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Smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands

D6.4 – Replication plans for the Follower Islands

Lead partner: Technical University of Crete - TUC

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[1] Dissemination level: **PU** = Public, PP = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)

[2] Creation, modification, final version for evaluation, revised version following evaluation, final

Executive summary

This deliverable outlines the comprehensive replication plans for the Follower Islands, Crete and the Western Isles as part of the ROBINSON project, funded by the European Union's Horizon 2020 Research and Innovation Programme. The primary goal of the ROBINSON project is to demonstrate the integration of local renewable energy sources (RES) and innovative energy storage systems to create flexible, secure, and cost-efficient energy solutions. The replication plan builds on the successful demonstration of these solutions on the Lighthouse Island of Eigerøy and adapts them to the unique conditions of the Follower Islands. The replication plan provides a roadmap for scaling ROBINSON's solutions to the distinct socio-economic and environmental contexts of Crete and the Western Isles, with particular attention to local energy demands, renewable energy potentials, regulatory environments, and stakeholder engagement strategies. The deliverable is structured into several key sections:

- **Challenges to the Replication of ROBINSON Concepts:** This section identifies and addresses the main technical, regulatory, and socio-economic barriers that could hinder the replication process. Challenges such as regulatory frameworks, grid integration, seasonal energy demand fluctuations, and financing constraints are discussed in detail. Proposed strategies for overcoming these barriers include enhancing policy support, optimising energy storage systems, and creating business models tailored to local needs.
- **Technical and Economic Feasibility:** A crucial aspect of this replication plan is its detailed feasibility analysis. This includes assessments of the renewable energy potential for each island, focusing on solar, wind, and biomass resources, as well as the integration of energy storage solutions. The section also provides a comprehensive analysis of the energy solutions' costs and benefits, long-term sustainability, and scalability. For both Crete and the Western Isles, the report highlights the economic viability of deploying renewable energy systems and their potential to reduce dependency on fossil fuels significantly.
- **Stakeholder Engagement and Involvement:** Active and early stakeholder engagement is critical to the replication plan's success. This section outlines how local governments, communities, businesses, and technical experts will be involved in the planning, decision-making, and implementation stages. Specific engagement strategies are discussed for each island, with an emphasis on creating energy communities that ensure broad participation and buy-in from local populations.
- **Replication Roadmap Development:** This section presents the step-by-step roadmap for implementing ROBINSON's solutions in Crete and the Western Isles. It includes the design and optimisation of energy systems, the adaptation of technologies to local conditions, the identification of critical milestones, and the allocation of roles and responsibilities to stakeholders. The roadmap aims to provide a flexible but structured approach, ensuring the replication process is efficient, scalable, and adaptable to unforeseen challenges.
- **Specific Replication Plans for Crete and Western Isles:** Tailored replication plans are presented for each island, considering their unique geographic, economic, and energy infrastructure characteristics. For Crete, the replication focuses on harnessing solar and biomass resources, while addressing community level energy needs. For the Western Isles, the impact of ROBINSON's EMS to increase local energy resilience and efficiency are emphasised.
- **Risk Management and Mitigation Strategies:** This section provides an introductory risk management framework to ensure the long-term success of the replication efforts. It identifies potential risks such as regulatory changes, financial challenges, and technical integration issues

and offers relevant mitigation strategies that can be applied throughout the project's implementation phase.

- **Monitoring, Evaluation, and Continuous Improvement:** The deliverable also introduces a monitoring and evaluation (M&E) framework to track the progress of the replication efforts. Key performance indicators (KPIs) are established to measure the success of the energy solutions in terms of cost savings, carbon emissions reductions, energy efficiency, and stakeholder satisfaction. The feedback loops in this framework allow for continuous adjustment and improvement of the replication plans.

This deliverable presents a comprehensive approach to replicating the ROBINSON energy solutions across diverse island contexts. By addressing the replication process's technical, social, and economic aspects, the plan provides a scalable and adaptable framework for deploying sustainable energy solutions that meet the specific needs of island communities.

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List of abbreviations

CHP – Combined Heat and Power

CO2 – Carbon Dioxide

DC – Direct Current

EIA – Environmental Impact Assessment

EMS – Energy Management System

EU – European Union

FIRP – Follower Islands Replication Plans

GHG – Greenhouse Gases

GRP – Generic Replication Plan

HVDC – High Voltage Direct Current

IPTO – Independent Power Transmission Operator

kWh – Kilowatt-Hour

LCA – Life Cycle Assessment

LHV – Lower Heating Value

MES – Multi-Energy System

MWh – Megawatt-Hour

NECP – National Energy and Climate Plan

NIIs – Non-Interconnected Islands

PPC – Public Power Corporation

PV – Photovoltaic

PV-T - Photovoltaic and Thermal Collector

RES – Renewable Energy Sources

SRA – Sustainability & Replicability Analysis

TYNDP – Ten-Year Network Development Plan

WtE – Waste-to-Energy

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1. Introduction

Replication is a key element of the ROBINSON concept, and this is reflected in its strategy of having two follower islands (Crete and Western Isles), replicating solutions demonstrated and validated at the Eigerøy island. The main objectives of WP6 (and especially of Task 6.4) were to produce a Generic Replication Plan (GRP) and guidelines for applying and upscaling ROBINSON solutions as well as specific detailed Follower Islands Replication Plans (FIRP), by adapting and applying the strategy described in the DoA, Section 1.3.4. To fulfil the objectives of WP6 more methodically, comprehensively and efficiently, the Project's Work Plan outlined an interactive process of gradual build-up and refinement of the FIRP, started by M6 (D1.1, Islands documentation and mapping reports) and continuing to M48. Thus, according to the DoA:

"a continuous feedback process with the previous technical WPs was envisaged within this task. This feedback was facilitated and materialized by including a devoted section regarding the replication strategy in all the technical deliverables."

An essential requirement of this process was that almost any technical deliverable produced by the Project should also include a replication section that provided (or summarized from its other sections) technical information about how the solutions, methods, data and knowledge developed and described in that deliverable could be applied to the replication of ROBINSON. This section described any specificities of the follower islands, application issues, configuration/sizing/customization parameters and options, favourable conditions and constraints, technical/organizational/ business/ regulatory requirements, things to do or avoid, recommendations and application guidelines.

Although this WP6 process focused especially on the follower islands and their replication plans, its scope was not limited to them. It encompassed replication in other islands (or islanded areas), in concert with networking and external stakeholders' engagement in T7.3-7.4.

1.1. Aim of the task

The primary aim of Task 6.4 was to create detailed and comprehensive replication plans for the two Follower Islands—Crete and the Western Isles—building upon the technologies and practices successfully demonstrated at the Eigerøy site. This task ensured that the ROBINSON energy solutions could be scaled and adapted to these islands by considering their local contexts. The replication process involved analysing the islands' existing energy infrastructure, the role of renewable energy sources (RES) in the energy mix, current and future energy needs for residential and industrial sectors, and the interoperability of different energy systems.

One critical aspect of Task 6.4 was to identify the most suitable technological solutions for these islands based on the economies of scale and innovations developed within the ROBINSON project. Another key priority was integrating an Energy Management System (EMS) along with technical solutions. The EMS was developed and simulated to manage the islands' Distributed Energy Resources (DERs) while considering environmental conditions, ensuring that the energy system remained efficient, reliable, and resilient.

A Replication Roadmap Tool has been developed to facilitate and streamline the replication process. This tool provided a structured and systematic approach to guide the replication of ROBINSON's

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solutions across different locations. The tool supports decision-makers by helping them identify the best technologies, adapt the solutions to local energy conditions, and develop tailored project plans. Using this tool, stakeholders can ease the process of replicating the technologies from Eigerøy, ensuring that the solutions could be effectively scaled and implemented in diverse environments.

The replication strategy was reinforced by a continuous feedback loop with previous technical work packages (WP2, WP4, WP5), ensuring that lessons learned and technical data from earlier stages of the project were incorporated into the replication plans. TUC was the leader of the overall replication process, providing guidelines during the project's Kick-off meeting and throughout the development of the replication plans. KRITI and CNES supported the creation of the specific replication plans for Crete and the Western Isles, respectively, ensuring that each island's unique energy challenges were addressed and that the replication of ROBINSON's solutions is successful.

1.2. Interactions with other tasks and work packages

The interactive process for gradual development of the FIRPs and the GRP and guidelines was based on the following steps:

1. Each technical deliverable had to include a replication section.
2. Following deliverables had to consider results, especially the replication sections, of previous ones,
3. To facilitate this process and gradually form an outline of the replication plans, WP6 (T6.4) issued **Interim Progress Reports on Replication**
4. These summarized the replication sections of previous deliverables and outlined the progress on the flower islands replication plans.
5. Other WPs and Tasks were invited to comment on these progress reports.
6. Starting also from M13, an **Evidence Base** (**EB**) was developed, with the purpose of convincing for ROBINSON's uptake and facilitating its replication at the follower islands and elsewhere. EB contains selected information from deliverables and progress reports, as well as any additional information collected by WP7.
7. By M30 a **Market Analysis** report for the replication in the follower and other islands had been submitted and incorporated in the FIRPs and the GRP.
8. By M36 a **Business Planning** report for energy systems' management and the formation of energy communities had been submitted and incorporated in the FIRPs and the GRP.
9. By M48 the final replication plans and guidelines have been completed.

The term **Technical Deliverables** was used in this context to denote deliverables directly relevant to the replication of the ROBINSON concept and specifically to the development of the follower islands' replication plans. These were categorized into four categories:

A. Deliverables that describe the selection, configuration, design, application and optimization (in setup or in operation) of ROBINSON system components (e.g. CHP, AD-BES, EMS).
B. Deliverables that describe the composition and setup of the ROBINSON system.
C. Deliverables that describe facts and details for the application of the ROBINSON system and its integration into existing energy systems and their island environments.
D. Deliverables that describe a methodology and/or provide results or information directly usable for developing the replication plans.

According to the above definition:

- **Category A** included deliverables D2.1 (M12), D2.8[3] (M16), D2.9[3] (M16), D2.2 (M24), D2.3 (M24), D3.2 (M24), D2.7 (M29), D2.8 (M16), D2.9 (M16) and D3.3 (M29).
- **Category B** included deliverables D1.3 (M12), D1.4 (M12), D5.1 (M12) and D3.5 (M39).
- **Category C** included deliverables D1.2 (M12), D3.1 (M24), D4.1 (M36), D4.2 (M36) and D4.5 (M48).
- **Category D** included deliverables D1.5 (M24), D7.5 (M24), D5.6 (M24), D5.4[3] (M29), D3.4 (M33), D5.2 (M48), D5.3 (M48), D5.5 (M48), and D5.7 (M48).

Complete lists of technical deliverables, grouped by Work Package number are presented in Figure 1. These deliverables had to include at the end (e.g. as an Appendix) a Replication Section (RSc) describing technically how the concepts and results in the deliverable can be replicated. The section had to contain, at a minimum, a synopsis and conclusion of information selected from other report sections, re-arranged to highlight key implementation/replication issues. To that, additional data, information and knowledge (collected by the respective task but not included in the report), as well as expert advice and recommendations for each case, also had to be complemented. The approach has been partially embraced by our technical partners, presenting specific challenges in consolidating all the information into a comprehensive deliverable.

