. Within IANOS, the challenge of this fluctuation of energy will be faced by implementing storage facilities for electricity and add innovative elements that could increase the electricity supply. This storage facility will create the opportunity for the tourism sector to make the transition to electricity and (partly) biogas, without increasing the peak demand as much due to increased storage capacity. This storage capacity will make sure that overproduction is stored, that can be used when consumption exceeds production in that moment of time. This increases the use of sustainable energy, following the line of the so called 'Trias Energetica'. Trias Energetica means that you first try to reduce as much energy as possible, then try to make the transition to sustainable energy sources as much as possible and use fossil resources as efficient as possible for

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what is left. On Ameland this means: try to isolate the households and touristic residences first, and try to make them demand a little as possible, then implement the innovative elements on the island, to produce as much as is needed to match the energy demand, and the final difference between demand and production should be filled up with fossil fuels (which in case of Ameland should be none after IANOS).

Within IANOS, around €34.500.000 is invested over the period of the IANOS-project in all innovative elements in order to reach the goal of IANOS (decarbonisation of the island). The benefits of these investments can reach quite far. The most important benefit is to (virtually) be independent of the mainland grid. Next to that, investments in smart energy systems are expected to help avoid investments related to grid reinforcement. The exact value of these smart energy systems is unknown, since grid operators cannot determine what type of investments these smart systems prevent. The energy systems alleviate the grid by coordinating energy as efficient as possible, which prevents the need to investing in the grid. How much exactly this smart system prevents, is unknown due to the innovativeness.

The investments in the innovative elements could also create indirect benefits. During IANOS, innovative elements will be implemented on the island. This will create some technical need of work on the island, which will cause an increased demand of work in the industry/construction sector. Another indirect benefit that could be caused by the IANOS project are potential spinoffs as a result of collaboration among different project partners. The exact value of these indirect benefits cannot be captured in an amount.

TECHNOLOGICAL ASPECTS

This section focuses on the technological aspect of Ameland. It describes a list of devices which are already existing in the island and the ones that will be implemented during the project of IANOS. Moreover, the section will highlight some specific parameters which are relevant for the operation of the assets.

According to the Klimaat Monitor (2019), the total consumption of energy in Ameland is 492TJ, which includes natural gas, district heating, traffic and transport, regeneration heat and 25,8GWh of electricity. The industry is the

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largest consumer of energy with 373TJ which represent 76% of energy usage in the island. It is followed by household consumption which represents 11% of the total, tourism which represents 8% and the mobility sector which only accounts for 5% of total energy consumption in Ameland.

In 2017, the total energy generated from renewable sources was 34TJ and they represented 27.5% of the total electricity usage (93 TJ) on the island. Before IANOS, renewable energy sources account for 33% of the total energy usage in the island. During the period of the IANOS project, Ameland aims to be energy neutral and independent by 2035, meaning to eliminate imports of energy from the mainland grid connection.

In order to achieve Ameland's ambitions, the objective of IANOS is to maximize the generation of energy from renewable energy sources. Furthermore, the project also focuses on increasing the flexibility in the energy system which balances the supply and demand for electricity through the installation of storage facilities and supporting infrastructure. Moreover, the project aims to achieve energy independence with the combination of a reliable smart grid and the active engagement of the local community. In the next section, a detailed overview of the devices that will be operational during the IANOS project is provided.

Existing Technology

In Ameland, a ten-hectare solar park, composed of 23.000 solar panels, was developed to produce 7GWh (2022) of electricity, which generates enough electricity to power 2.500 households. The solar farm is community- owned through a local energy cooperative, Amelander Energy Cooperative (AEC). Moreover, a Combined Heat and Power (CHP) with a capacity of 75kWe is operational in order to maximise self-consumption of renewable energy and provide a stable flow of energy.

In regards to the mobility sector, the municipality of Ameland has already installed 10 public charging stations, as most of the tourists use public transport for mobility on the island. Moreover, 4 municipal vehicles, 6 electric busses and their chargers are operational and they will be monitored and connected to the iVPP during the project.

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A gas distribution network is responsible for the supply of natural gas by fuelling condensing boilers in Ameland. During IANOS project, the demand for heat on the island aims to be fully decarbonized by expanding the already existing heating grid which is located at Klein Vaarwater holiday park. In addition, 35 CH4 fuel cells, which are fed with CH4 from the district grid, are already operational and privately owned in 35 individual homes. Moreover, there are 135 hybrid heat-pumps (HHPs) which are located in residential neighbourhoods and connected to the iVPP. The HHPs have a total capacity of 150 KWe. The boiler has a capacity of 20kWth and each HP is 1.1kWe/5kWth.

Since 1986, the natural gas platform has been operated by the Nederlandse Aardolie Maatschappij (NAM) off the coast of Ameland. The production of natural gas by the platform is 1 mio m3/day, of which 10k m3/day is used as fuel to power the platform. In order to reduce the pollution of CO2 and NOx in the platform, the project aims to replace the modules which are powered by gas with electric ones and connect the platform to the electricity grid of Ameland. Thus, the offshore cable connection to the island was implemented in 2021.

Planned Technology

A solar farm which is paired with a battery and an electrolyser. The solar farm has a capacity of 3MWp and the large-scale battery is able to store 2MWh. The battery will be connected to the grid and paired with the solar farm and the electrolyser. Moreover, the party which controls the iVPP will be responsible of managing the State of Charge (SoC) of the battery and ensuring that the remaining capacity is sufficient to maximize the consumption of renewable energy.

Furthermore, the energy generated by the solar farm will be absorbed by the battery for output stabilization and used to feed the wastewater treatment plant and in the future a electrolyser which generates green hydrogen. In regards to electricity generation, 1MW of solar panels will be installed in residential households in order to maximize self-consumption. Moreover, two small wind turbines will be installed with a capacity of 15kWe. In addition, a tidal kite will be implemented with a capacity of 500kWe, in order to generate enough electricity to power 700 households. As tidal energy is constant and 100% renewable, it provides a reliable generation of energy. In the village of Nes, a biobased saline

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SuWoTec battery will be implemented as an energy storage facility in order to maximise self-consumption in the island and provide demand-side management services. The organic battery will have a capacity of 120kWh and a charging capacity of 50kW. It will be used to store excess energy for later use, minimizing the energy cost for the heat pumps.

Regarding the mobility sector, a smart charging infrastructure will be developed using information on the energy grid and transport movements on the island. In the case of Ameland, GOPACS will be used to mitigate grid congestion while offering a new revenue stream for large and small parties using their available flexibility.

Moreover, a Smart Energy Router and Hybrid Transformer are installed to minimize power losses and optimise user's generation and storage. In the Klein Vaarwater recreational park, a 500kWe fuel cell will be installed in combination with the 75kWe CHP. The fuel cell will act as a CHP where the heat produced by the fuel cell will be directed to the already existing heating network. Moreover, the project has the ambition to decarbonize the village of Buren by eliminating the use of natural gas. Instead, an innovative heating grid infrastructure is being researched for the city of Nes. Finally, a digester will be installed in order to convert sewage and organic waste into green natural gas (CH_4), which can be used directly or fed into the natural gas grid, in combination with the iVPP it can act as virtual buffer. The digester's output will be combined with excess hydrogen from the electrolyser and converted to methane. Therefore, the CH_4 generated will be used in the existing natural gas network in order to feed the CHP (75kWe and 110kWth) and the fuel cell (500 kWe).

2.2.4 Environmental Aspects

Natural resources

Like all West and East Frisian Islands, Ameland is a unique piece of nature. The profusion of different plants on the island is caused by the immense variety of landscapes. One of the scenic areas is the Oerd, a large complex of dunes which is still expanding by the year. Because of the differing landscapes and types of flora, over 60 different species of birds are sitting there every year. At the eastern

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part of the Oerd lies a beach plain called the Hon. Besides dunes and beaches, Ameland has some woods, like the Nesser bos ("Wood of Nes").

Water

Two-thirds of the drinking water on Ameland comes from the mainland via the pipeline that was built in 1990. The rest of the water comes from the island itself. A disadvantage of water extraction on an island like Ameland is that the dunes can dry out when too much water is pumped out of the freshwater bubbles.

Natural resources management

Both high dunes and dune valleys characterize the landscape, the Oerd. Birdwatchers can indulge themselves here, because thousands of birds live here. The highest dune of Ameland, Oerdblinkert, offers a fantastic view of the sea and many bird species can be spotted. The herring gull is dominant here with a huge population, but other birds such as the curlew, wheatear, avocet and common tern also call 't Oerd their home. The area is open to walkers.

Not far from 't Oerd is the Hon. This nature reserve in East Ameland consists of young dunes and salt marshes. This area is still subject to change, new dunes are still being created. This region is known for the spoonbill colony that lives there. Seals can be spotted from the coast of Ameland. Most seals lie on the sandbar west of Ameland. On the west coast of Ameland (near the Borndiep) from the beach you can see them on the sandbank where they are enjoying the sun.

The Ameland Nature Center organizes ECO safaris, where tourists can explore the nature reserves on Ameland with an electric all-terrain vehicle. 2 tours are offered: One to the Kooiduinen in the east of the island, and one to the Hagedoornveld in the west. The guide drives over the dunes, along the Wadden Sea and right through nature. Because the cars are electric, they make no noise and nature is not disturbed.

Circular economy

One of the goals of the municipality of Ameland is to create a circular economy. Not only because of it's environmental impact but also because costs are lower when goods and materials can be produced and recycled on the island. On of the

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projects to improve the circularity of the economy is to use restaurant waste (swill and fat) and the sludge from the wastewater treatment plant as a source to create methane.

Energy Mix and Island Strategies

The penetration of renewable energy in Ameland aims to strengthen the infrastructure of the island and adapt to climate change solutions through smart digital solutions. Considering the latest LCA emission factor conducted as an average estimate for EU grids, one MWh of electricity is equivalent to 0.444 emissions of CO2, while the emission factor for solar PV is 0.030 and wind is 0.010 tCO2-eq [30]. Therefore, the integration of renewable energy solutions and the smartification of the grid in Ameland have significant environmental benefits compared to traditional dependence of the island to the mainland Dutch grid connection. IANOS contributes to building a climate resilient island by reducing the ecological footprint of its energy needs and increasing energy self-sufficiency.

At this moment a 6MWp solar park is being operated which produces ca. 20% of the electricity consumption of Ameland. With current and new projects Ameland wishes to become self-sufficient in the field of energy, leader in the energy transition and driver for the circular economy. The municipality stimulates energy savings in households and tries to make the heat demand more sustainable, which both will reduce the local emissions of CO2. Besides this, Ameland is working on a smart energy grid to integrate sustainable energy sources on a larger scale.

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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 the first step in defining the Master Use Cases. Section 3 presents the assessment **methodology** for the replication potential of the proposed use cases and solutions within the Lighthouse Islands energy network, IANOS Fellow Islands, 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 technologies.

In this context, in order to support further the energy transition in the medium and long term in geographical islands, IANOS project aims to explore the specific use cases to be **replicated and larger-scale deployed** at the island-wide level and at the grid level. Table 1 shows the set of **IANOS Use-Cases (UCs)**, as defined in the proposal stage, grouped under a common heading axis called "**Transition Track**", according to the requirements each interdisciplinary **Use-Case (UC)** addresses. **Three (3) complementary Transition Tracks (TT#1–TT#3)** make up the **Island Energy Transition Strategy** adopted by IANOS, which take into account the challenges and enablers for the demonstration and replication of solutions in the IANOS LH and Fellow islands.

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Table 1 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

Each UC is based on innovative and conventional solutions/technologies focusing on similar objectives in order to increase the energy impact.

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 and large-scale deployment potential** of some of those 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, and based on the island specific needs and energy transition aspects. The MUC will include innovative but also conventional IANOS solutions blended together to reach islands' energy sustainability goals. The specific capacities and areas for each of the selected technologies needs to be defined, alongside the grid topology where the targeted IANOS innovative technologies will be included. Economic figures of the MUCs will be also 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 **against 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 techno-economic and environmental-oriented results obtained with the IEPT tools will be given for all scenarios. 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. Results will help IANOS LH Islands build 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 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 oriented for smart island and smart grid projects. The **2nd version** will include a detailed **techno-economic assessment** and **cost-benefit analysis of the Master Use Cases** defined for both **decarbonisation scenarios.**

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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.