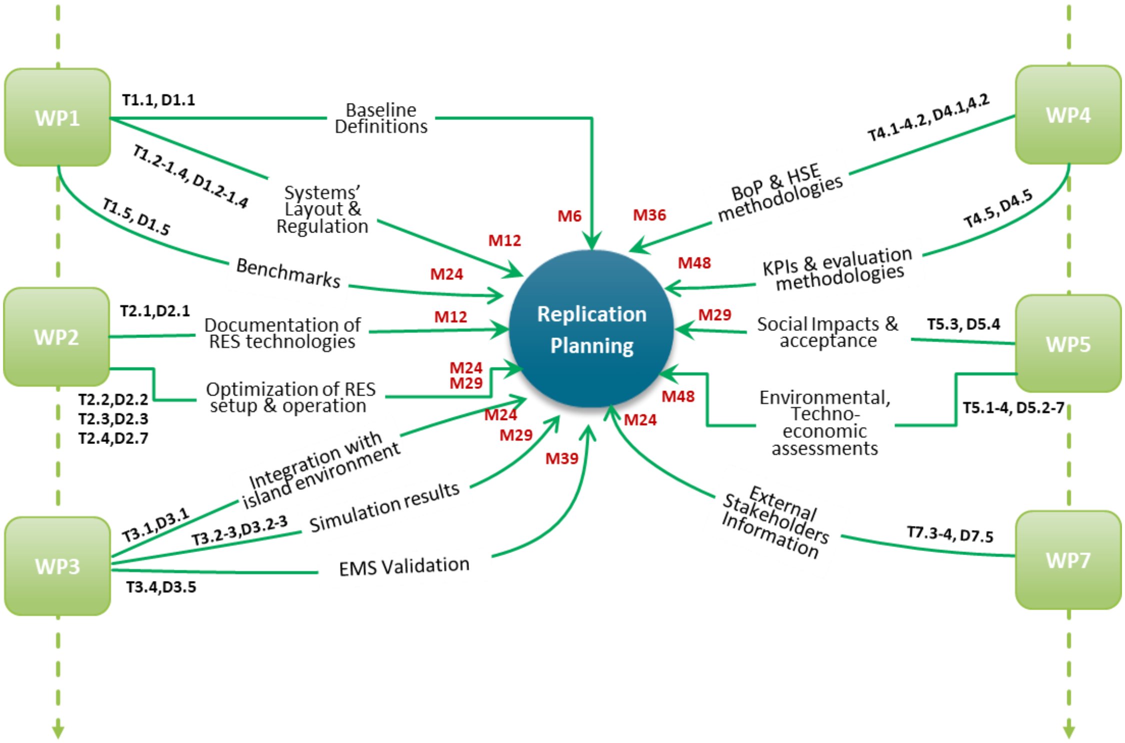

Figure 1: Inputs to replication planning from other WPs.

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[3] D2.2, D2.3 and D5.4 are interim reports summarizing preliminary results. A preliminary version of the replication section may be included in these deliverables, which can be finalized in the corresponding final reports D2.2, D2.3 and D5.5.

1.3. Structure of the Deliverable

This deliverable is connected to task 6.4, "Replication Plans for the Follower Islands", of Work Package 6 (WP6) - Business Planning and Replication. The primary purpose of this deliverable is to provide detailed replication plans for the Follower Islands of Crete and the Western Isles, outlining how the solutions demonstrated in the ROBINSON project can be applied to these islands. Additionally, it offers a generic replication roadmap for applying ROBINSON's solutions to other islands or isolated areas. The deliverable consists of 5 chapters and their subchapters, presented as follows:

- **Chapter 1** introduces the deliverable, its purpose, and objectives. It explains how this deliverable connects with other tasks and work packages and provides an overview of the replication process.
- **Chapter 2** outlines the challenges to replicating the ROBINSON concepts and introduces the Follower Islands, describing also the different replication levels and the replication approach's systematisation, including the development of a replication roadmap.
- **Chapter 3** delves into the feasibility of the replication plan, focusing on the technical, economic, and regulatory considerations for both generic and island-specific replication plans. It discusses the development process of the replication roadmap and highlights the key components necessary for successful replication.
- **Chapter 4** provides detailed replication plans for Crete and the Western Isles. Each section includes an analysis of local energy needs, RES potential, stakeholder engagement, technical solutions, and risk mitigation strategies. The replication plans are tailored to each island's unique conditions and challenges.
- **Chapter 5** summarises the key findings from the replication plans and offers final recommendations for implementing and scaling ROBINSON's solutions across other islands and isolated areas. It also addresses the broader implications for sustainability and replication in different contexts.

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2. Replication Scope

The term "replication" within the context of ROBINSON's Work Package 6 (WP6) refer to a comprehensive approach aimed at adapting and applying the project's innovative energy solutions across different geographical and contextual settings. Replication, as envisioned in WP6, was not a mere duplication of technical solutions but a strategic process involving customization, adaptation, and scaling to ensure that ROBINSON's integrated energy system could be effectively applied in various environments. The concept of replication within WP6 encompassed two key components:

A. **Primary Component: Replication in the Follower Islands**

The fundamental objective of WP6 was the replication of the ROBINSON system, which was initially demonstrated in the "Lighthouse Island." This replication focuses on applying the solutions successfully demonstrated in this initial setting to the two designated "Follower Islands": Crete and the Western Isles. The replication plans for these islands form the cornerstone of WP6's activities. These plans detailed, in technical, social, economic, and business terms, how the ROBINSON solutions could be customized, designed, and implemented on the Follower Islands. This requires a comprehensive assessment of the regional energy demands, prospects for renewable energy, involvement of stakeholders, and necessary infrastructure to guarantee that the solutions are both replicable and customized to the unique circumstances of each island. The goal is to facilitate the transition of these islands to more sustainable and resilient energy systems using the ROBINSON approach.

B. **Secondary Component: Upscaling on the Lighthouse Island and Surrounding Areas**

In addition to the replication on the Follower Islands, there was a supplementary yet strongly encouraged aspect of the replication process. This involved further development, enhancement, and upscaling of the ROBINSON system on the original "Lighthouse Island" where it was first demonstrated. The intention here is to expand the system beyond its initial scope to maximize its impact not only on the Lighthouse Island itself but also in its surrounding areas. This could involve scaling up energy production, integrating additional renewable energy sources, or enhancing the storage and distribution systems to meet broader energy demands. By demonstrating the scalability and adaptability of the ROBINSON system in its original context, this component serves to provide additional evidence of the system's robustness and versatility, thereby strengthening its appeal for replication in other locations.

Finally, a critical responsibility of WP6 is to ensure that the ROBINSON concept is replicable not only on the designated Follower Islands but across a broader European context (Figure 2). This involves supporting the uptake of ROBINSON's solutions in other isolated European communities, ensuring its applicability in diverse geographical and socio-economic conditions. The replication scope extends to a thorough identification of "elsewhere," meaning the careful determination of where, when, and why the ROBINSON system can be successfully replicated. In this light, energy needs, renewable energy resources, regulatory frameworks, and community engagement are key factors that might affect replication feasibility. In addition, the replication scope may include a redefinition of what constitutes an "island' considering, by extension, isolated or semi-isolated inland areas that share similar energy challenges, such as lack of connection to larger, more stable energy grids. These areas, often called "islanded" regions, face energy vulnerabilities and could benefit significantly from the ROBINSON approach. WP6 aims to ensure that ROBINSON's innovative energy solutions can contribute to Europe's broader energy transition and achieve its climate goals.

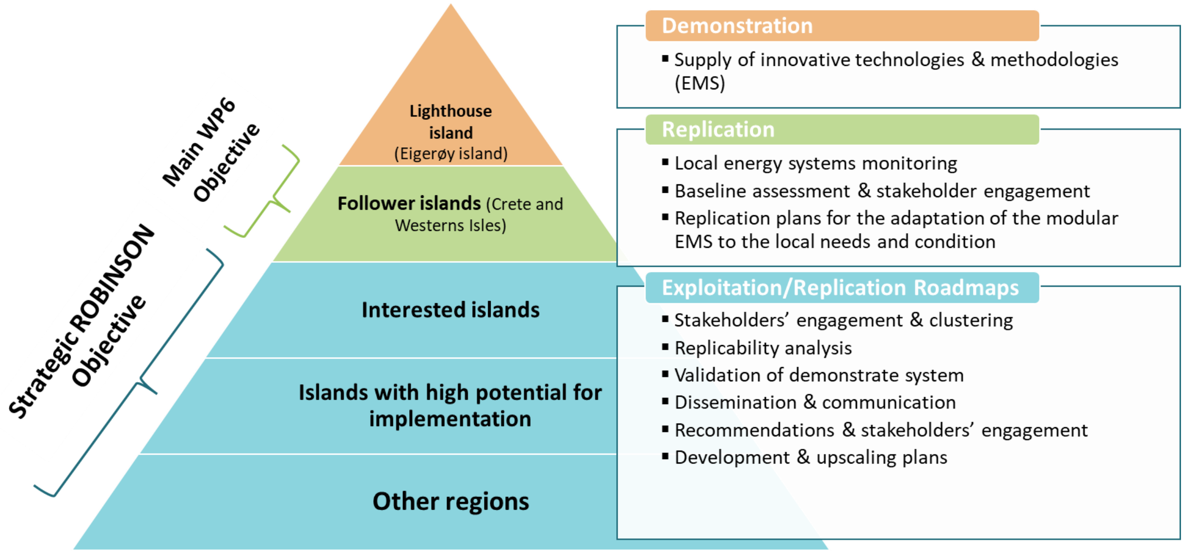


Figure 2: Replication strategic objectives

2.1. Challenges to the replication of ROBINSON concepts

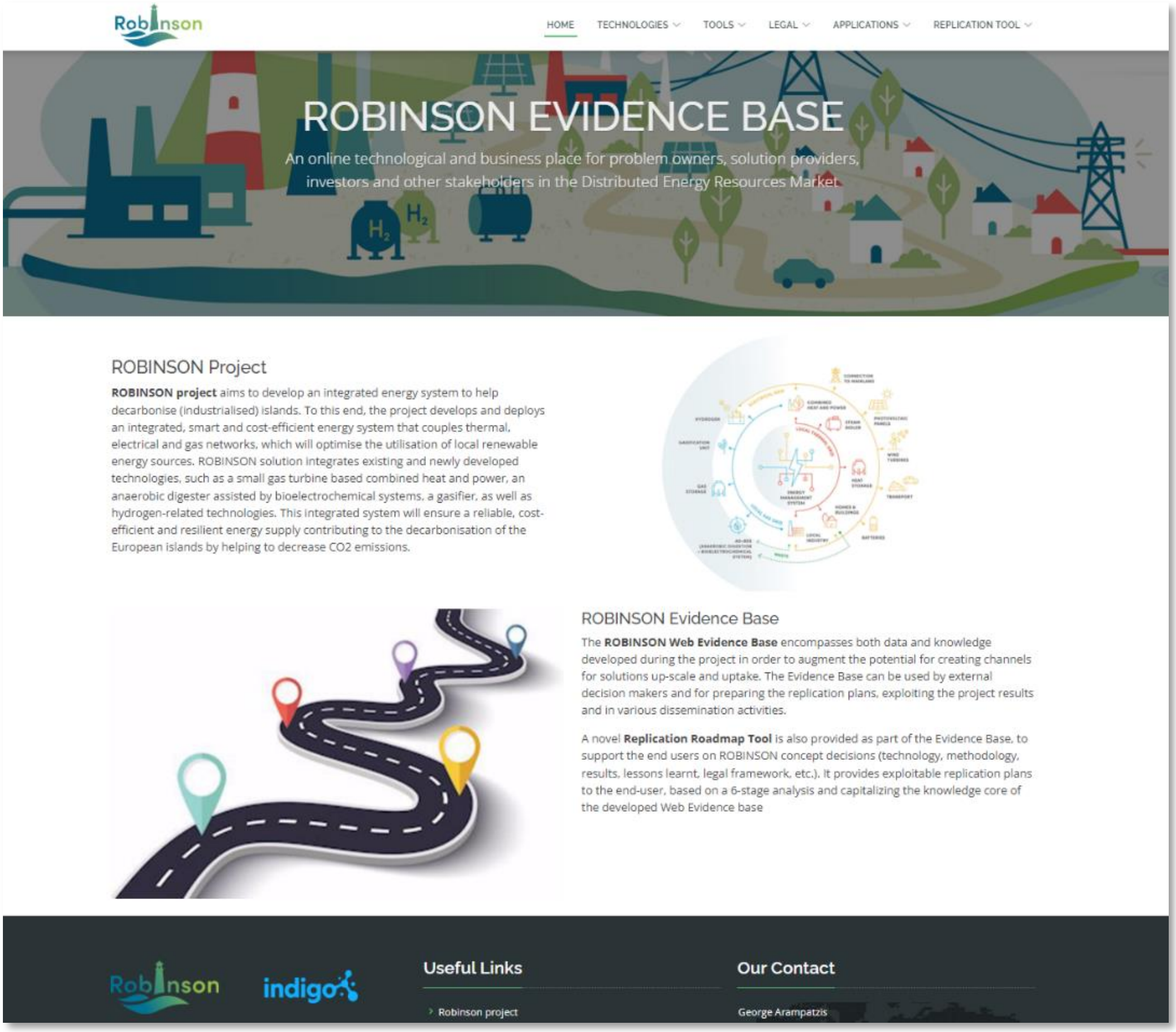
The replication of the ROBINSON concepts faced several key challenges that had to be addressed to ensure the successful adaptation and implementation of the solutions in new locations. One of the primary challenges was providing comprehensive evidence and clear guidelines to demonstrate the replicability of the ROBINSON solutions. Decision-makers and stakeholders require robust data to understand how these energy solutions can be effectively applied to different geographical, technical, and socio-economic conditions. To address these challenges, it was crucial to offer ongoing support to the relevant actors responsible for implementing the replication process. This included not only providing technical knowledge but also assisting with regulatory, financial, and community engagement aspects. Successful replication requires collaboration across various sectors and the ability to tailor solutions to the specific needs and conditions of the target regions. Motivated by these challenges, TUC developed two novel tools to facilitate the replication process:

A. **Flexible Digital Evidence Base**: This tool encompasses a wide range of information, including technical designs, implementation plans, data, and knowledge produced within the ROBINSON project. The evidence base (Figure 3) centralizes all necessary resources to facilitate the scaling up of solutions. External decision-makers can use this resource to gain insights and guidance on how to prepare replication plans, thus simplifying decision-making and enhancing the potential for successful implementation.