Table 2 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 2 *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: [38]	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: [39]	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 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

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	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: [40]	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: [41]	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: [42]	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 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

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	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: [43]	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: [44]	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 [45]. 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: [46]	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: [47]	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: [48]	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 [49] 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 [50] focuses on an integrated energy and economic assessment with a developed platform to evaluate different decarbonisation scenarios for 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 [51] 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 [52] 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 [53] 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 [54] looked into the FLEXITRANSTORE smart grid technology innovations' scalability and replication potential using a method adapted from BRIDGE methodology [55]. 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 LH 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. In order to ensure the most effective, stable, and reliable grid operation, IANOS LH islands will test to replicate use cases combining RES technologies available in the demos (pilot assets) and novel IANOS solutions e.g., environmentally friendly batteries, flywheels, etc. 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 Terceira

Terceira LH Island aims to implement energy efficiency, grid flexibility and e-mobility measures in the context of the island's decarbonisation. The main objectives of the Azorean Island are the optimization of the behind-the-meter assets towards maximizing the RES self-consumption of households, the provision of ancillary energy flexibility services for the grid by the deployed energy storage systems, and the electrification of the transport sector. Terceira will examine further replication or large-scale deployment of the UCs demonstrated in IANOS in order to deliver a detailed replication plan for achieving carbon neutrality in the long run. The Master Use Case will consider the set of UCs 1, 3, 4 and 5 in order to investigate their replication potential and feasibility, based on the foreseen decarbonisation scenarios. The following conventional and innovative technologies will be deployed and tested in these UCs:

- Battery energy storage system (BESS) of 15 MW/3 MWh
- 2 V2G charging stations with a rated power of 10 kVA (EFAEM)
- Electrochemical Batteries (16 batteries with a total capacity of 3.3 kWh)
- PV panels with embedded microinverters with a total capacity of 1.5 kWp (5x300Wp) (BeON).
- Heat Batteries with a total heat storage capacity of 3.5 kWh (SunAmp)
- 5 Electric Water Heaters with a capacity of 150L (UNINOVA)
- 2 Smart Energy Routers with a battery of 5 kWh each deployed (UNINOVA)
- A Flywheel (100kW) (Terraloop)
- Hybrid Transformers (400kVA) (EFACEC)

3.4.2 Master Use Case (MUC) of Ameland

The entire set of IANOS UCs that will be implemented by the LH Island of Ameland, focusing both on energy efficiency and decarbonisation aspects, will be examined also in terms of replication and upscaling potential. The Master Use Case will consider the aggregation of all interventions included in the UCs in order to investigate their replication potential and feasibility, based on the defined decarbonisation scenarios. A detailed description regarding the included technologies per transition track (TT#1 and TT#2) and their specific characteristics is presented.

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Energy efficiency

The technologies involved to create more RES, energy storage, promotion of self-consumption and smart energy services are:

- Solar Farm: 6 MWp Solar Farm at the airport of Ameland.
- Solar Farm & Battery Storage: 3 MWp Solar Farm & BESS with DC-connections at Ballumerbocht Ameland.
- BioBased Saline Battery: 120 kWh biobased saline SuWoTec battery
- Electrolyser: In the proposal a 2 MW Electrolyser was planned in combination with a water taxi which would be realised by Wagenborg (ship owner) and would use the hydrogen from the electrolyser. Wagenborg decided to not run that project. This not only means that there is no water taxi within the IANOS project but also that there is no use for a large scale electrolyser. A small-scale electrolyser will be installed and tested in the Ballumerbocht. With this a combination will be made with the wastewater treatment plan to use the oxygen and a hydrogen fuelled cleaning truck.
- Households with battery packs, PV and µCHP's: 3 houses with battery pack (3.5kWh), solar panels and micro-CHP (1kWe, 5.5kWth)
- Hybrid Heat Pumps: 135 Hybrid Heat-Pumps (20kWth gas boiler + 1.1kWe/5kWth Heat Pump)
- Methane Fuel Cells: 35 privately owned CH4 Fuel Cells. These are already being in operation and funded by the National Project Slimme Stroom.
- Virtual Power Plant: Platform to connect all assets and regulate energy flow

Decarbonisation

The technologies involved to decarbonise transport, decarbonise large industrial load, decarbonise heating networks and to utilize waste streams to create methane are:

- Digester: A digester to use restaurant waste (swill, fat) and sludge from the water treatment plant as a source for methane production.
- Charging Infrastructure: 10 new public charging stations, privately owned charging stations, municipality owned charging stations
- CHP Plants
- Electric Bikes: All Bike rental companies offer electric bikes for tourists.

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- Electric Buses: All buses are electric.
- Electric Cars available for tourists: Available at taxi rental company.
- Electric Cars of the municipality: 3 electric cars of the municipality of Ameland.
- Sea Water Heat Pumps
- Heating Grid Nes/ Heating Grid Buren: the development of two new heating grids in Nes and Buren
- Heating Grid Klein Vaarwater/ Large Fuel Cell/CHP Plants: an extension of the current heating grid with a fuel cell and CHP's as heat source.
- Tidal Kite: 500kWe Tidal Kite to be installed between Ameland and Terschelling
- AWG Natural Gas Platform: Replace gas-driven compressor by electrical compressor
- Hydrogen fuelled transport: a cleaning truck which is planned to rent from another municipality
- Wind Turbines: There are some small-scale wind turbines installed on Ameland. Municipality promoted installing turbines. There are now 3 permit requests (2 regular turbines, 1 vertical axis). Hydrogen storage

The Master Use Cases 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 briefly presents 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 [56]. 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.

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.

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 3 shows the relevant IANOS KPIs and their links with each of the IEPT tools.

Table 3 *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 LH Islands - Grid Energy Modelling and Analysis

The first step for the Replication Assessment is the description of the baseline. Only the baseline scenario results are included in this 1st version. The RES penetration scenarios (50% RES and Fossil Free) will be described and analysed in the 2nd version of this work. For the purposes of the energy simulation scenarios, the electric systems of the IANOS islands were developed with the utilization of INTEMA.grid tool and PowerSystems library. Details regarding the model development process and the simulations are presented in the following sections.

4.2.1 Terceira LH Island

4.2.1.1 Energy system description – Current status (Baseline)

Terceira is one of the largest islands in the archipelago and as all islands in the Autonomous Region of the Azores, has an independent electrical system. A rough estimate of the annual energy production on Terceira is around to 190GWh [57]. Over 30% of the energy emitted is produced by renewable energy sources, while the rest of the energy production comes from fossil fuels. A large thermoelectric plant, combusting Heavy Fuel Oil (HFO), is responsible for assurance on the network's security, stability and quality of supply. The electrical power system of Terceira Island, which is depicted in Figure 16, consists of eight electricity production plants and five substations.

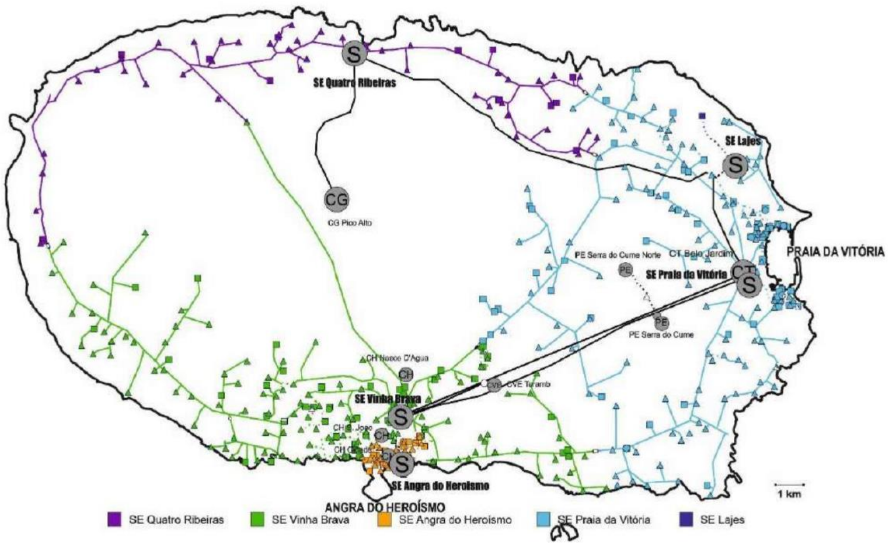

Figure 6 Terceira's electrical grid

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The electrical production system includes a **thermoelectric power station**, *Belo Jardim (CTBJ)*, a **geothermal power station**, *Pico Alto (CGPA)*, a **solid urban waste plant** *(TERA)*, the *Serra do Cume (PESC)* and *Serra do Cume Norte* **wind farms** *(PESN)*, and three smaller **hydro-electric power stations**, the *City Water Power Plants (CHCD), Nasce D ´Água (CHNA)* and *São João (CHSJ)*, whose general data are presented in the Table 44.

Table 4: Generation plants of Terceira

Name	Installed Power [MW]
Belo Jardim	58.116
Pico Alto	4.675
Tera Waste Plant	2.6
Serra do Cume	9
Serra do Cume Norte	3.6
City Water Power Plants	0.265
Nasce D ´Água	0.720
São João	0.448

The substation connected to Belo Jardim constitutes the central component of the entire electricity production system. **Five other substations**, which design specifications are presented in Table 55, are included in the medium voltage (MV) transmission network in different parts of the island, i.e., the cities of Praia da Vitória and Angra do Heroísmo, the civil parishes of Quatro Ribeiras and Lajes.

Table 5: Substations and characteristics

Name		Voltage Level Transformation [kV]	Installed Power [MVA]
Belo Jardim	SEBJ	30/15	10
Praia da Vitória	SEPV	30/15	20
Vinha Brava	SEVB	30/15	20
Angra do Heroísmo	SEAH	30/15	10
Quatro Ribeiras	SEQR	30/15	10
Lajes	SELJ	30/6.9, 30/15	12.5, 1

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Terceira's **transmission system** consists of a **30 kV MV network** that connects the Praia da Vitória Substation, Vinha Brava and Angra do Heroísmo substations. A 30 kV MV line is established from SEPV to the Lajes Substation, which supplies the US military detachment and the Portuguese Air Force (FAP - BA4) infrastructure, which in turn interconnects with the Quatro Ribeiras substation.