B. **Replication Roadmap Tool**: To ease the replication process, a Replication Roadmap Tool has been developed. This tool offers a structured and systematic approach to guide stakeholders through the entire replication process. By providing step-by-step instructions, it helps decision-makers identify the most suitable technological solutions, adapt them to local conditions, and develop tailored project plans.

C. **Integration of Open Tools, Methodologies, and Legislation repository**: In addition to the internal tools, several open-access resources, methodologies, and legislative repository interlinked with the Replication Roadmap Tool. These include public technological tools and guidelines that offer external support for decision-making. By leveraging this wealth of information, the roadmap tool ensures that replication efforts are aligned with existing best practices and legal requirements, further increasing the feasibility and success rate of the replication process.

Together, these tools provide critical support to overcome the technological, regulatory, and financial challenges of replicating ROBINSON's energy solutions, ensuring that the process is more efficient, adaptable, and scalable across diverse European regions.



ROBINSON EVIDENCE BASE

An online technological and business place for problem owners, solution providers, investors and other stakeholders in the Distributed Energy Resources Market

ROBINSON Project

ROBINSON project aims to develop an integrated energy system to help decarbonise (industrialised) islands. To this end, the project develops and deploys an integrated, smart and cost-efficient energy system that couples thermal, electrical and gas networks, which will optimise the utilisation of local renewable energy sources. ROBINSON solution integrates existing and newly developed technologies, such as a small gas turbine based combined heat and power, an anaerobic digester assisted by bioelectrochemical systems, a gasifier, as well as hydrogen-related technologies. This integrated system will ensure a reliable, cost-efficient and resilient energy supply contributing to the decarbonisation of the European islands by helping to decrease CO2 emissions.

ROBINSON Evidence Base

The **ROBINSON Web Evidence Base** encompasses both data and knowledge developed during the project in order to augment the potential for creating channels for solutions up-scale and uptake. The Evidence Base can be used by external decision makers and for preparing the replication plans, exploiting the project results and in various dissemination activities.

A novel **Replication Roadmap Tool** is also provided as part of the Evidence Base, to support the end users on ROBINSON concept decisions (technology, methodology, results, lessons learnt, legal framework, etc.). It provides exploitable replication plans to the end-user, based on a 6-stage analysis and capitalizing the knowledge core of the developed Web Evidence base

Figure 3: The ROBINSON web Evidence base (https://robinson-eb.eu/)

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3. Replicating ROBINSON's solutions

3.1.1. Levels of replication

Following the description of the scope of replication within the ROBINSON project, Chapter 3 focuses on the specific challenges involved in replicating the ROBINSON solutions. This chapter explores the technical, regulatory, and socio-economic barriers that were addressed to ensure the successful application of these solutions on the Follower Islands and in other regions. Although WP6 focused on the issues and plans concerning the replication of ROBINSON solutions in the two Follower Islands, the overall ROBINSON approach to replication (to which other WPs contributed, with WP6 responsible for their integration and application) extended across two levels:

A. **At the 1st level, the replicability of ROBINSON solutions was validated**, proving that they could be replicated and were not limited to a one-off solution applicable only to the conditions of the Lighthouse Island. At this stage, the presuppositions, conditions, applicability/feasibility ranges, and constraints were investigated. A concise Sustainability & Replicability Analysis (SRA) was conducted. This analysis consisted of two stages: a techno-economic analysis (covering sustainability, economic feasibility, and technical feasibility) and an internal and external environment analysis, focusing on boundary conditions that could make replication feasible or unfeasible. These factors included existing energy systems, capacity constraints, regulations, social impacts, and the perspectives of different stakeholder groups. An applicability framework was defined as a result of this analysis.
   Most of the base work needed for the SRA had already been carried out in WP3 and WP5, including simulations, technical analysis, specification of solutions, LCA assessment, and economic, social, and environmental sustainability assessments for both the Lighthouse and Follower Islands. Results from WP1, WP4, and WP7 were also utilized. WP6 compounded and extended this base work in the SRA, drawing conclusions regarding the replicability and upscaling of ROBINSON solutions, both in the Follower Islands and beyond.
B. **At the 2nd level, a comprehensive replicability plan was developed** to ensure the successful replication of the ROBINSON solutions, primarily focusing on the Follower Islands. This was the main priority of WP6 while facilitating the broader uptake and replication of ROBINSON solutions across a wide range of practical applications. WP6 developed several replication support tools to support this effort, including an Evidence Base, Business Models, Application Guidelines, and Roadmaps. The Replication Roadmap Tool was crucial in ensuring the scalability of ROBINSON solutions and provided stakeholders with a clear framework for implementation. Additional tools and methodologies for planning replication and upscaling, such as LCA and EMS simulations, were also developed in WP3-5 and incorporated into the Replication Guidelines.

Key SRA results and conclusions, from level I analysis formed the first part of the Replicability Plan, both providing replicability evidence for convincing future stakeholders and providing technical plans, key figures, parameters & options, KPIs, etc.

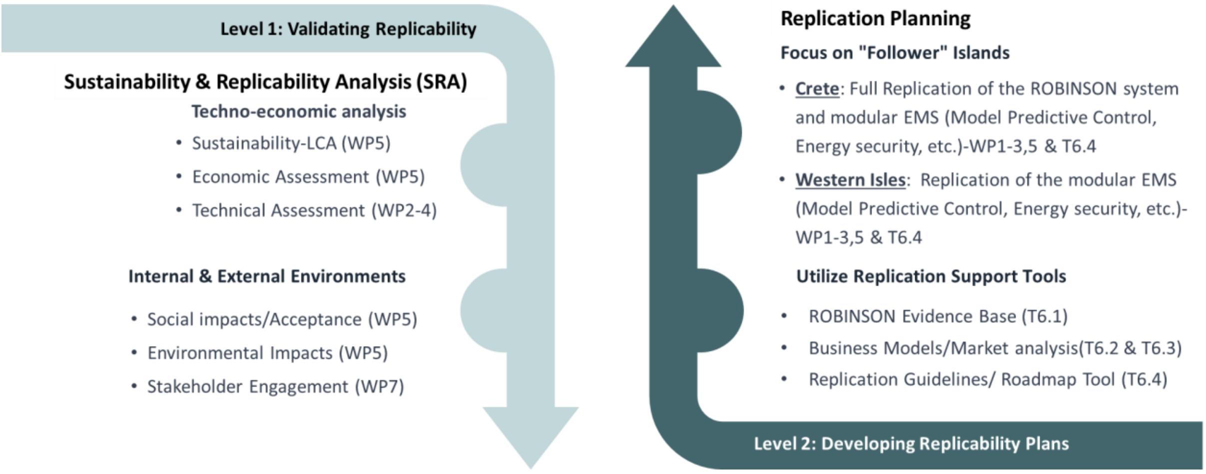


Figure 4: Levels of Replication in the Robinson Project

3.1.2. Systematization of the replication approach

To fulfil the objectives of WP6 and address the main challenges to the replication, an interactive process of gradual build-up of Replication planning has been developed. The steps foreseen in this procedure were:

1. **Provide evidence to convince strategic stakeholders about the replicability of the solutions:** This step aligns with the broader concept of "Level 1: Validate the replicability of ROBINSON solutions" in the overall replication plan structure. It involves gathering evidence and conducting a Sustainability & Replicability Analysis (SRA).
2. **Identify the application range for ROBINSON, including conditions, constraints, assets, limitations, and define users and use cases, as well as the baseline for ROBINSON applications:** This step corresponds to various elements within the overall replication plan, including market analysis, regulatory considerations, and defining the scope and objectives of replication.
3. **Research the market and identify the marketability of ROBINSON solutions and its critical factors:** Market research aligns with the market analysis component of the overall replication plan. Understanding market trends and factors that affect marketability is crucial for replication success.
4. **Identify the business models needed to replicate ROBINSON to other locations and assist in the business planning of the replication projects:** This step corresponds to the section in the overall replication plan that discusses business models and revenue generation strategies.
5. **Map and propose funding sources and schemes for replication of the ROBINSON concept to other locations, including connections to private investors and planning:** Identifying funding sources and mechanisms is a critical part of the overall replication plan, as financial resources are essential for replication.
6. **Produce an Overall Replication Plan and guidelines for applying and upscaling ROBINSON solutions:** This step directly aligns with the development of the Overall Replication Plan and guidelines as described in the overall replication plan structure.
7. **Produce specific detailed Replication Plans for the two “follower” islands:** Developing specific detailed Replication Plans for the follower islands aligns with the task of creating Follower Islands Replication Plans (FIRPs) within the overall replication plan structure.

Provide evidence to convince strategic stakeholders about the replicability of the solutions.

Identify the application range for ROBINSON, including conditions, constraints, assets, limitations and define users and use cases, as well as the baseline for ROBINSON applications.

Research the market and identify the marketability of ROBINSON solutions and its critical factors.

Identify the business models needed to replicate ROBINSON to other locations and assist in the business planning of the replication projects.

Map and propose funding sources and schemes for replication of the ROBINSON concept to other locations, including connections to private investors and planning.

Produce a GRP and guidelines for applying and upscaling ROBINSON solutions.

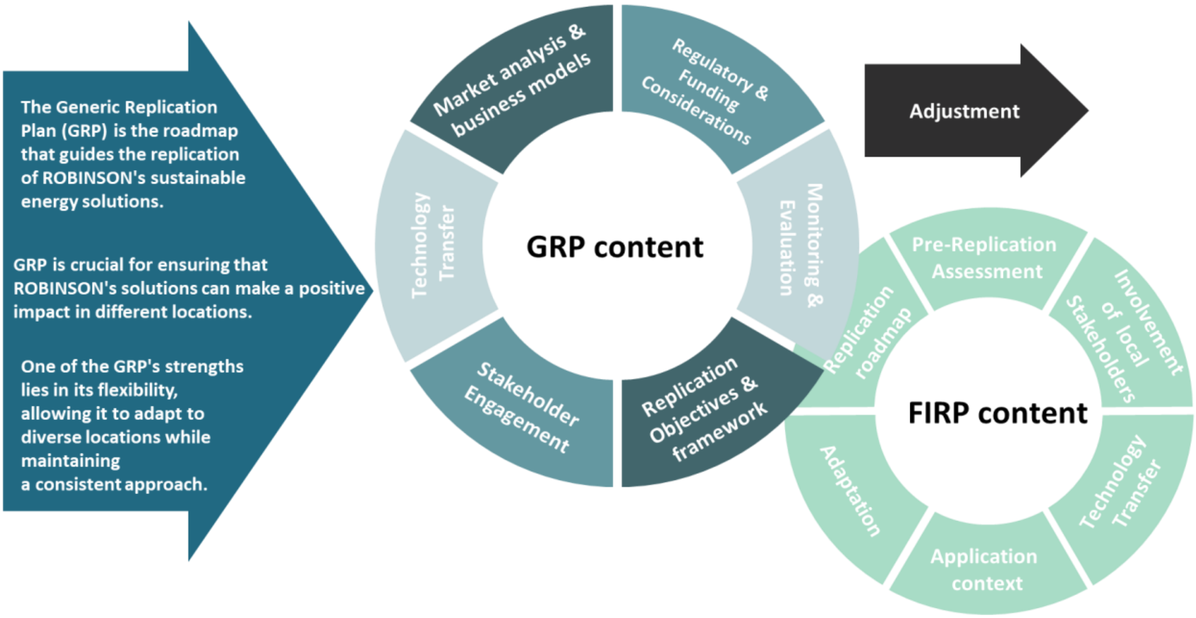
Prepare specific detailed Replication Plans for the two "follower" islands.