All power stations are interconnected through the MV transmission network **at 30 kV**, as depicted in the simplified diagram of Figure 7, except for the **hydro power plants** in the center of Angra do Heroísmo, which are **connected to the MV distribution network at 15kV.** Part of the distribution network is at the level of 6.9 kV connecting the SELJ substation to a private network of the US military. The **low voltage distribution** network is at **0.4 kV.**

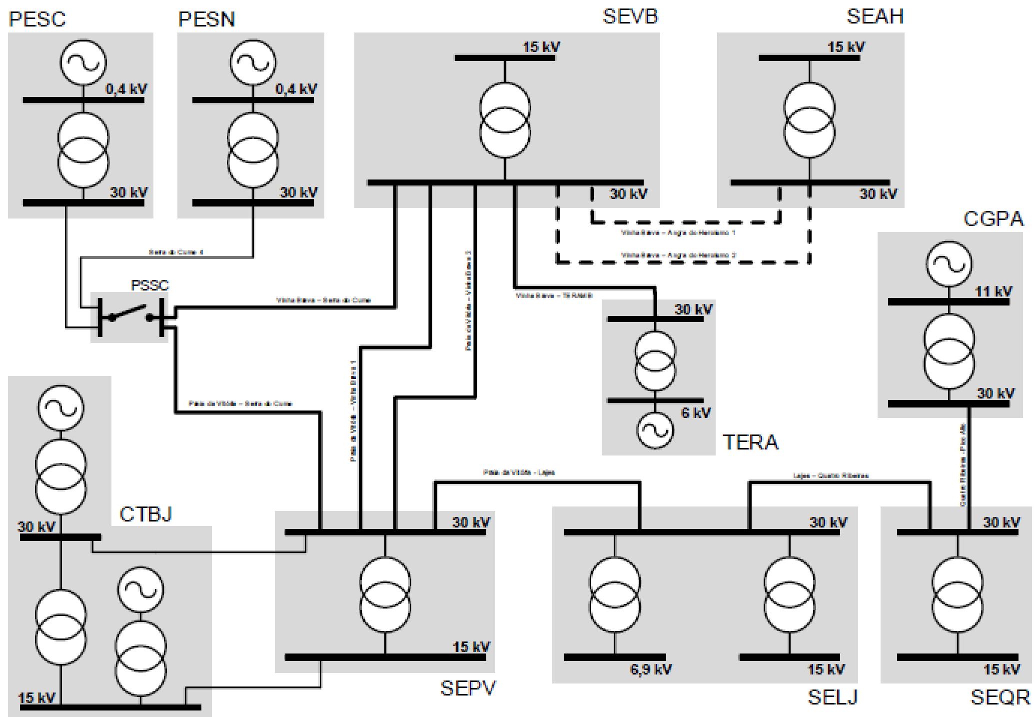

Figure 7: Simplified scheme of the 30kV transmission network [57]

Fossil-based power production plants

Belo Jardim is a conventional thermoelectric plant of reciprocating generation groups running on fuel oil. It is the largest power plant on the island and represents **more than 70%** of the power system's total installed power. The **single-line diagram** of the power station is shown in Figure 8. At the Belo Jardim power station, the 3 out of 9 generation groups are connected through coupling

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transformers to the **15kV busbar** of the power station, while the rest are connected to the **30kV busbar** of the substation.

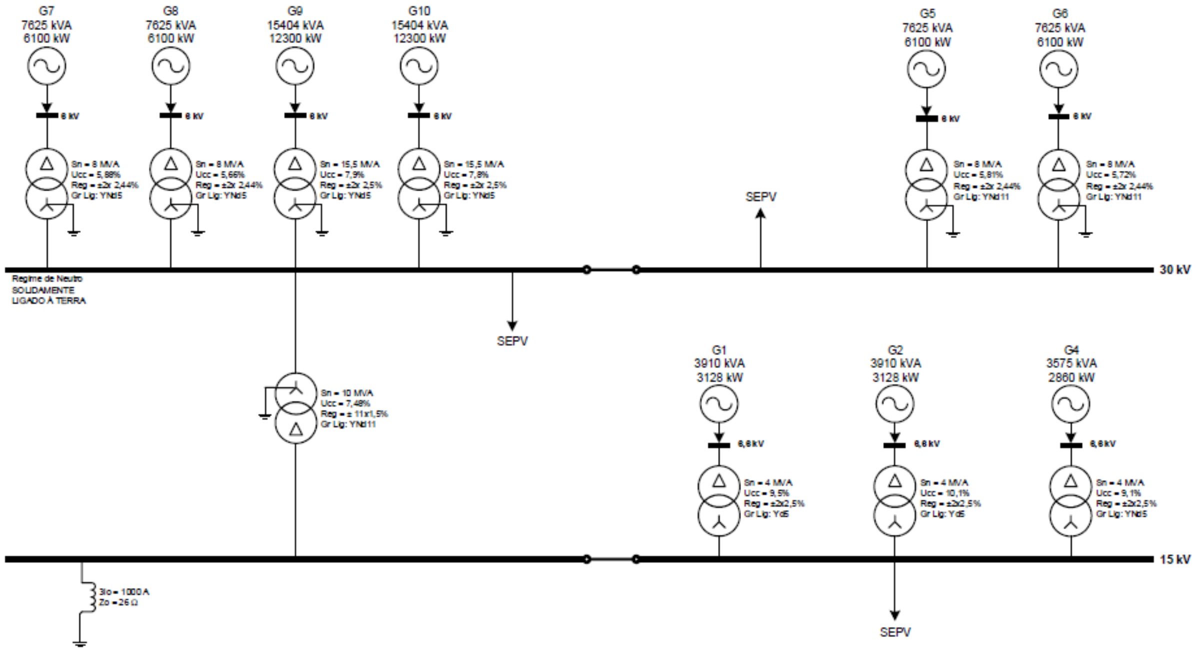

Figure 8: Single-line diagram of the Belo Jardim power station [57]

RES-based power production plants

As for the renewable plants, the **Pico Alto** geothermal power station comprises a single generator set, which is connected through a coupling transformer to a **common 30 kV** bus leading to MV transmission lines that **connect to Quatro Ribeiras substation**, as it appears in Figure 9.

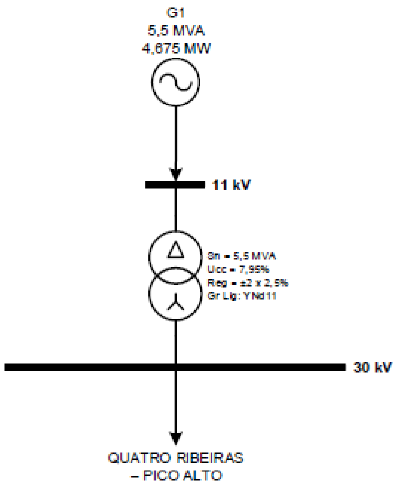

Figure 9: Single-line diagram of the Pico Alto geothermal power station [57]

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Furthermore, over **15% of the energy production** comes from **RES exploiting wind energy**. The Serra do Cume **wind farm**, Figure 1010, consist of 10 Enercon E-44 wind turbines of 900kW capacity and are **connected to 30kV** buses through coupling transformers.

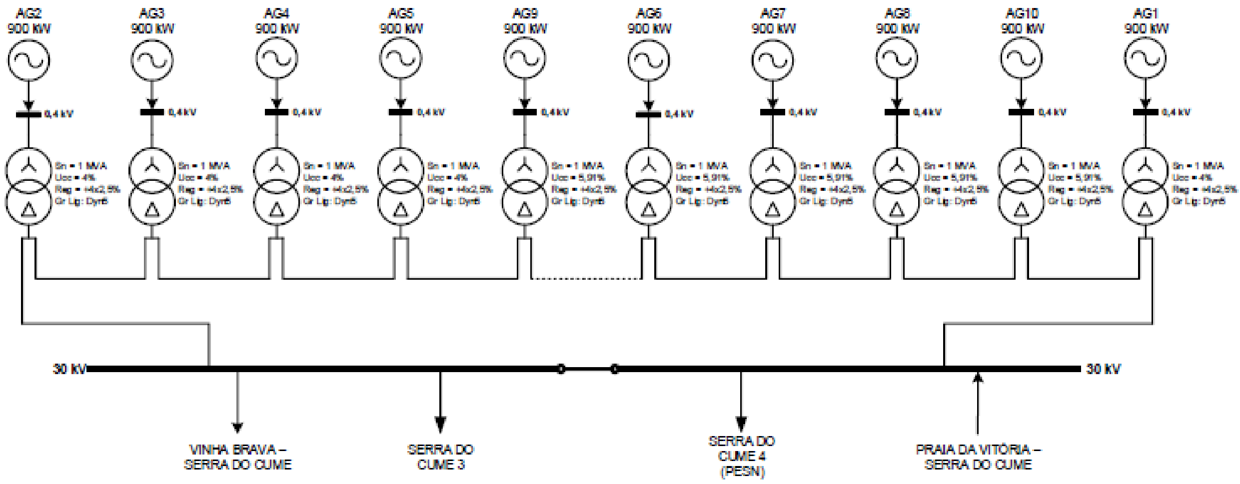

Figure 10: Single-line diagram of the Serra do Cume wind farm [57]

The **Serra do Cume Norte wind farm** is owned by an **independent producer** and hence relevant information is limited. However, there is an online database containing comprehensive details about various wind power installations from a variety of players in the worldwide industry—wind farm developers, operators and owners, turbine manufacturers [58]. Information from this database confirm that the Serra do Cume Norte wind farm consists of 4 Enercon E-44 wind turbines of 900kW$_e$ each, amounting to a total of 3.6MW$_e$ installed power.

Similarly, **independent producers** have ownership of the **Tera solid urban waste plant**. Consequently, there are very limited details available regarding the power plant's waste composition, being combusted. Despite that, the scenario of a single generation group is adopted, similarly to geothermal power station. Tera waste plant is connected through a 6/30kV step-up transformer and a MV line to Praia da Vitória substation.

4.2.1.2 Baseline Scenario – Results and Discussion

For the simulation of the baseline conditions, Terceira's power system 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 terms. These

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scenarios will be defined, detailed, and modelled in the next version of this Deliverable.

MODEL SETUP

Terceira's network has been modelled with the aid of **INTEMA.grid**, part of the greater INTEMA suite of tools, which was presented in depth in D.3.5 [59]. The tool uses the open-source PowerSystems (PS) library. As a lighthouse case, Terceira's grid is described by a fair level of complexity. Due to the lack of adequate data and information, for the purposes of the **baseline scenario** only **the 30 kV MV transmission network has been modeled**, as well as the part of the MV distribution network that connects to the hydro power stations. It was crucial that all generation plants are included in the network model but the rest of the MV and the LV distribution system had to be disregarded, as they would introduce many difficulties in the model development and would not result in any significant improvement on the outcomes of the load flow simulations. The main attributes of the developed network model, as shown in Figure 1111, include the generation plants, the substations and the common buses, the transmission lines and the loads at each substation.

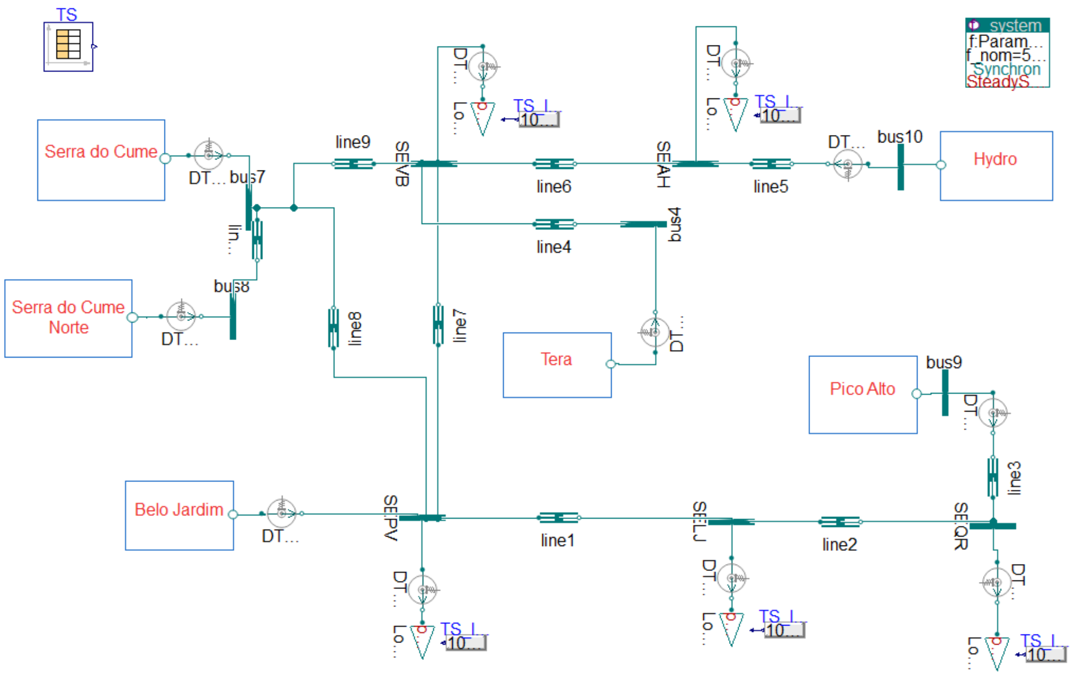

Figure 11: Model of Terceira's electrical network

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The electricity production system consists of **six power plants**. A thermoelectric plant, a geothermal one, an urban waste plant, two wind farms and a hydro power plant (all 3–*CHCD, CHNA, CHSJ*–are modelled as 1). The **five substations** are included in the model, as well as **five other common buses**. All of them are at 30kV. **Aerial lines and cables** are all modeled as concentrated RX-impedances with varied resistance (X_s) and reactance (X_m) parameters [57]. There are **five loads** in total, one at each substation. Their specified power demand can vary dynamically and is determined by signal-inputs (timeseries).