Figure 5: General approach to replication.

3.2. Generic & Follower islands replication plan feasibility

The **Generic Replication Plan (GRP)** and the **Follower Island Replication Plans (FIRP)** were integral components of the ROBINSON project's strategy to replicate its energy solutions across diverse contexts, providing a cohesive yet adaptable framework. While the GRP set the overarching roadmap, ensuring solutions were replicable in various regions, the FIRP focused on specific implementation plans for the Follower Islands, such as Crete and the Western Isles, accounting for each island's unique conditions. The GRP was designed to be a flexible guide, allowing for customization based on local needs. It included vital components such as stakeholder engagement, replication planning, technical and economic analysis, business model development, and monitoring and evaluation. The plan emphasized early stakeholder involvement to ensure local actors were engaged. Replication planning involved adapting solutions to different geographical and socio-economic conditions, while technical and economic analyses ensured the feasibility and sustainability of the projects. Business model development explored market viability and funding sources while continuous monitoring and evaluation ensured feedback mechanisms were in place to drive ongoing improvements. The GRP's adaptability and focus on sustainability were essential for ensuring long-term impact and success.

Building on this, the FIRP (part of this deliverable) provide detailed, localized strategies to implement ROBINSON's solutions on the follower islands. FIRP began with a pre-replication assessment, conducting a detailed analysis of local conditions, energy needs, and existing infrastructure. This stage established a baseline for the islands' current energy systems, ensuring that proposed solutions were adapted to the specific challenges of each location. The FIRP also emphasized stakeholder engagement, mapping local stakeholders and developing strategies to ensure their early and active involvement. The technical and economic analysis in FIRP includes simulations tailored to each island's specific conditions, ensuring that the solutions are viable and sustainable. Replication planning provides a comprehensive approach with detailed timelines, milestones, and specific actions necessary for successful implementation. As with the GRP, monitoring and evaluation were critical components, offering a framework for ongoing review and adjustments to ensure that objectives were met and the solutions continued to meet the islands' evolving needs. By integrating the GRP's broader strategic framework with the FIRP's localized, detailed plans, ROBINSON ensures that its energy solutions are scalable and sustainable across different regions.



The Generic Replication Plan (GRP) is the roadmap that guides the replication of ROBINSON's sustainable energy solutions.

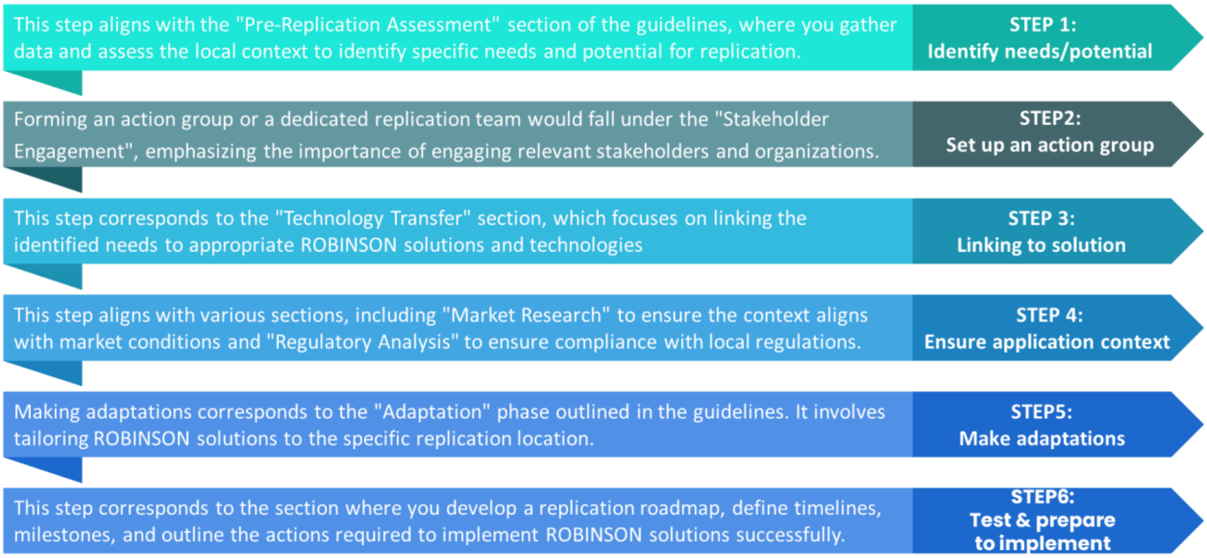
GRP is crucial for ensuring that ROBINSON's solutions can make a positive impact in different locations.

One of the GRP's strengths lies in its flexibility, allowing it to adapt to diverse locations while maintaining a consistent approach.

Figure 6: Key Components of the Generic and Follower Island Replication Plans

3.3. Replication roadmap development process

To ensure the application and systemization of this approach, a novel Replication Roadmap tool for applying and upscaling ROBINSON solutions has been developed. This tool offered a high level of decision support integration since it extracts and integrates facts and knowledge from relevant sources. An exploitable replication plan is provided to the end-user based on a six-stage analysis. Based on a wide variety of successful application cases, it applies its expertise to new instances by offering Roadmaps, i.e. verified workflow methods, for accomplishing goals in any decision step, employing existing knowledge, tools, data, and professional assistance



This step aligns with the "Pre-Replication Assessment" section of the guidelines, where you gather data and assess the local context to identify specific needs and potential for replication.

STEP 1: Identify needs/potential

Forming an action group or a dedicated replication team would fall under the "Stakeholder Engagement", emphasizing the importance of engaging relevant stakeholders and organizations.

STEP2: Set up an action group

This step corresponds to the "Technology Transfer" section, which focuses on linking the identified needs to appropriate ROBINSON solutions and technologies

STEP 3: Linking to solution

This step aligns with various sections, including "Market Research" to ensure the context aligns with market conditions and "Regulatory Analysis" to ensure compliance with local regulations.

STEP 4: Ensure application context

Making adaptations corresponds to the "Adaptation" phase outlined in the guidelines. It involves tailoring ROBINSON solutions to the specific replication location.

STEP5: Make adaptations

This step corresponds to the section where you develop a replication roadmap, define timelines, milestones, and outline the actions required to implement ROBINSON solutions successfully.

STEP6: Test & prepare to implement

Figure 7: Replication roadmap development process

The replication roadmap development process for the ROBINSON project involves several key steps (Figure 7) to ensure the successful adaptation and implementation of its solutions across different regions, particularly the follower islands such as Crete and the Western Isles. This process is designed to be comprehensive, flexible, and tailored to the specific needs and conditions of each location. A detailed process flowchart is presented in Figure 8,Figure 9,Figure 10, while a short description of each steps is provided in Table 1.

Table 1: Key steps of the replication process (TUC, 2022)

Step 1: Identify Needs and Potential
This step is crucial for establishing the foundational context in which the ROBINSON concept will be replicated. It begins with a comprehensive assessment of the local energy needs and environmental conditions, using historical interannual and seasonal data to understand the area's energy dynamics. The analysis identifies the electrical and thermal requirements of potential stakeholders, which guides decisions on whether to implement combined or stand-alone energy systems, based on demand patterns and resource availability. In addition, the assessment considers any existing strategic energy policies or sustainability roadmaps that local stakeholders may have adopted. This ensures that the replication aligns with broader objectives, such as reducing emissions, improving energy efficiency, and fostering sustainable development. Following the energy needs assessment, an evaluation of renewable energy sources (RES) potential is conducted. This step assesses the availability and efficiency of local RES technologies, such as photovoltaic systems, wind turbines, and biomass. It also involves determining the feasibility of sustainable siting, considering logistics like transportation, storage costs, and proximity to installation sites. Proximity to suitable locations is key, as it enhances the efficiency of RES installations and reduces operational, maintenance, and security expenses. Compliance with local regulations and laws may pose challenges during the process. This affects both the installation of RES and their integration with the local energy grid. Careful consideration of the regulatory landscape is necessary to ensure successful deployment. The result of this step is a clearly defined framework for replicating the ROBINSON concept. It establishes the local energy needs, evaluates the RES potential, and ensures that the integration of renewable energy technologies aligns with both sustainable practices and local regulations. This facilitates the smooth implementation and operation of RES projects within the target area.
Step 2: Set Up an Action Group
This step involves forming an action group to oversee the replication of the ROBINSON concept. Engaging stakeholders early is essential to address challenges promptly and ensure broad support. The local community, regional and municipal authorities, and technical and economic bodies are vital actors. Local stakeholders like farmers or business owners may contribute resources like biomass. Early stakeholder engagement ensures commitment and clarity on the benefits of the ROBINSON concept. Responsibilities are assigned based on expertise, and roles are clearly defined to ensure efficient project management, with regular monitoring to ensure progress. This step aims to identify critical actors and assign responsibilities early, addressing legislative, financial, and operational challenges effectively. Stakeholder mapping allows the project team to gauge interest and cooperation levels, ensuring smoother implementation and support for the replication process
Step 3: Linking to Solution
This step focuses on selecting technical components and infrastructure required for replicating the ROBINSON concept based on the potential of the local renewable energy source. The selection considers cost, expected returns, lifespan, maintenance needs, and compliance with legislation.

Once the components are selected, the next step is system modelling to ensure the design meets local energy and thermal demands efficiently. Accurate modelling is critical, especially when integrating with existing infrastructure and other installed assets, as it demonstrates the solution's environmental and economic benefits, making it more attractive to potential adopters. Integrating new technology with existing systems ensures continuity and maximizes resource use, reducing the need for extensive system reconstructions. This step also lays the groundwork for the Business Model, using the results of technical, environmental, and economic assessments to guide financial and operational decisions. The outcome of this step is a realistic, technically sound plan for replicating the ROBINSON concept, providing a clear link between the solution's technical feasibility and its environmental and economic benefits, supporting stakeholders in making informed decisions for successful implementation.

Step 4: Ensure the Application Context

This step focuses on creating the framework for successfully replicating the ROBINSON concept. It involves preparing key contextual factors, such as the Business Model, regional/local spatial planning framework alignment, and financial tools. The Business Model will cover financial planning, resource allocation, organizational structures, etc. The framework also depends on national legislation, which can impact the availability of financial support tools essential for implementation. Potential funding sources include national or European programs, regional financing, loans, or local stakeholder investments. In addition to developing the Business Model, it is important to establish cooperation and synergies between stakeholders. This could be cooperative structures or agreements like a Memorandum of Synergy to secure stakeholder commitments and define roles. Furthermore, a clear understanding of the impact assessment framework must be established to track the progress and effectiveness of the project, ensuring adaptability for future replications.

Step 5: Make Adaptations

Adapting the replication plan requires a deep understanding of local conditions and site-specific challenges. Each replication yields data on technical, energy, socio-economic, and environmental requirements, which must be balanced with cost-efficient and energy-efficient solutions. Adaptations may vary across different replication cases, and the level of customisation needed should be well-defined and decision driven. Shifts in cooperative structures or resource allocation may be necessary, and these must be carefully documented to convince and secure the commitment of all stakeholders. This step emphasises the importance of adaptations to ensure that the ROBINSON concept can be efficiently replicated.