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 were provided by EDA - Electricidade dos Açores, SA. Time-series data for load demands at all substations, as well as, time-series for the energy produced by all generation power plants, in hourly granularity, were provided. A **pre-processing step** has been followed, including data cleansing and homogenization, to ensure the integrity and validity of the input data.

The first task involved the **data filtering process which was carried out** in a 2-fold way. That was deemed necessary, due to a significant number of **outliers** and **missing samples** that appeared in the data acquired from the tele-counting devices contained, as shown in Figure 12.

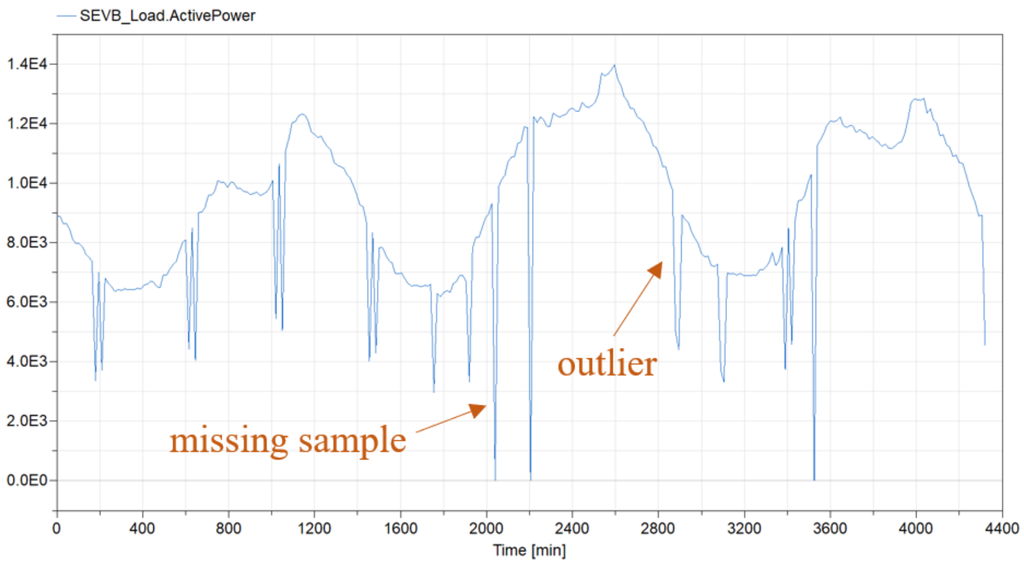

Figure 12: Diagram example of missing samples and outliers

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The **outliers** were removed with the use of the well-documented **Hampel filter** [60], while **missing samples** of larger periods were **replaced with the average values** of former and latter equivalent periods (e.g., same days of previous and following week).

The next task regards the **data verification** process. The provided time-series were compared against reference data source, described in the official EDA document [57]. More precisely, estimations for **the annual energy production and consumption** of 2021, as well as for the **total network losses** were found to be **193.06, 179.43** and **13.62 GWh**, respectively. Calculations for the annual energy consumption using the data (load time-series) provided by EDA led to a slightly different estimation, at **177.53 GWh.** This difference is in the range of **1%** discrepancy between the EDA estimates and the calculated value. In order to damp this deviation, the **filtered data were used** for the calculation of the annual consumption. The estimation came up to **180.27 GWh,** resulting in an insignificant **0.46% error**. Additionally, due to the stochastic nature of wind production, it is often that a short-term mismatch between generation and demand is tracked. A high level of uncertainty is introduced to the system's operation, as more RES are infiltrating the energy production. Therefore, **ancillary services** for frequency and voltage regulation are vital. The **Belo Jardim** thermoelectric power station has sole responsibility to provide these services. For this purpose, EDA suggested that an approximate **1% (500-650kW) of its installed power** is constantly required. The **monthly energy requirement** from CTBJ is shown below, in Figure 13. As a result, the annual energy production allocated to **ancillary services total up to 5.3GWh** approximately.

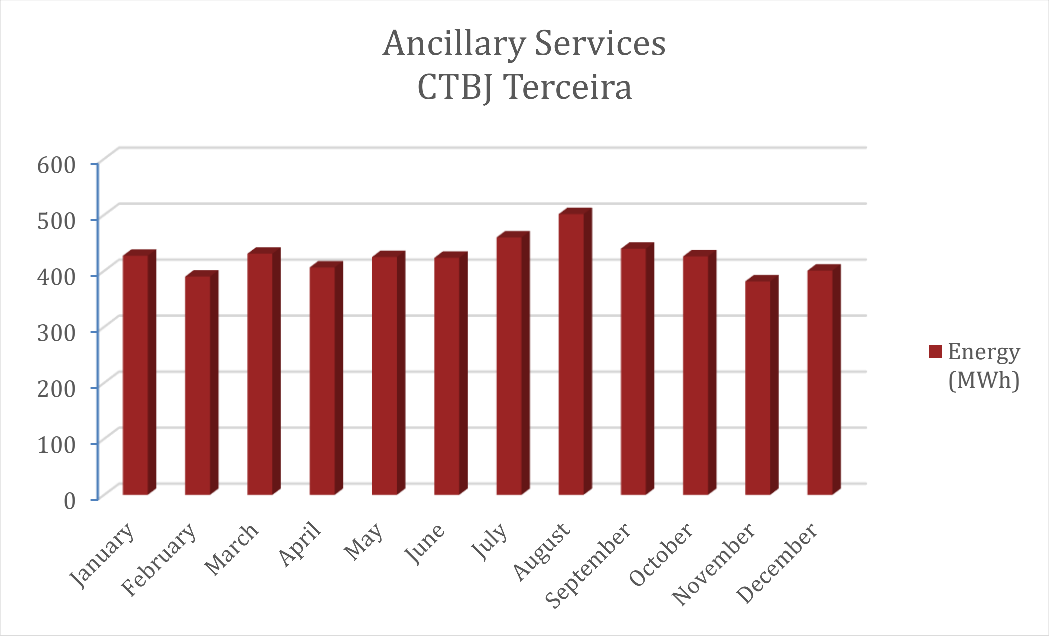

Figure 13: Energy requirement for monthly ancillary services

Simulation results

The filtered data were used to run annual **power flow simulations**. The simulation interval time was set equal to 365 days, and run with a constant time step of 4 samples per hour (i.e. a 15min timestep). The actual duration of the power flow lasts for 85.7 seconds, representing one year of simulation. The graph in Figure 14 shows the power generated by all power plants combined in blue and the power generated by renewable energy sources (e.g., geothermal, waste and hydro plants, wind farms) in red.

The simulation results revealed an **annual energy production** based on the **filtered** generation time-series that amounted to **181.6GWh.** The **1.4GWh** difference between the energy production and consumption calculations is due to the **impedance of the transmission lines**, resulting in **less than 1%** losses.

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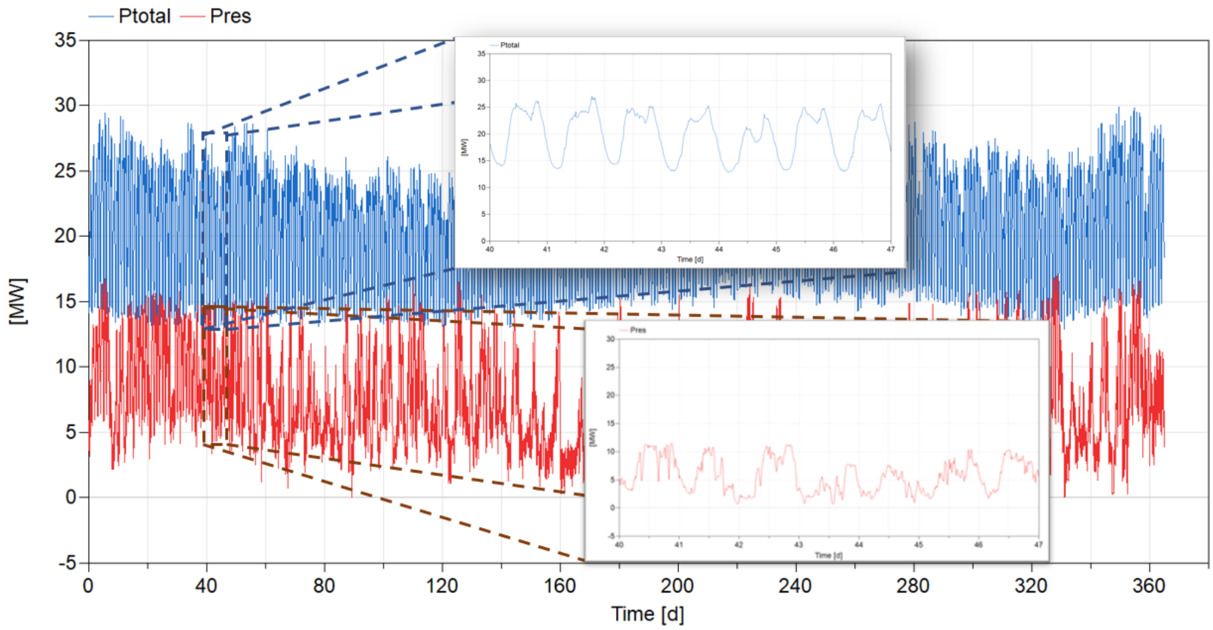

Figure 14: Annual simulations for total generated and RES generated power

As it appears in Figure 15, the transmission losses entail an almost constant **difference** of approximately **0.25MW$_e$, between the generated and demanded power**.

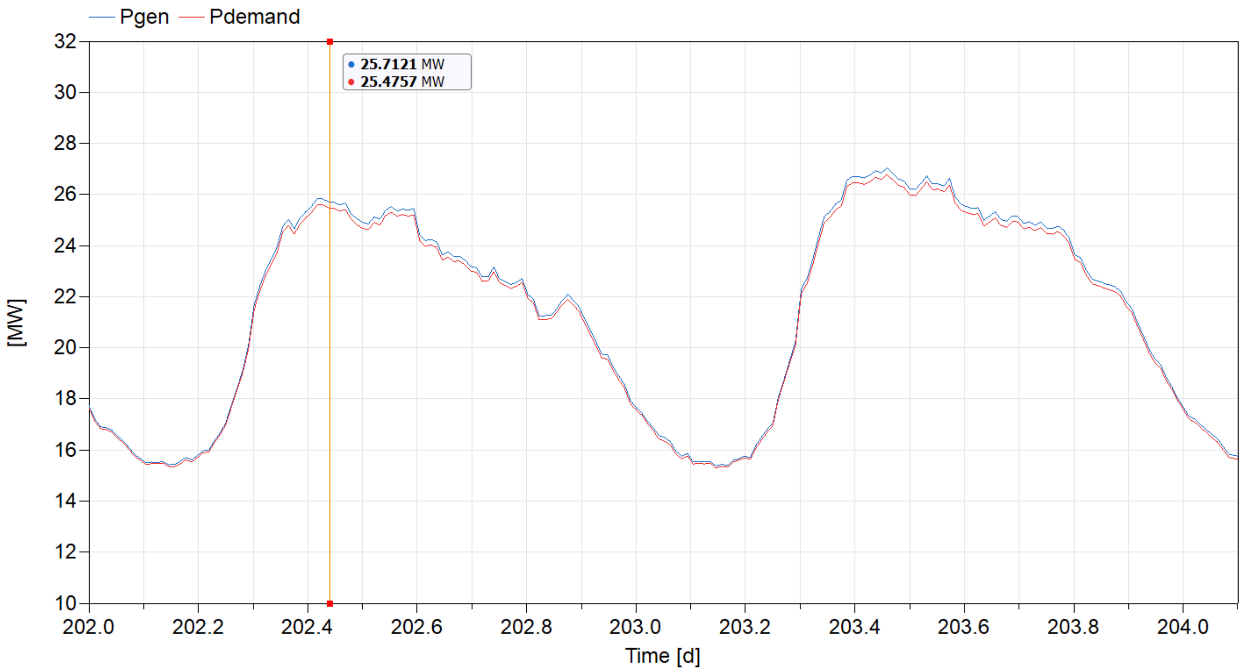

Figure 15: Demanded and generated power for 202-204 day of the year

If the annual energy for ancillary services is factored in, then the energy production sums up to 186.9 GWh. Taking into account the reference data stating that the generated energy for 2021 was around 193 GWh, the calculations entail a **6 GWh energy gap**. It is assumed that **losses in the distribution network**, which are

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not numerically accounted for, owed to the non-consideration of the MV/LV grid power lines topology, is the cause of this apparent energy gap. The energy production and consumption estimations are provided in Table 6 and the comparison to the reference data is explicitly portrayed.