Step 6: Test and Prepare to Implement

This step involves a comprehensive evaluation of the adopted solution to address potential issues that may affect stakeholders. The solution must be assessed in terms of legislation, sustainability, energy needs, and economic impact to ensure alignment with strategic plans and long-term objectives. A review of results and recommendations from each stakeholder, including key actors and policy makers, is essential to confirm mutual interests and ensure commitment. Due to the complexity of replicating the ROBINSON concept, continuous follow-up and correction mechanisms must be in place to address any unforeseen issues that arise during the implementation process. The goal of this step is to test and prepare the ROBINSON project for implementation in a specific case. By resolving potential issues through thorough evaluation and feedback mechanisms, stakeholders *can act independently and collaboratively, ensuring the project's efficiency and maximizing benefits for all parties involved.*

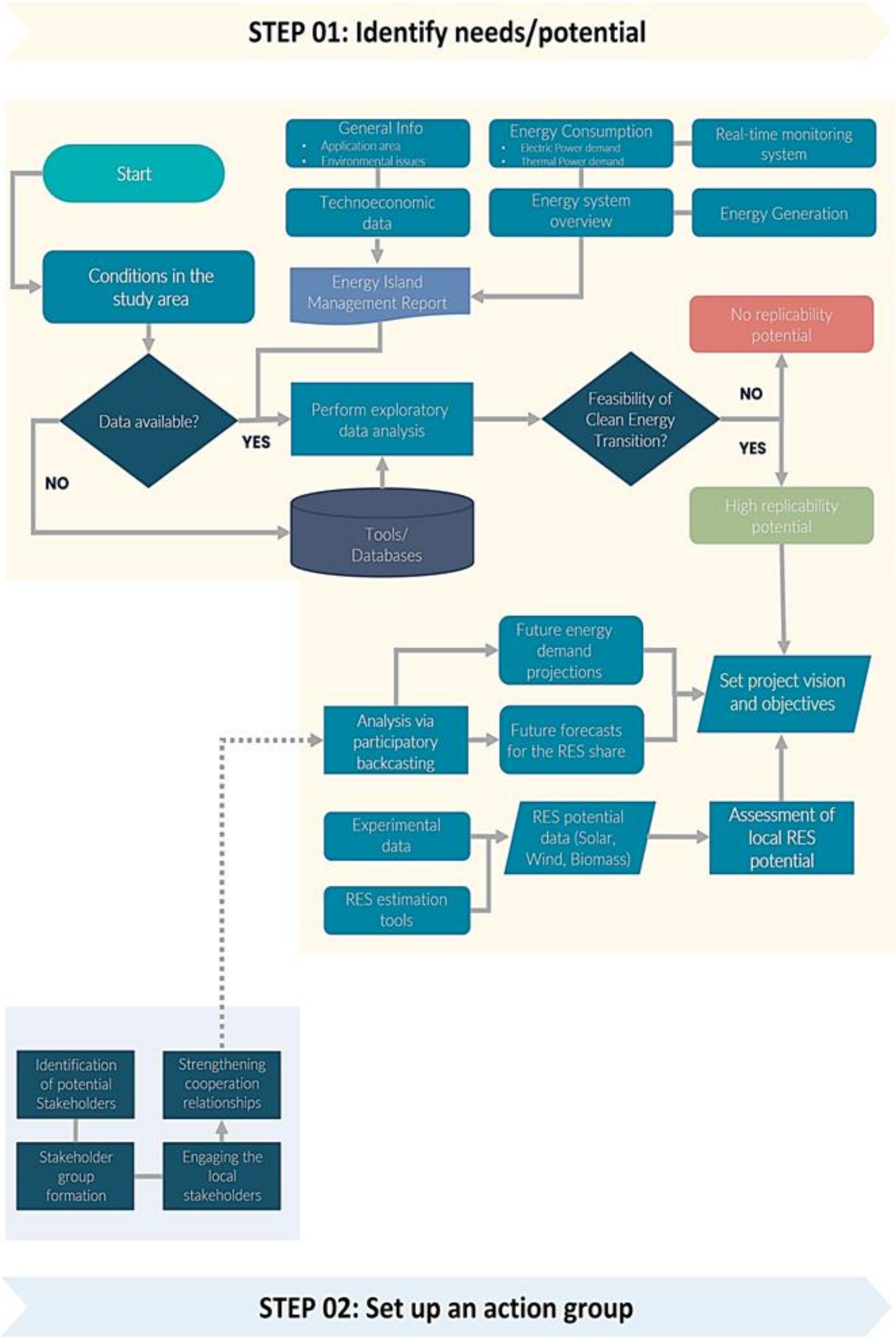


Figure 8: Replication process flowchart (Step 1&2)

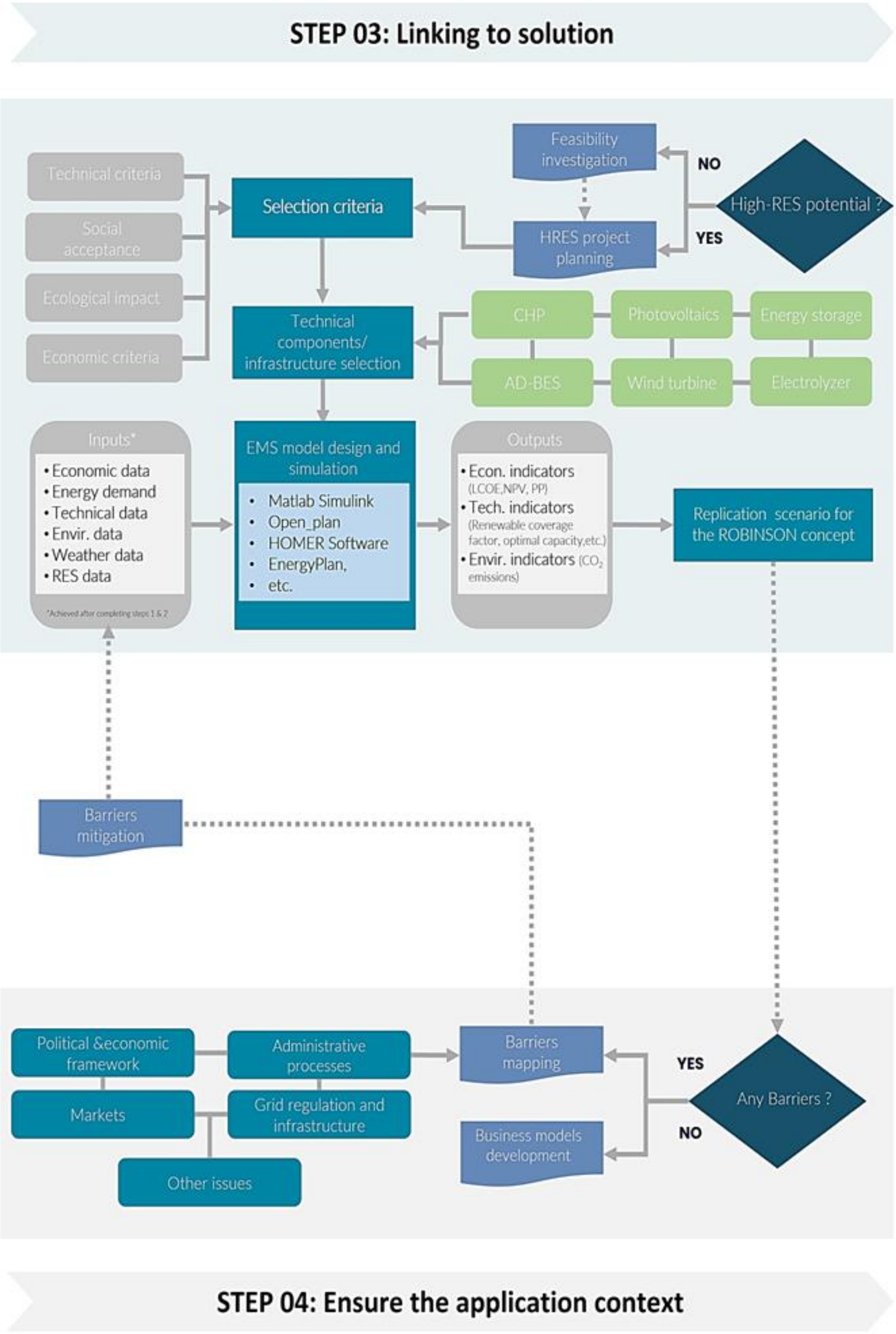


Figure 9: Replication process flowchart (Step 3&4)

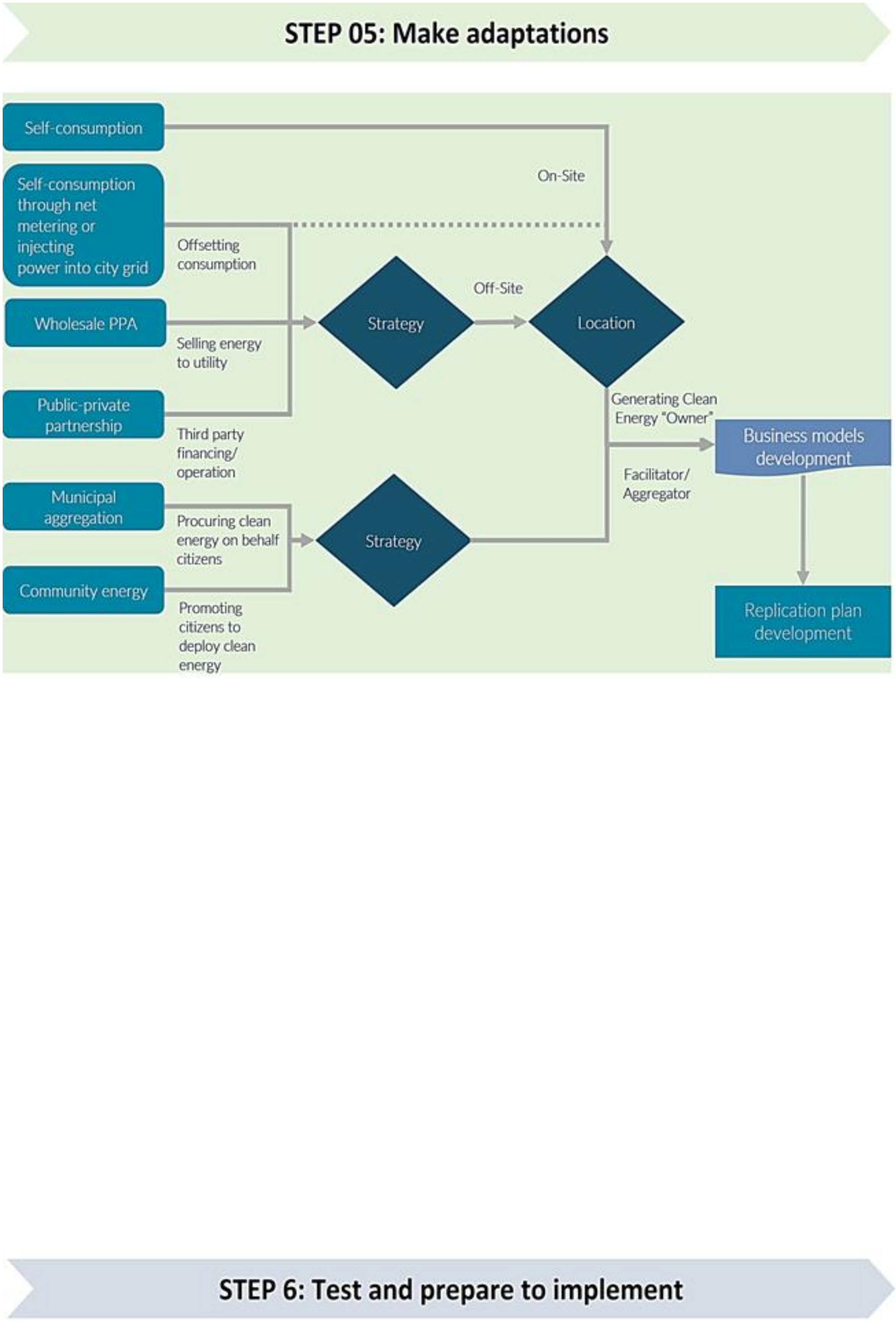
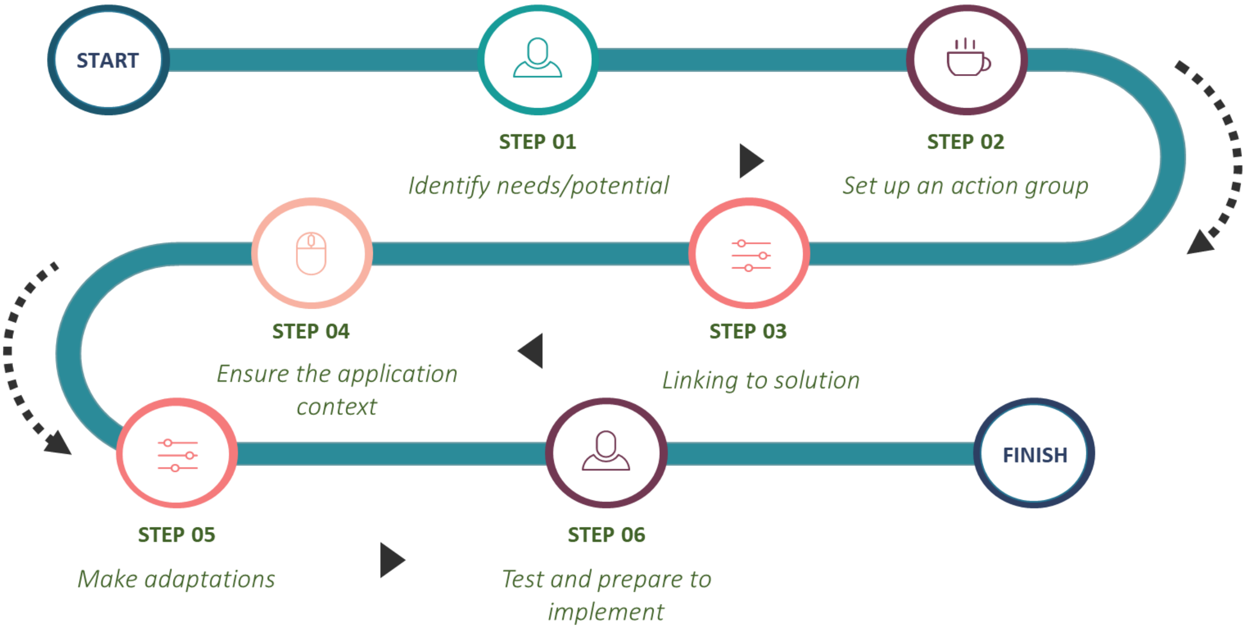