Table 6: Energy production and consumption verification

	Reference Data	TS calculations	Filtered TS calculations
Energy Consumption	179. 43 GWh	177.53 GWh	180.27 GWh

	Reference Data	Filtered TS simulation results	Filtered TS simulation results + Ancillary services
Energy Production	193.06 GWh	181.60 GWh	186.90 GWh

A noteworthy observation is that the energy contribution of every power plant in the energy production mix varies depending on the season. The 4 stacked area graphs in Figure 16 offer a visual representation of the **power plants' contribution** over a randomly chosen 5-day period **in each season** (summer, fall, winter, spring).

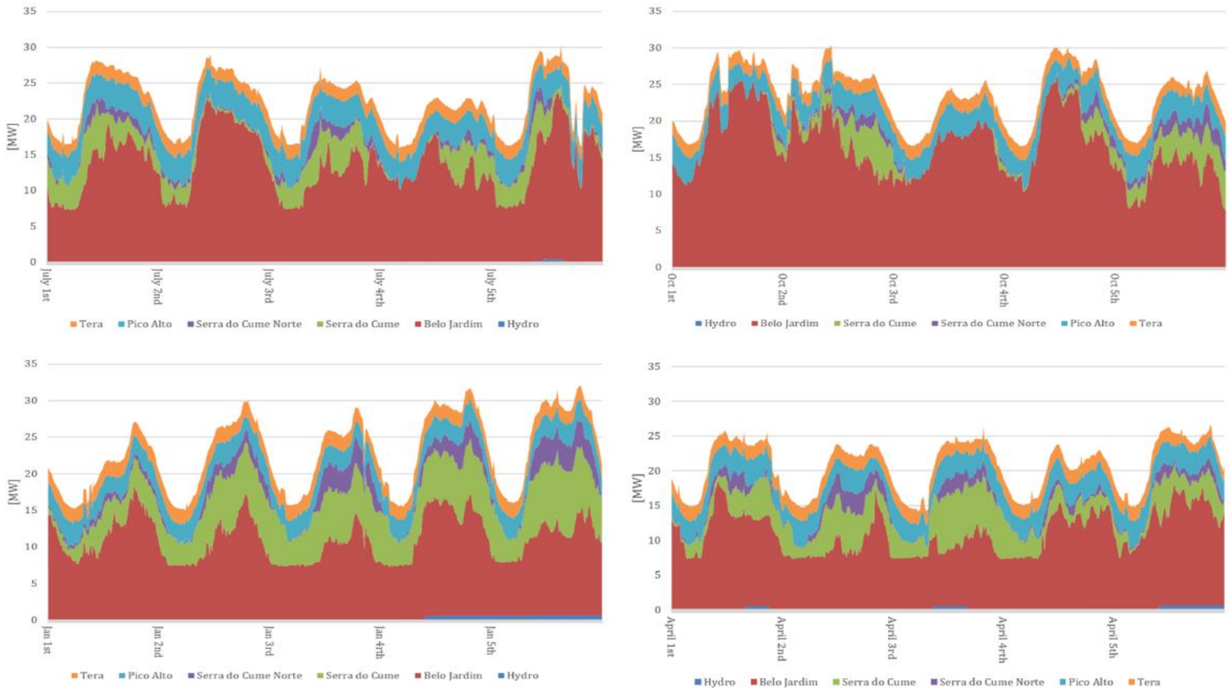

Figure 16: Power plants' contribution to the energy production in the summer (top left), fall (top right), winter (bottom left) and spring (bottom right)

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Evidently, the **energy produced by the geothermal and the solid urban waste plant** remains, almost constantly, at the level of **20% of the production** throughout all seasons. On the contrary, the **hydro plants'** production follows a non-periodic profile, as its **operation cycle appears to be very irregular**. It sparsely contributes to the mix and thus, hardly reaches the **1.1% of the annual production**. The **total energy generated by the 2 wind farms** peaks in winter and appears relatively low in the summer and fall. These results state, that during the **winter months, 31%** of the demand is covered by wind energy, while this percentage drops to **14% and 9% in the summer and fall** months, respectively. Lastly, it appears **the average energy demand is the highest in the fall, across the whole year,** and the **thermoelectric plant** primarily covers this increase. Subsequently, its **contribution to the energy mix is raised from ~50% to 71%.** The **record high in fossil fuel-based energy** production appears on September 2nd and **rates at 85.5%.**

Since the distribution network is not a part of the currently developed model, the system's energy demand is represented by **5 concentrated loads, one at each substation** connected to a 30kV bus. As the loads change by the hour, the **voltage magnitudes of the buses** are affected, as displayed prominently in Figure 17 for a 30kV bus, part of the Angra do Heroísmo substation.

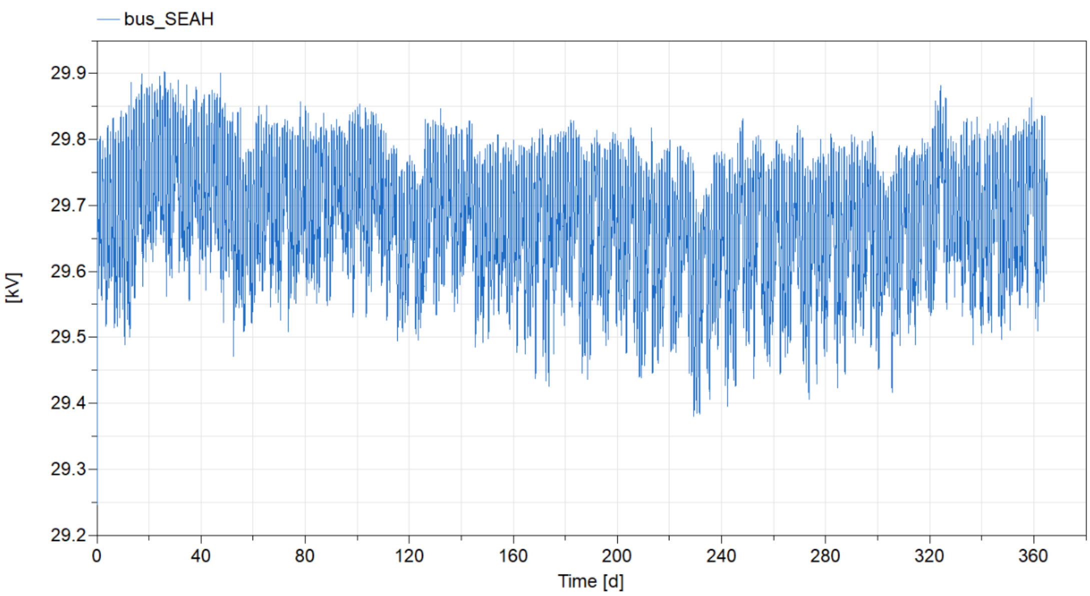

Figure 17: Voltage deviations at a 30kV bus at SEAH

Furthermore, because of the impedance of the transmission lines, there is an additional deviation in the **voltage level of the buses** at the beginning and end of a line. This **deviation** ranges between **1.5 – 2%** at all load buses. The **accepted voltage drop** for the MV transmission lines is less than **<10%** [61].

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Generation plants are responsible for providing reactive power to the system and ensuring voltage stability at the buses close to their proximity. As displayed in Figure 18, the **voltage magnitude at the bus connected to Belo Jardim** is **constant at 30kV,** while the **reactive power** emitted to the system by the plant shows an **average of 4.77MVar**. The voltage level of the buses connected to other power plants remains constant accordingly and the reactive power produced follows a similar profile.

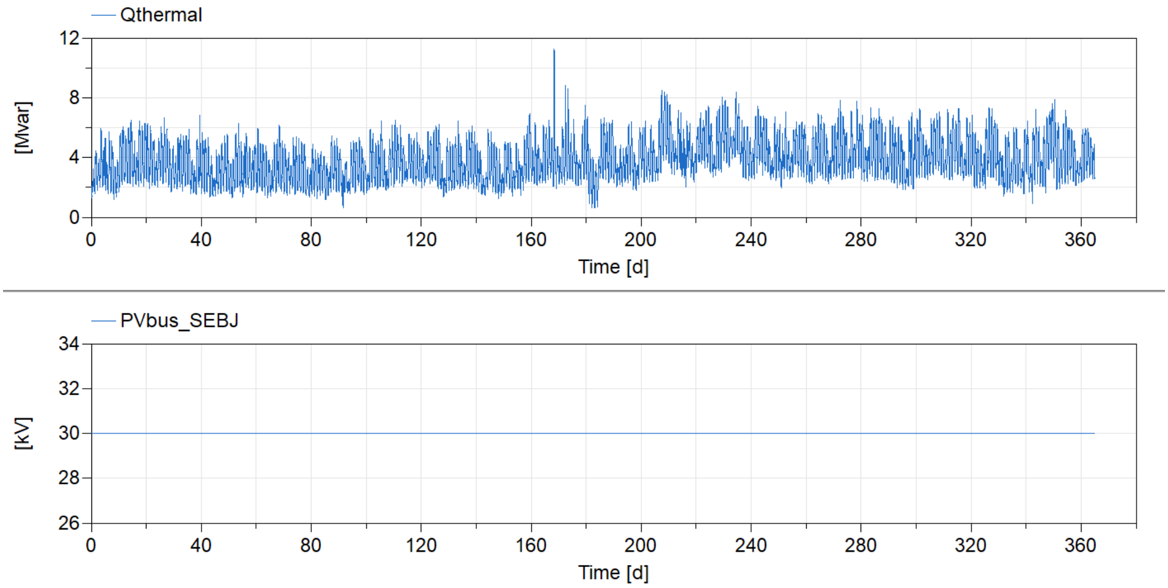

Figure 18: Reactive power (top) and voltage magnitude (bottom) at the bus connected to Belo Jardim

4.2.2 Ameland LH Island

4.2.1.1 Energy System Description – Current Status (Baseline)

The energy system of Ameland is a multi-commodity system: a medium voltage electricity infrastructure, a natural gas infrastructure and a limited heating grid for one of the recreational parks present on the island. The electricity infrastructure and gas infrastructure are interconnected to the mainland grid.

MODEL SETUP

The impact of the IANOS use cases is mainly on the electricity infrastructure as a result of electrification of heat demand, electrification of the gas production

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platform. The level of detail to describe the energy system is chosen to be the medium voltage grid, since the impact of the use cases can be determined from the effects on the medium voltage transformers (MSR) on the island. In Figure 19, the island's MSRs are shown as red squares. In that same figure the area that is logically connected to the MSRs is shown as well (MSR area, in a Voronoi diagram style). A meshed network infrastructure connects the MSR to each other, as well as the redundant connectivity to the mainland connects the island to the mainland (both not shown).