Figure 10: Replication process flowchart (Step 5&6)

4. Follower Islands Replication Plan

4.1. Replication plan for Crete

4.1.1. Replication in a nutshell



The replication plan for Crete focused on utilizing the island's significant renewable energy potential—mainly through solar and biomass resources—to transition to a more sustainable energy system. A vital element of this replication effort was the community of Platanos, where local stakeholders such as farmers and business owners were actively involved in the energy transition by providing biomass and participating in energy communities. Additionally, the bakery industry in Crete, which requires high-temperature heat for its operations, served as a critical use case for integrating tailored multi-energy systems to meet economic and environmental targets. By aligning with Crete's regional spatial planning and reducing reliance on fossil fuels, the plan addresses the island's seasonal energy demand fluctuations, especially during peak tourism seasons. Integrating smart grids, energy storage, and community-driven energy projects ensures greater energy resilience and economic sustainability, as demonstrated by the executed simulations. The core outcome of the replication plan is to create a low-carbon, energy-efficient system that not only lowers emissions but also supports local economic growth and enhances social equity across the island.

4.1.2. Analysis and diagnosis of the status, needs and potential for sustainable/flexible energy solutions.

4.1.2.1. Determination of the local energy needs and conditions

General information – Crete

Crete is the biggest island in Greece and the fifth in size in the Mediterranean basin, regarding both its area (8,336 km^2) and population (624,408 inhabitants). Crete is located between the geographical longitudes from 23° 30΄E to 26° 22΄ E and latitudes from 34° 53΄ N to 35° 42΄ N. The Crete's length from the eastern to the western coast is approximately 260 km, while its width from the northern to the southern coast ranges from 12 km to 60 km. The island's coastline has a total length of approximately 1,000 km (Katsaprakakis et al., 2022). According to the most recent census data, Crete had a slight population growth (+0.2%), while during the tourist season (May to October), the island's population increases further (Figure 12), resulting in higher energy demand and seasonality. Additionally, Crete demonstrates a positive trend in comparison to several other regions in Greece concerning population aging: 44.6% of the island's population is under 39 years old, while only 26.2% is aged 60 and above (Hellenic Statistical Authority, 2021). The distribution of age groups within Crete's total population is presented in Table 2.

Figure 11 Location of Crete in relation to Greece (GEODATA.GOV, 2024)

Table 2: Age Distribution of the Permanent Population in the Region of Crete (Hellenic Statistical Authority, 2021)

Age Group	Population		Percentage Change (%)
	2021	**2011**	
0-9	62,214	69,924	-11
10-19	70,247	68,459	+2.6
20-29	67,202	82,605	-18.6
30-39	78,685	97,447	-19.3
40-49	95,628	88,815	+7.7
50-59	86,702	72,308	+19.9
60-69	69,264	60,089	+15.3
70-79	53,027	50,890	+4.2
80+	41,439	32,528	+27.4
Total	**624,408**	**623,065**	**+0.2**

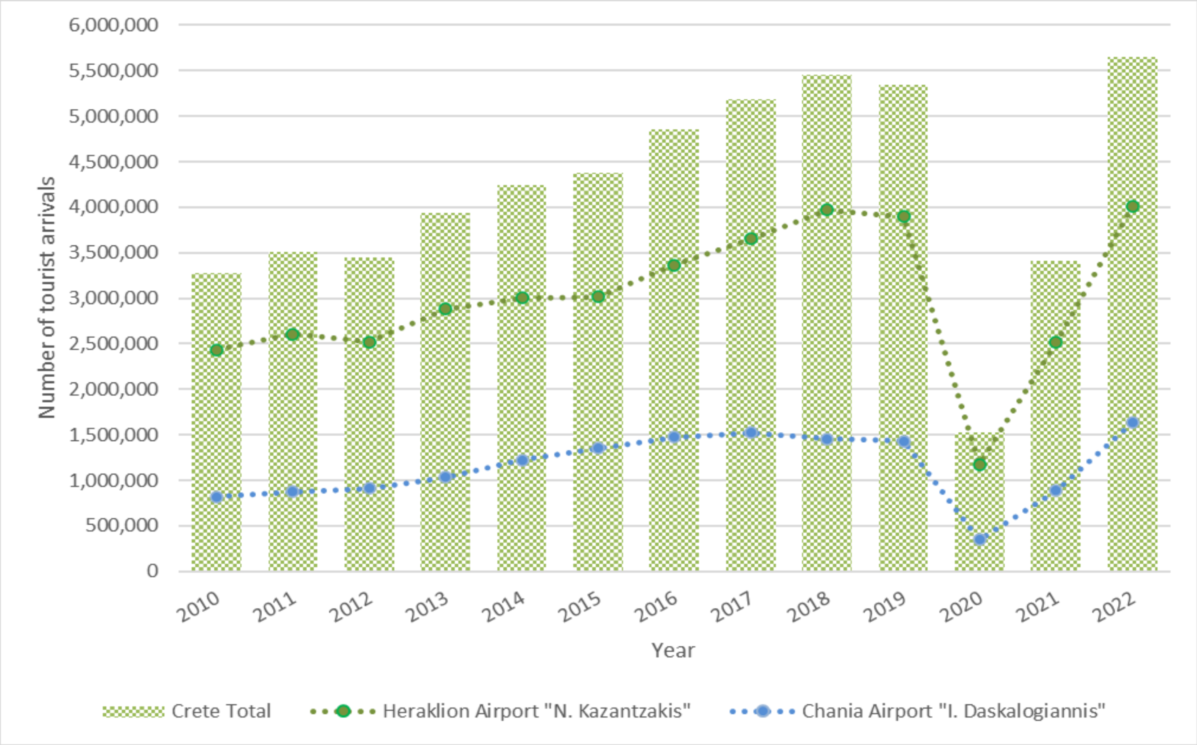


Figure 12: Number of arrivals at the main airports in Crete (Heraklion, Chania) from 2010 to 2022.(Crete Tourism Observatory, 2023)

The economic conditions in Crete are shaped by a significant reliance on key sectors such as tourism, commerce, and agriculture, which collectively contribute approximately 49.6% of the island’s overall economic activity. The evolution versus time of the per capita gross domestic product (GDP) in Crete, segmented by the island's four prefectures - Heraklion, Chania, Rethymno, and Lasithi - is presented in Figure 13. In this figure, both the impact of the global economic crisis that struck Greece starting in 2008–2009 and the effects of the COVID-19 pandemic during 2020-2021 on the local economy are clearly depicted. Furthermore, the unemployment rate in Crete, which stood at 11.22% in 2021, reflects broader economic challenges that the region of Crete continues to face.

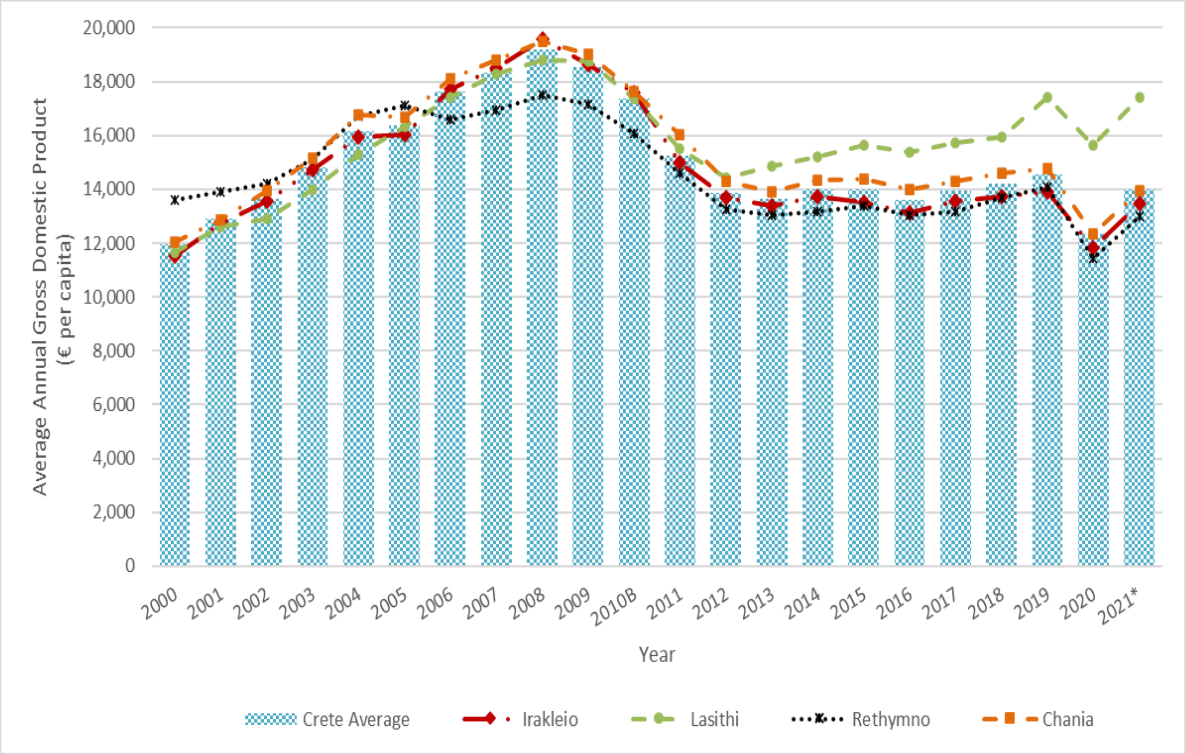


Figure 13 Variation of per capita average annual gross domestic product versus time (2000–2017) in Crete (Hellenic Statistical Authority, 2021)

These data underscore the potential vulnerabilities of Crete's economy in the face of external shocks, while also highlighting the critical need for a stable and reliable energy system. Ensuring a flexible and resilient energy infrastructure is essential for sustainable development and stability in Crete's key economic sectors, particularly as the island seeks to navigate future challenges.

The Region of Crete is a Public Law Entity and operates as a second-grade local self-government authority in Greece. Its jurisdiction covers the entire island, which is organized into four Regional Units: Heraklion, Lasithi, Rethymnon, and Chania. Furthermore, the Region of Crete is tasked with the strategic planning and implementation of policies in alignment with national and EU directives. This responsibility is carried out at the regional level, adhering to the principles of sustainable development and social cohesion. Administratively, the island is divided further subdivided into communities and municipalities. In Greece, municipalities represent the lowest level of government within the state's organizational structure. As of 2021, there are 332 municipalities, divided into 1,036 municipal units and 6,136 communities (Hellenic Republic, 2024). Local governments are autonomous, and their leaders are elected by universal secret ballots, as stipulated by Article 102 of the Constitution of Greece. While municipalities may collaborate to provide services, these partnerships are governed by elected representatives. The national government supervises but does not interfere with local initiatives and is required to fund local governments adequately. Each municipality is governed by a mayor-led council and a municipal consultation committee, responsible for managing local affairs.(Hellenic Parliament, 2019)

Genera info – Municipality of Kissamos/Community of Platanos

The Municipality of Kissamos, encompassing both the municipal unit of Kissamos (the broader area of the ROBINSON solution's replication) and the community of Platanos, is situated in the northern and western parts of the Chania regional unit. Its administrative centre, Kissamos (also known as Kastelli), lies 37 kilometres from the city of Chania (Municipality of Kissamos, 2017). The municipality covers an area of approximately 340 km² and, according to the 2021 census by the (Hellenic Statistical Authority, 2021), has a permanent population of 10,633 residents. It shares borders with the Municipality of Kantanos-Selino to the south and the Municipality of Platanias to the east. The municipality's area accounts for 12.3% of the total area of the Chania regional unit and 4.1% of the entire Region of Crete. The municipality's population represents 6.8% of the regional unit of Chania's population and 1.7% of the total population of Crete (as shown in Table 3).

The largest settlement within the municipality is its administrative centre, Kastelli, which is dynamic with a permanent population of 4,321 residents. The second-largest settlement is Platanos, with 1,232 residents (Hellenic Statistical Authority, 2021), and it is the nearest settlement to the ROBINSON intervention area. The coastal settlements along the western front of the municipality primarily serve as holiday destinations, while Platanos and other nearby settlements contribute significantly to the primary and secondary economic sectors of the city. Together, these areas represent the most vibrant and active parts of the region. A notable aspect of the spatial organization within the municipal unit of Kissamos is the development role of the town of Kissamos. It serves as a critical regional and national hub due to the presence of the port of Kissamos, which facilitates both administrative services and economic activity. The port of Kavonisi, located at the westernmost point of Crete, plays a vital role in the economic growth of the broader region. In addition to handling passenger traffic, the port supports commercial activities, including the transportation of oil, citrus fruits, vegetables, building materials, agricultural supplies, and other goods (Municipality of Kissamos, 2017).

Table 3: Aggregated data regarding the permanent population for the area of Kissamos (Hellenic Statistical Authority, 2021)

Description	Area (km²)	Population (inhabitants)	Population as a Percentage of Region of Crete	Population as a Percentage of Regional Unit of Chania	Population as a Percentage of Kissamos Municipality
Greece		10,482,487			
Region of Crete	8,336	624,408	-	-	-
Regional Unit of Chania	2,376	156,706	-	-	-
Municipality of Kissamos	340.0	10,633	1.70%	6.78%	100%
Community of Platanos	~32.48	1,232	0,20%	0.79%	11,59%

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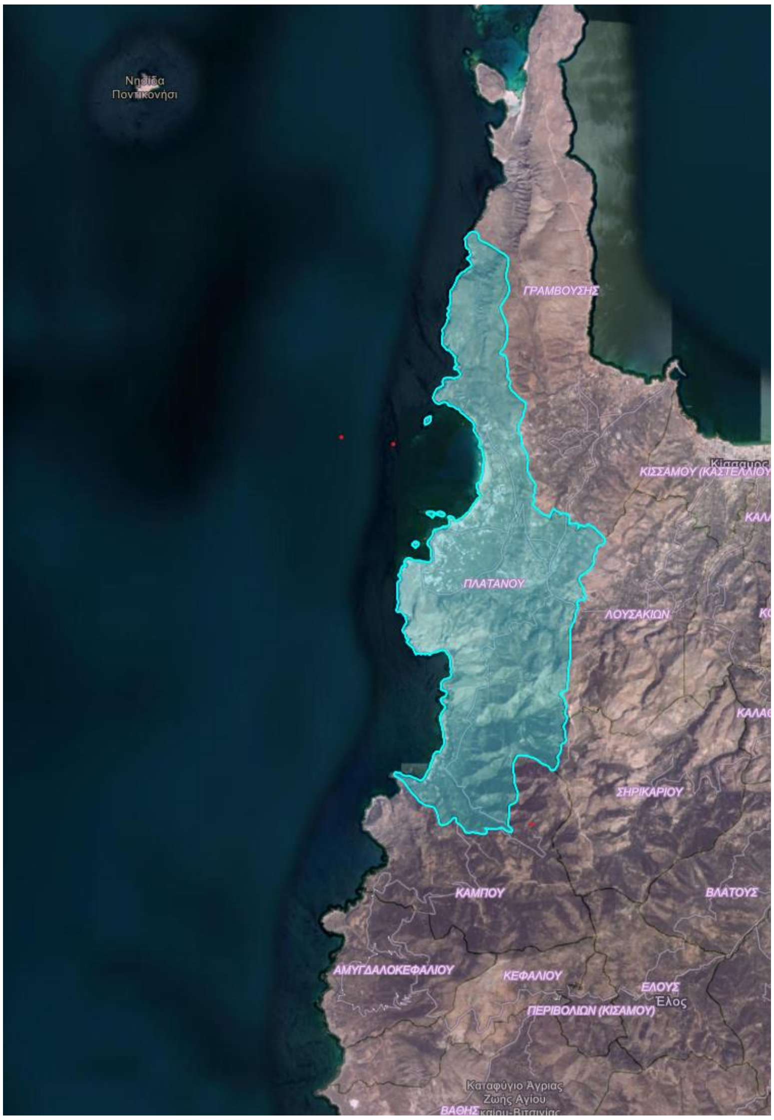

Figure 14: Geographic boundaries of Platanos community (Municipality of Kissamos, 2017)

The available data on the economically active population in the Municipality of Kissamos and the Community of Platanos provides insight into the distribution of employment across various economic sectors. As of the most recent data, the Municipality of Kissamos has a total population of 10,633 residents, of which 4,609 are considered economically active. Among this group, 4,173 individuals are employed, with the remainder (439) classified as unemployed. The employed population is distributed across the three primary economic sectors: the primary sector (agriculture, forestry, and fishing), the secondary sector (industry and manufacturing), and the tertiary sector (services). In the Municipality of Kissamos, 1,394 individuals are employed in the primary sector, reflecting the region's strong reliance on agricultural activities. The secondary sector employs 545 individuals, while most of the workforce (2,229) is engaged in the tertiary sector, including tourism, commerce, and services. At the same time, the unemployed population represents approximately 9.5% of the economically active population.

In the Community of Platanos, which falls within the Municipality of Kissamos, the economically active population is 543 individuals, of which 499 are employed and 41 are unemployed (Table 4). The primary sector plays a particularly significant role in Platanos, with 283 individuals employed in agriculture and related activities. The secondary sector employs 51 people, and 170 individuals work in the tertiary sector, with the community’s unemployment rate standing at approximately 7.5%, slightly lower than that of the wider municipality. This distribution of economic activity underscores the importance of agricultural production in the Municipality of Kissamos, particularly in the Community of Platanos, where a substantial portion of the population is engaged in the primary sector. The continued focus on agriculture, coupled with the growth of the tertiary sector driven by tourism, is essential for understanding the economic dynamics and future development prospects in the area of interest (Hellenic Statistical Authority, 2021).

Table 4: Population Distribution by Economic Activity Status in the area of interest.(Hellenic Statistical Authority, 2021)

Description	**Total**	**Economically active population**						**Economically inactive population**
		Total	Employed	Sectors			Unemployed	
				Primary	Secondar	Tertiary		
Municipality of Kissamos	10,633	4,609	4,173	1,394	545	2,229	439	6,021
Community of Platanos	1,232	543	499	283	51	170	41	692

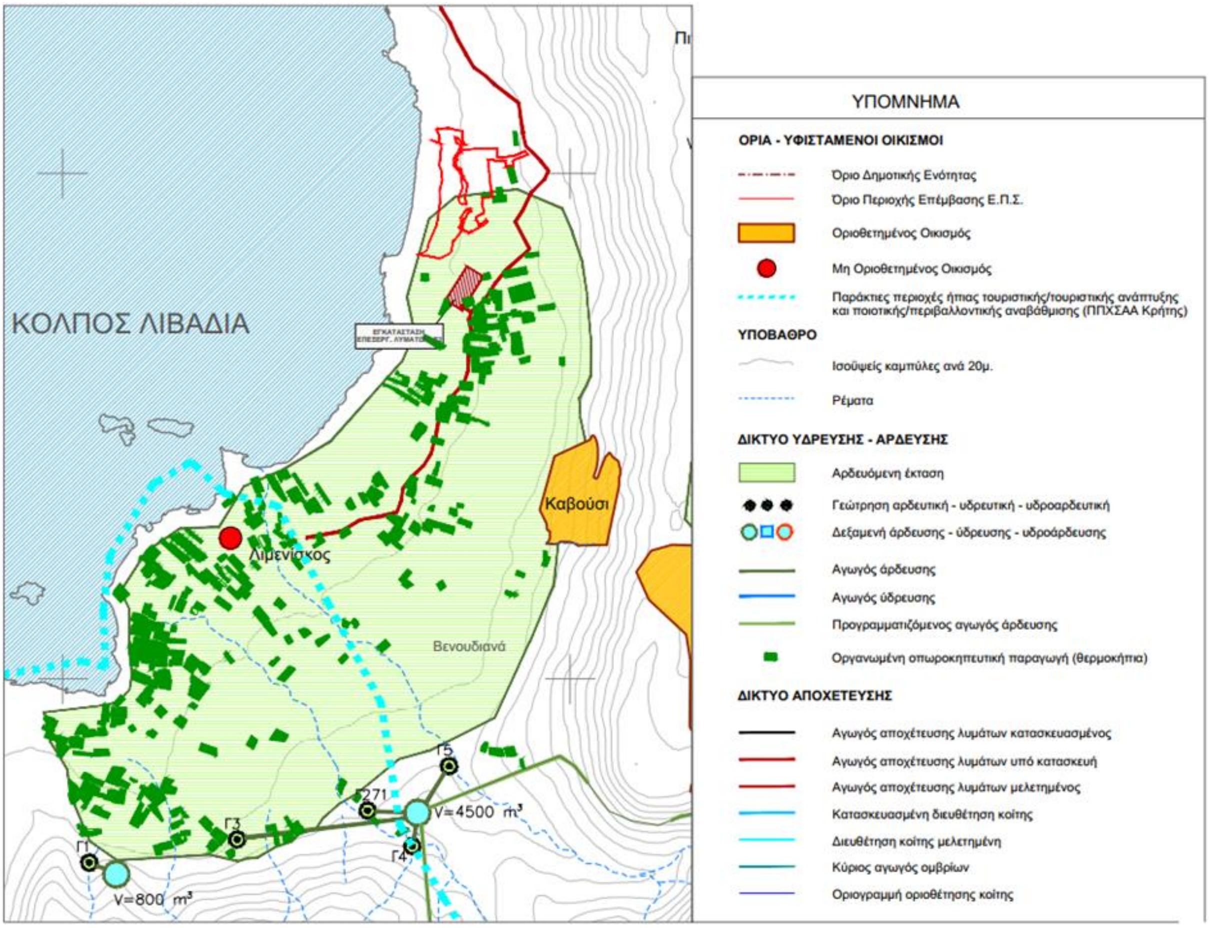

Figure 15: Land uses in the peri-urban area (greenhouse cultivation are highlighted in dark green) (Municipality of Kissamos, 2017)

Table 5: Agriculture Land in the area of interest in Crete (OPEKEPE, 2019)

Description	Agriculture Land (ha)					
	Greenhouse tomatoes cultivation			Olive trees cultivation		
	2017	2018	2019	2017	2018	2019
Municipality of Kissamos	112.5	109.8	115.7	7,357.3	7,385.2	7,453.4
Community of Platanos	102.1	99.6	104.9	820.2	823.1	830.7

According to the active General Urban Plan for the Municipality of Kissamos, several key aspects of agricultural production stand out:

- **Olive Production**: Olive cultivation is a dominant activity, occupying 86.5% of the agricultural land within the municipality. This figure is even higher in the Community of Platanos, where 87% of the agricultural land is dedicated to olive groves. Olive production remains a cornerstone of the local economy and a vital part of the region's agricultural landscape.
- **Vegetables and Greenhouses**: Vegetables and greenhouse farming collectively account for 1.34% and 1.26% of the agricultural land, respectively. Greenhouse farming is especially prominent in the Community of Platanos, with an increasing focus on tomato cultivation. Other important crops include melon, spiny chicory, and pepper, which reflect the growing diversification of vegetable production in the area.
- **Citrus Fruits**: Citrus fruits occupy around 5% of the agricultural land, although this cultivation is generally more scattered throughout the region.