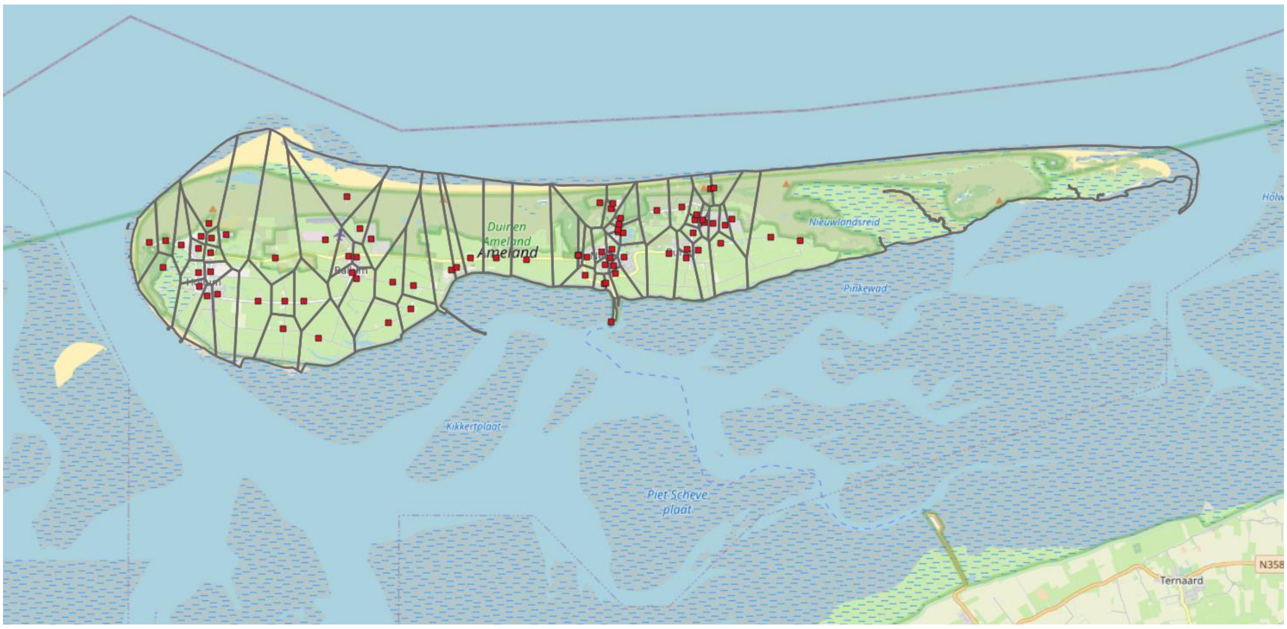

Figure 19 Medium voltage transformer infrastructure on Ameland (MSR, red squares). The connected areas to the MSRs are shown. Connections between the MSRs and to the mainland are not shown here.

To be able to set up the simulation model the proper *assets* need to be identified, together with all the dimensioning parameters, and the *energy related data* in terms of volumes, hourly profiles. Spatial information combines assets, infrastructures and energy related data.

Input Data

Energy Related Data

Since it is necessary to simulate the energy system on MSR level, on an hourly basis the data needs are determined on a spatial level (MSR) and temporal level (per hour). For that purpose, on the level of MSR-area the following data has been gathered:

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- Baseload aggregated hourly electricity profile of every MSR (acquired from DSO), including dimensioning parameters such as nominal capacity (kVA)
- Aggregated heating demand in the area (energy volumes, CBS data)
- Normalized hourly profiles of heating demand for different types of buildings (houses vs businesses)
- Type and specifications of production assets that are connected (PV parks, Solar PV, …)
- Type and specifications of heating producing assets (especially hybrid heat pumps since they require electricity)

Spatial linking of data.

The data acquisition requires the combination of different data sets from different origin (i.e. historic statistical data (CBS), infrastructure data with geo spatial information (DSO), generated profiles (e.g. solar, MSR baseloads) or measured statistical profiles (NEDU) and location data of assets (municipality of Ameland). A number of these sets are combined using geo spatial analysis. For example: CBS (statistical energy) data is based on a zipcode level, DSO data is on a MSR level, network infrastructure is based on physical dimensions, and so on. QGIS (REF) has been used to perform the geo-spatial mapping between these different levels of spatial granularity.

System Assets applicable for the baseline

Below the assets are listed that are installed at the start of the project. When modelling and simulating the use cases of IANOS, at a next iteration of this document, the list of relevant assets will be much more extensive. New assets will be added to the system and more dynamic behaviour is introduced with the iVPP. But for the baseline the following assets are part of the system:

- Transport infrastructures
    - Electricity transport infrastructure consists of all the connections between the MSRs and the connection to the mainland
    - Gas infrastructure. Included logically to see the effect (later on) when the use cases are in place

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- Limited heating grid for a recreational park
- 60+ Medium voltage transformers (MSR)

- (Renewable) production assets
  - A large PV park at the airstrip
  - Note that Ameland does not contain large (fossil) production plants due to the connectivity with the mainland
- Conversion assets
  - Hybrid Heat pumps (130+, different brands and types), at specific building/house locations around the island
  - Gas boilers (connected to the gas infra), logically grouped
  - NAM gas production platform (uses upstream gas for conversion to electricity, a local system. This platform will be connected to the island electricity system in one of the upcoming use cases)
- Demand assets
  - Demand electricity per MSR area
  - Heat demand per MSR area
  - Electric transport (busses, vehicles, bikes)

Note that no storage assets are currently present in the system. Due to the mainland connection the use of storage is not required from a technical point of view.

As an example, Figure 20 shows an indication of the locations for a number of hybrid heat pumps (blue, red and green circles), together with MSR areas (Voronoi diagram) and MSRs in that area (red squares).

Figure 20 Detail of hybrid heat pumps (circles) in relation to MSR areas (Voronoi diagram) and MSR (squares)

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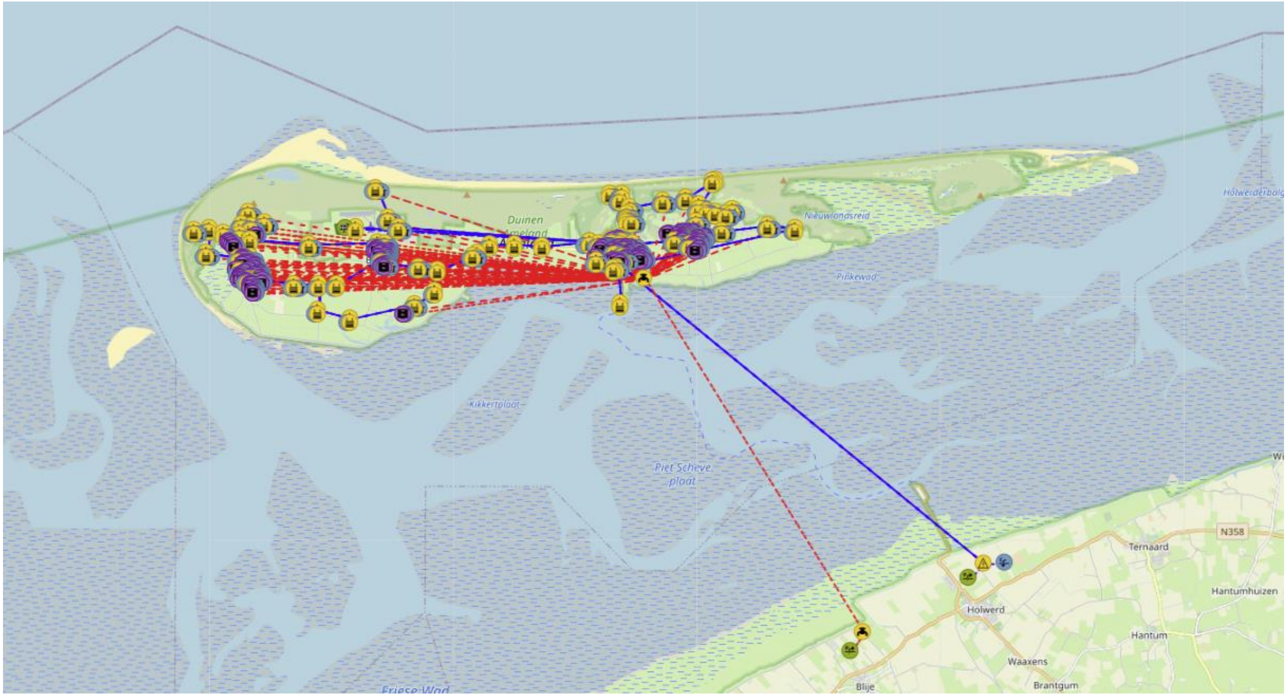

Figure 21 ESDL model of Ameland baseline - detailed

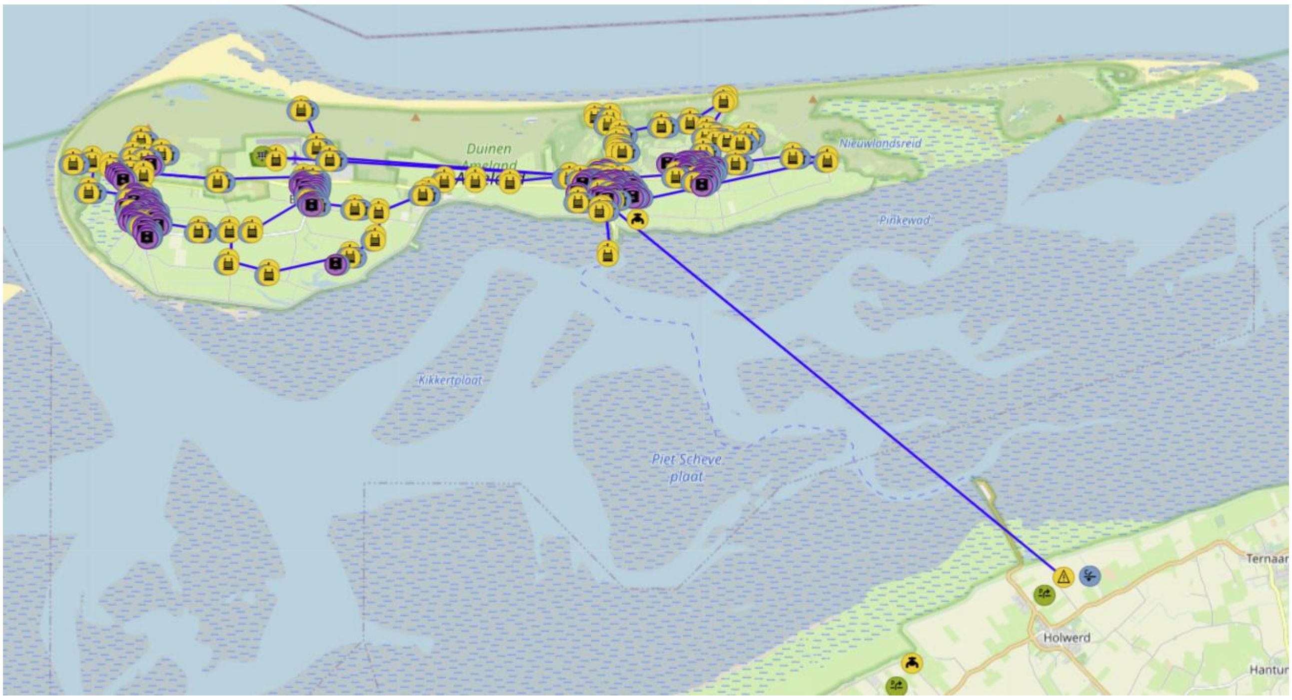

Figure 22 ESDL model of Ameland baseline - electricity network graph

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Figure 23 ESDL model of Ameland baseline - electricity network graph focused

ESDL model description

Based on the gathered data, a simulation model of the energy system is developed using Energy System Description Language (ESDL) and the toolsuite it encompasses. For more information about ESDL Toolsuite, refer to the online documentation[2]. Figure 21 shows a detailed ESDL model of the island in MapEditor (a graphical user interface used to visualize and manipulate ESDL models) as defined in the baseline, with all its connections and energy assets. The red dashed lines indicate logical gas connections between Ameland's gas consumption assets and the mainland gas connection. Please note that this model does not include the actual physical infrastructure, such as pipes. The blue connections indicate the graph connections between different island's MSRs, which can be seen in more detail in Figure 22. Again, this model does not show the physical cables on the island. Figure 23 shows the focused view of one of the island's areas.

As the model consists of a large number of assets, a script is developed that generates this model and adds the data associated to each of the assets. Ameland island has a gas and an electricity connection to the Dutch main grids, through which these commodities are imported, as needed. The energy assets modelled on the island itself are considered to be a part of the local model, while everything

[2] https://energytransition.gitbook.io/esdl/

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coming from and to the mainland is import and export, respectively. The model consists of network assets (yellow icons), which model the commodities transportation, such as transformers, production assets (green icons), consumption assets (blue icons) and conversion assets (purple icons), which convert one commodity to another (e.g., a gas heater). This can be seen in more detail in Figure 23. To get an insight into the effects of different interventions on network energy flows, island's medium voltage transformers and (individual and aggregate) assets connected to them are modelled, as well as the network lines connecting different transformers.

All the individual hybrid heat pumps currently installed on the island are modelled, and connected to their appropriate transformer. Attached to every transformer is its baseload profile, representing the aggregate electricity consumption in the area connected to the transformer, while the electricity demand from hybrid heat pumps is modelled separately. This demand is determined by ESSIM, such that the electrical part of the hybrid heat pump is used to its full capacity to meet the heating demand of a building. Whenever the electrical part is insufficient to meet the demand, the gas part of the hybrid heat pump is turned on.

Furthermore, aggregate heating demand per area connected to a specific transformer is modelled, and connected to Ameland's gas grid. Each of these demands represent aggregate heating demand of a specific area in Ameland, excluding that of the houses that have a hybrid heat pump.

Finally, with respect to local energy resources, the 6 MWp solar park close to Ameland's airport is modelled, as well as the 1 MWp residential rooftop PV panels, distributed over the island.

Simulation results

This section presents ESSIM simulation outcomes for IANOS Ameland LH baseline. These outcomes show network balances for each of the energy carriers (electricity, heat and gas), on an hourly basis, for a period of one year. Energy assets and their aggregate yearly production or demand are shown on the right-hand of the dashboard, while the graphs visualize hourly values. Energy production is indicated by a negative sign, while energy demand is indicated by a positive sign.

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The simulation is run for every hour for the whole period of 2019, when the baseline is set and for which data is available (i.e., the simulation timestamp is one hour). The following subsections describe the simulation results for different commodities in the Ameland baseline model.

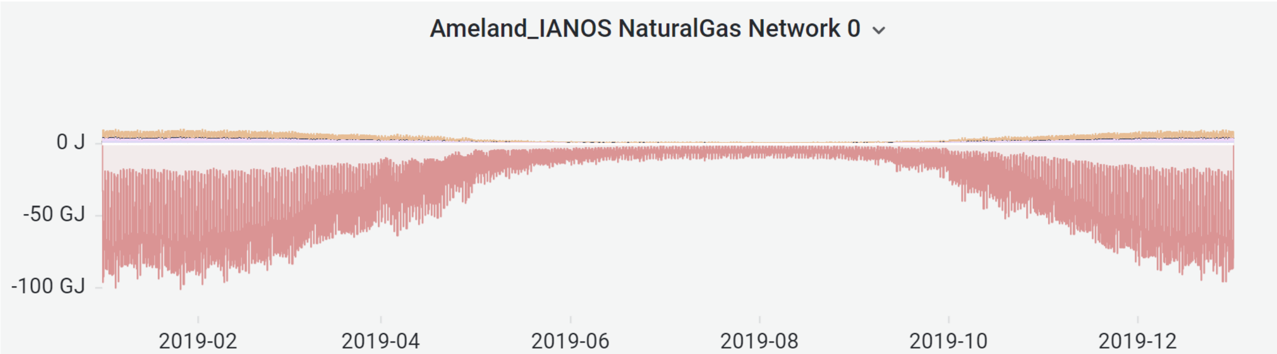

Figure 24 Natural gas network simulation results in joules – all the assets

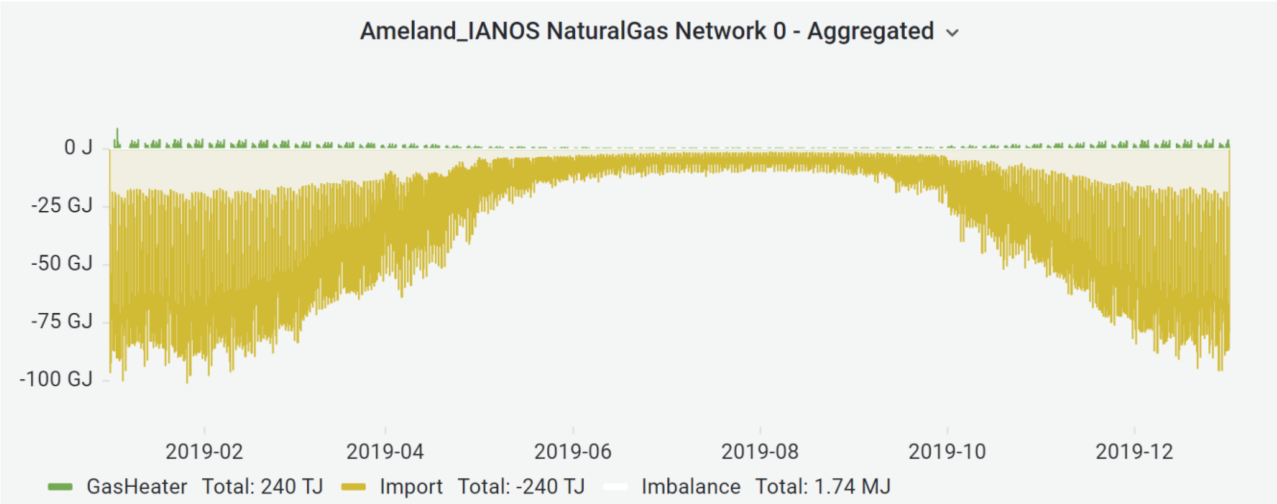

Figure 25 Natural gas network simulation results in joules– aggregated

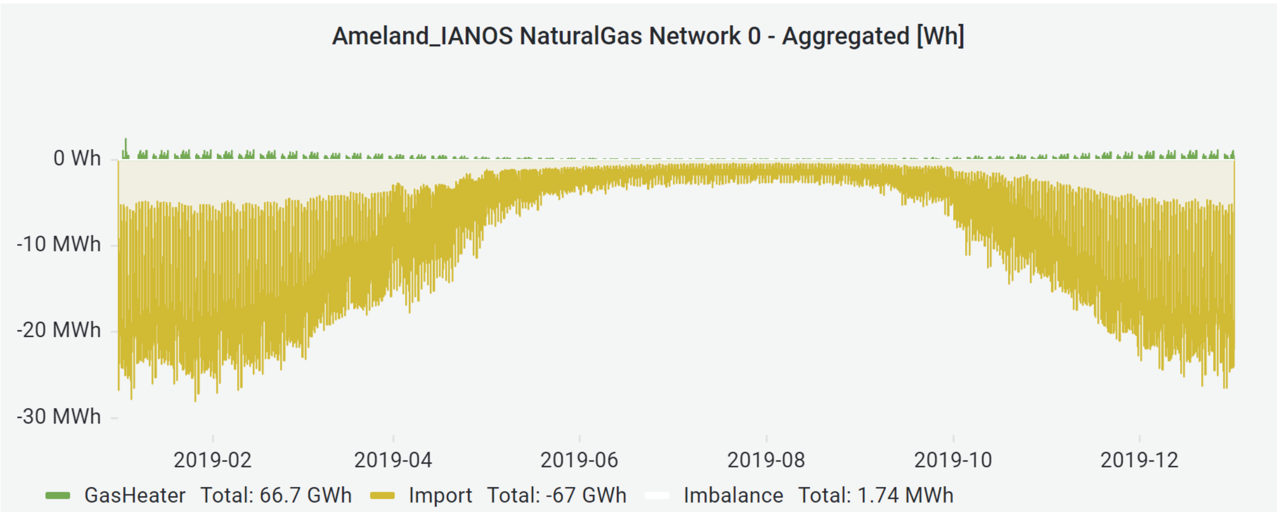

Figure 26 Natural gas network simulation results in watt-hours – aggregated

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Figure 24 shows the simulation results for the natural gas network of Ameland, including all of its assets. To get a better insight into total gas demand and gas import of the island, Figure 25 and Figure 26 show the aggregated values in joules and watt-hours, respectively. The total gas import amounts to 240 TJ (67 GWh).

Ameland electricity network

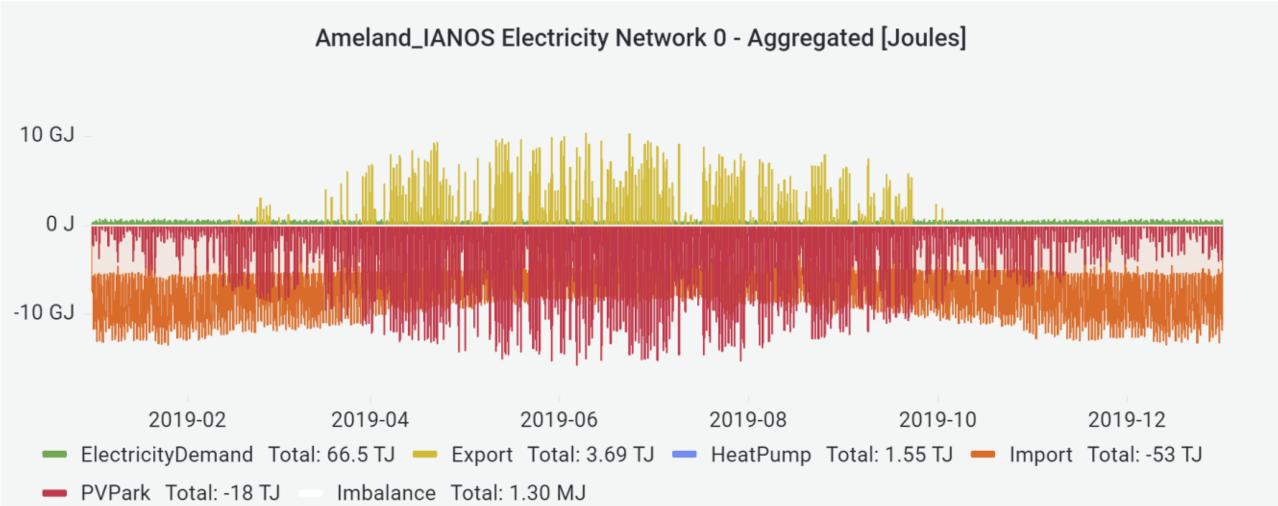

Figure 27 Electricity network simulation results in joules – aggregated

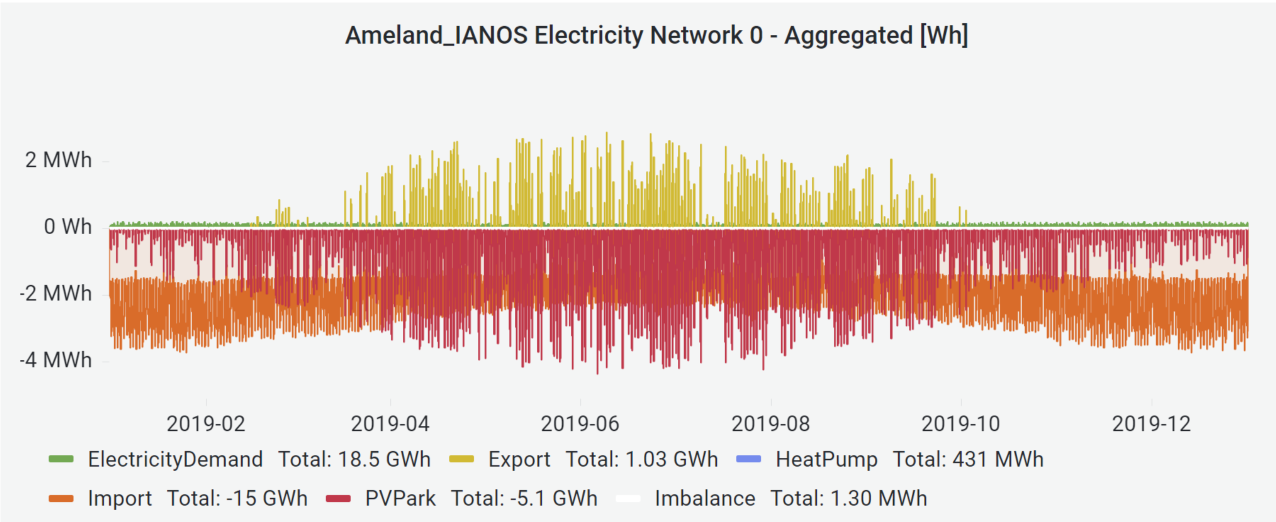

Figure 28 Electricity network simulation results in watt-hours – aggregated

Figure 27 and Figure 28 show the simulation results for Ameland's electricty network in joules and watt-hours, respectively. The total electricity demand on an MSR level (excluding electricity demand from hybrid heat pumps) is 66.5 TJ (18.5 GWh). Note that this number also accounts for rooftop PV production connected to the MSRs that is used to meet a fraction of the demand or is exported if in excess. Electricity demand from the hybrid heat pumps is 1.55 TJ (431 MWh),

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amounting to a total of 68.05 TJ (18.9 GWh) electricity demand on the island. When the demand met by the rooftop PV production (850 MWh) is also accounted for, the total electricity demand is 19.78 GWh. The total local electricity production comes from the 6MWp PV park and 1MW 400 rooftop PV installations, amounting to a total of 21.1 TJ (5.95 GWh) PV production. The rest of the electricity is imported from the mainland, amounting to 53 TJ (15 GWh). There are 3.69 TJ (1.03 GWh) of electricity export, coming from the large 6MWp PV park. Figure 29 shows the transport flows of Ameland's electricity network, including all its assets.

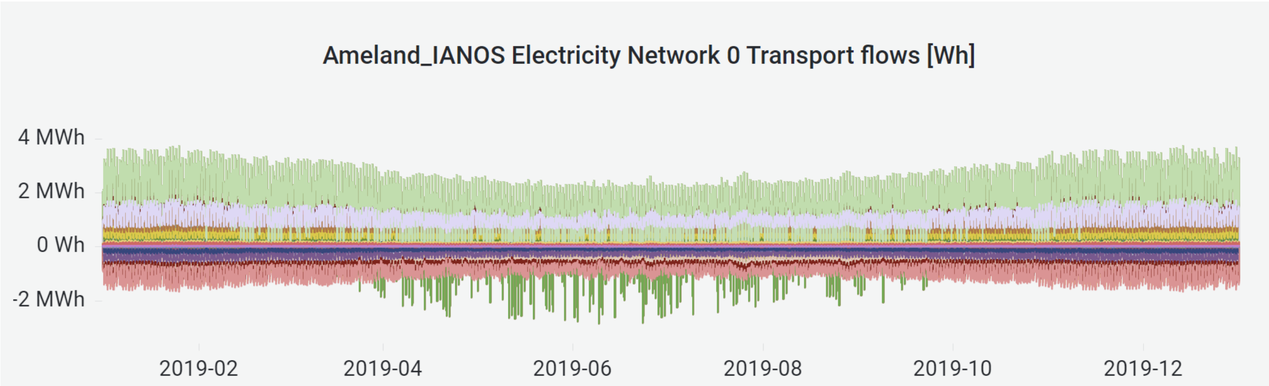

Figure 29 Electricity network transport flows in watt-hours – all the assets

Figure 30 shows the load duration curve of the cable connecting Ameland and the mainland. As seen in the graph, Ameland imports its electricity for most of the year, while there is a short period of time during which there is electricity export to the mainland grid.

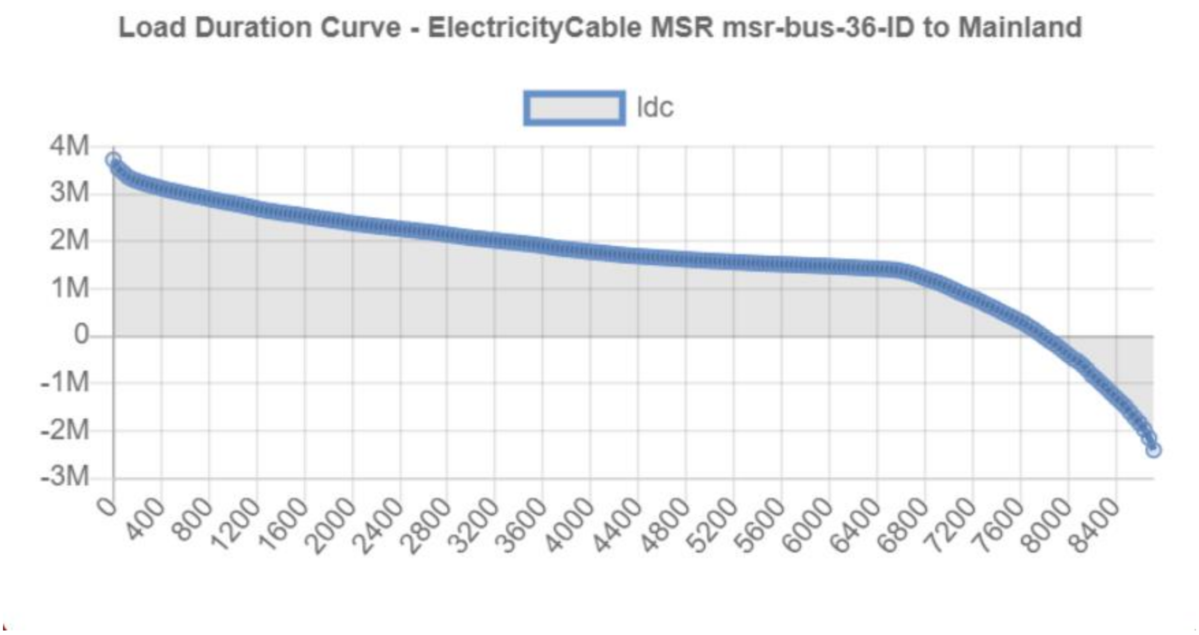

Figure 30 Load duration curve of the mainland cable

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Figure 31 focuses on the transport flows of MSR 80 which has the highest number of hybrid heat pumps connected, namely 14. This transformer has a capacity of 400 kW. The simulation results show that the combined transformer load (consisting of the electricity base load and the electricity demand of the hybrid heat pumps), the load never exceeds 250 kW, and with that its limit.

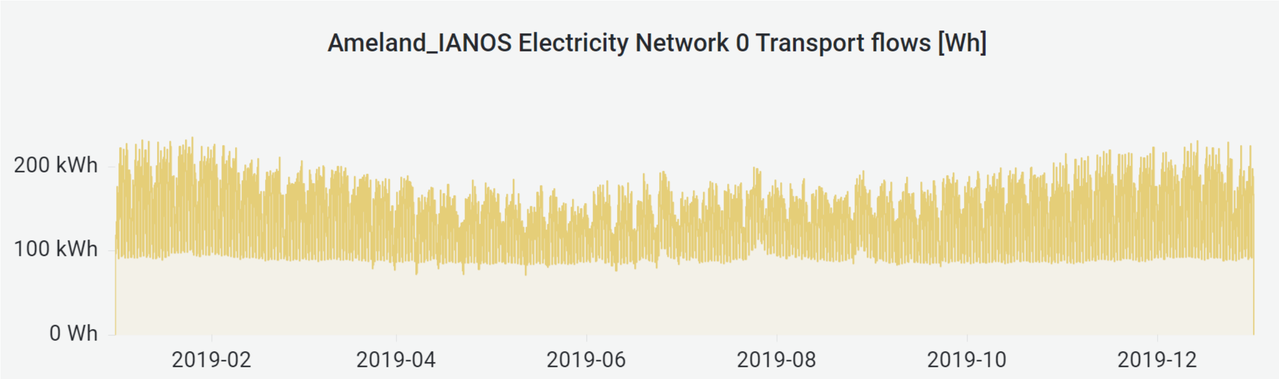

Figure 31 MSR 80 transport flows in watt-hours

Key Performance Indicators

This section presents the simulation results as a number of Key Performance Indicators (KPIs). The following KPIs are calculated: RES Generation, Degree of energetic self-supply by RES, kWp photovoltaic installed per 100 inhabitants, Primary Energy Demand.

RES Generation

In Ameland baseline, the local RES production comes from the 6 MWp PV park and 1 MWp rooftop PV installations and is applicable to the electricity energy commodity only.

PV Park production = 5.1 GWh

Rooftop PV production = 850 MWh

Gres = 5.95 GWh

G_{res} = total energy generated by RES (GWh/year)

Degree of energetic self-supply by RES

The total simulated electricity demand (excluding hybrid heat pump demand) is decreased by the amount of rooftop PV production, as this is used to meet a fraction of the demand. This information is provided by the MSR baseload profiles

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(see section Energy Related Data). Therefore, to calculate the total electricity demand, the total rooftop PV production and the demand of the hybrid heat pumps are added to the simulated electricity demand.

Total electricity demand = Total MSR baseload electricity demand + rooftop PV production + hybrid heat pump demand

Total electricity demand = 18.5 GWh + 0.85 GWh + 0.431 GWh = 19.78 GWh = 19780000 kWh

Production = PV Park + Rooftop PV = 5.1 GW + 0.85 GWh = 5.95 GWh = 5950000 kWh

$$DE_E = \frac{LPE_E}{EE_C} \cdot 100$$

$$DE_E = \frac{5950000}{19780000} \cdot 100 = 30.08$$

- DE_E = Degree of electrical energy self-supply based on RES
- LPE_E = Locally produced electrical energy [kWh/year]
- EE_C = Electrical energy demand (simulated) [kWh/(year)]

kWp photovoltaic installed per 100 inhabitants

According to the statistical data, in 2019 there were 3673 inhabitants on Ameland[3], the year for which the baseline is established. As stated in the previous KPIs, the local PV production comes from the 6 MWp PV park and 1 MWp rooftop PV.

kWp of photovoltaic installed in area = 6000 kWp + 1000 kWp = 7000 kWp

$$PVInt = \frac{PV_{installed} * 100}{N_{inh}}$$

$$PVInt = \frac{7000 * 100}{3673} = 190.58\ [kWp]$$

- $PVInt$ = Interpolated value of kW_p of PV installed per 100 inhabitants
- $PV_{installed}$ = kW_p of photovoltaic installed in area/sector
- N_{inh} = Number of inhabitants in area/sector

[3] https://www.cbs.nl/nl-nl/visualisaties/dashboard-bevolking/regionaal/inwoners

Primary Energy Demand

To calculate the primary energy demand (simulated), the following primary energy factors are used:

$PEF_{gas} = 1.08$

$PEF_{electricity} = 2.04$

$$PE_d = GE_d \times PEF_G + EE_d \times PEF_E$$

$$PE_d = 67000000 \times 1.08 + 19780000 \times 2.04 = 112711200\ [kWh]$$

- $\mathrm{PE_d}$ = Primary energy demand (simulated) [kWh/(year)]
- $\mathrm{GE_d}$ = Gas energy demand (simulated) [kWh/(year)]
- $\mathrm{EE_d}$ = Electrical energy demand (simulated) [kWh/(year)]
- $\mathrm{PEF_G}$ = Primary energy factor for natural gas
- $\mathrm{PEF_E}$ = Primary energy factor for electrical energy

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5. Conclusions

The opportunities for the energy transition of IANOS Lighthouse Islands (LHs) 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 LHs 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.

IANOS LHs aim to test specific use cases and solutions, implemented in the project, for replication or deployment at a larger scale in order to achieve their sustainability goals. A tailored Master Use Case for each LH island, 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.

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, LHs 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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