The protection of agricultural land in the lowland areas of the Municipal Unit of Kissamos is essential for sustaining the local economy. This land not only supports traditional farming practices but also offers opportunities for synergistic activities, such as highlighting local agricultural techniques. These initiatives could attract attention to the area's agricultural landscapes, promoting interactions between the primary sector and other economic activities, thereby contributing to the region's overall economic development. (Municipality of Kissamos, 2017)

Environmental Conditions

The health and well-being of local communities in Crete are deeply connected to the services provided by the island's ecosystems. In recent years, significant progress has been in raising awareness about these ecosystems' benefits, particularly in enhancing economic performance and fostering social cohesion. Initiatives like the NATURA 2000 network aim to protect the natural environment, not only preserve biodiversity but also improve living standards and quality of life. Additionally, they create new opportunities for investment and employment across Crete. Ecosystem services refer to the various contributions of the natural environment to human well-being. These services include the direct provision of essential goods, such as food, and timber, as well as the formation of soils that maintain crop and livestock productivity. Recognizing the value of these benefits demonstrates that investing in natural capital can have significant economic advantages. In Crete, the NATURA 2000 sites span approximately 141,318 hectares, with 54 areas currently included in the network, according to Greek Law N. 3937/2011 on biodiversity conservation. These protected areas underscore the importance of integrating ecological preservation with socio-economic development for the region's future. In areas designated as part of the NATURA 2000 network, any technical intervention or development project typically requires a specific Environmental Impact Assessment (EIA). This process is crucial to ensure that the proposed activities do not negatively affect the site's protected habitats, species, or overall integrity. Licensing such interventions involves thoroughly reviewing potential environmental impacts, especially concerning biodiversity. The assessment must demonstrate that the project will not harm the conservation objectives of the NATURA 2000 site. If any significant adverse impacts are identified, the project may be modified, mitigated, or even rejected, depending on the severity of the risks.(Ministry of Environment and Energy, 2023)

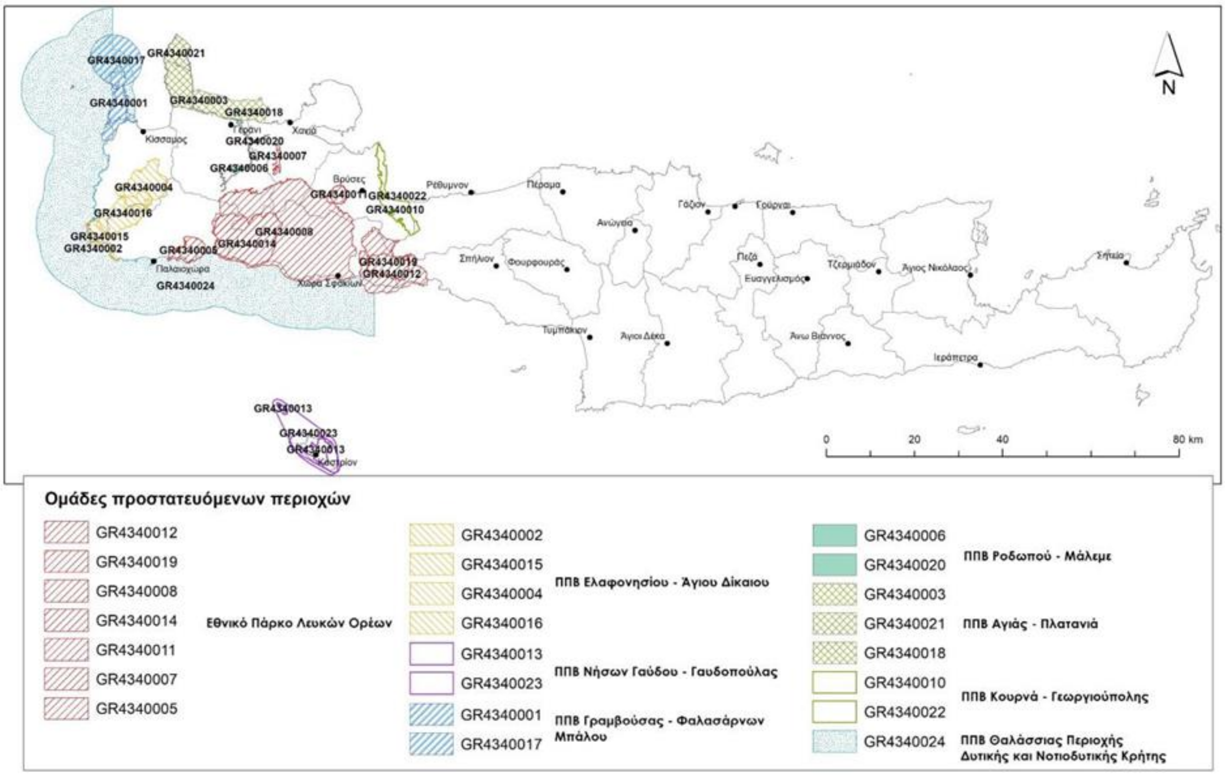

Figure 16: Grouping of NATURA 2000 areas and their classification according to Article 46 of Greek Law 4685/2020

The area considered for the replication of ROBINSON's solutions is located close to the Special Conservation Area (SCA) of the network Natura 2000 "GR4340001 - Imeri and Agria Gramvousa - Tigani and Falasarna - Pontikonissi, Ormos Livadi - Viglia". To the west of the area is the marine protected zone "GR4340024 - Marine Area of Western and Southwestern Crete". To the north, about 10 km from the community of Platanos, the area is part of the Special Protection Areas (SPA) for Birds "GR4340017 – Gramvousa Peninsula and Imeri and Agria Gramvousa Islands, Pontikonissi".(*Cretan NATURA2000*, n.d.)

Nearby is a small island wetland 'Y434KRI225 – Falasarna' (Presidential Decree No 229/2012), 2.33 ha located approximately 6 km nortwest. The entire protected area of SAC 'GR4340001' area's proximity to ecologically sensitive zones, including SPAs and Important Bird Areas, highlights the need for protection and sustainable management of the surrounding landscapes. These areas also include locations of exceptional natural beauty, as indicated in the Ministerial Decision - 31/36852/2942.

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The energy system in Crete

The energy system in Crete is heavily reliant on imported fossil fuels, primarily for power generation and transportation, which are the most significant sources of greenhouse gas emissions on the island. Power production is based on fossil fuel imports, and this dependency is exacerbated by the island's transportation sector, both for internal movement and for connections to and from the mainland. An analysis of energy-consuming and emissive activities on Crete is provided in Table 6, providing a detailed picture of the island's annual final energy consumption.

Table 6: Final energy consumption analysis in Crete in 2019.(Katsaprakakis et al., 2022)

Energy consumption sector	Final energy consumption (MWh)	Percentage share (%)	CO_2 emissions (tn)
Electricity consumption			
Public buildings	237,519	7.7	537,754
Residential buildings	1,064,217	34.6	2,409,441
Primary sector	199,400	6.5	451,453
Industry	220,757	7.2	499,805
Tertiary sector	1,295,020	42.2	2,931,991
Public lighting	55,015	1.8	124,556
Total	**3,071,926**	**100.0**	**6,954,999**
Transportations on the island			
LPG	51,959	1.3	12,985
Diesel	2,006,359	50.3	582,647
Gasoline	1,929,588	48.4	530,637
Total	**3,987,906**	**100.0**	**1,126,268**
Transportations from and to the island			
Maritime transportations (heavy fuel)	2,605,827	36.7	917,251
Maritime transportations (diesel)	119,429	1.7	34,682
Air transportations (kerosene)	4,374,194	61.6	1,093,111
Total	7,099,450	100.0	2,045,044
Heating and other uses in buildings			
Oil burners for indoor space heating	350,687	41.6	101,840
Wood / solid biomass for indoor space heating	60,000	7.1	0
LPG for cooking	272,783	32.3	68,168
Solar collectors for hot water production	160,178	18.9	0
Total	**843,648**	**100.0**	**170,108**
Total	**15,002,930**		**10,296,320**

As shown in Figure 17, Crete's energy demand fluctuates seasonally, driven largely by tourism, which peaks from April to October. This period accounts for 58% of the year and significantly increases the island's electricity consumption, particularly in the buildings sector. In Table 6, the residential and tertiary sectors are the largest consumers of electricity, with buildings responsible for a substantial portion of energy use for heating and cooling. Tourism also contributes to a higher energy demand during summer due to the extensive use of cooling systems. At the same time, winter months see a

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smaller increase, partly due to a shift from oil-fired boilers to heat pumps for heating needs. The analysis of final energy consumption in Crete highlights the dominance of the transportation sector in overall energy use, particularly for transportation from and to the island. In 2019, transportation fuels, including diesel, gasoline, and jet fuel, contributed significantly to the island's energy consumption and CO_2 emissions. Similarly, maritime and aviation transport accounted for a major share of energy use and emissions, with jet fuel for aviation contributing the largest portion.

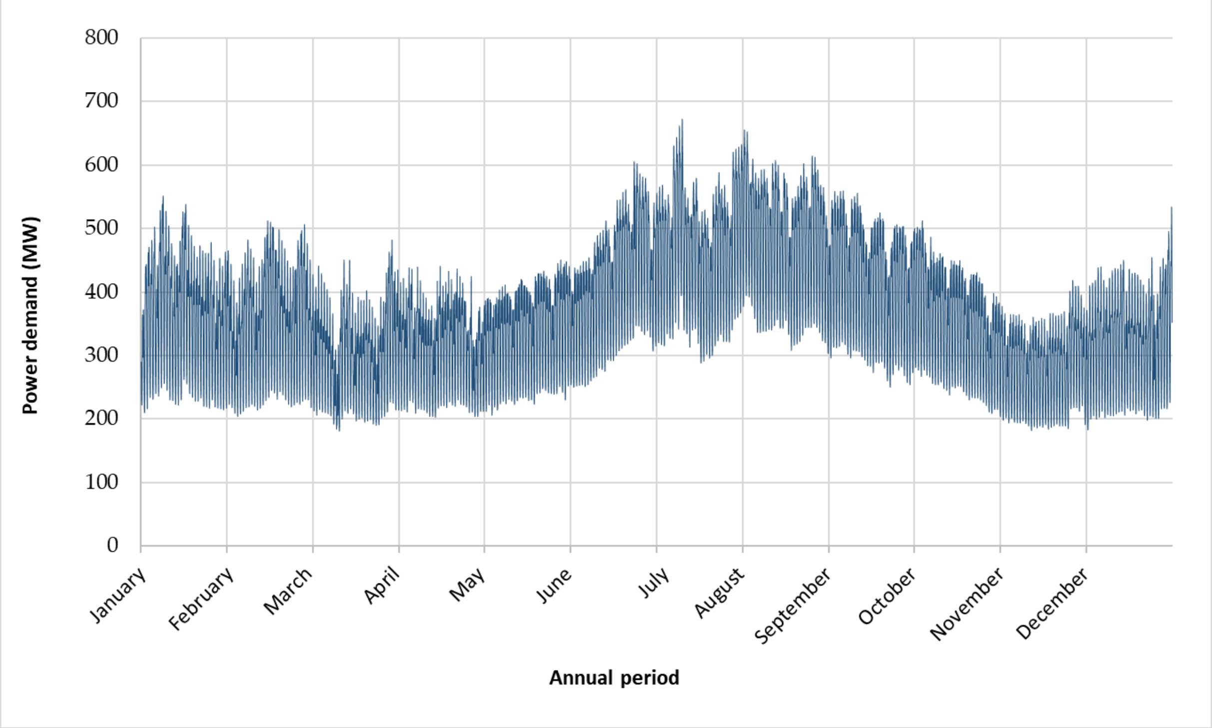

Figure 17: Annual electricity demand fluctuation for the year 2019 as per hours (RAAEY, 2022)

Electricity production in Crete is primarily dependent on three thermal power plants, which utilize a range of technologies, including steam turbines, diesel generators, gas turbines, and a combined cycle system. These conventional power generation methods are supplemented by renewable energy sources such as wind farms, photovoltaic (PV) systems, and a small hydroelectric plant. Photovoltaic installations are found both in rural areas and on rooftops of residential and commercial buildings. The total installed electrical capacity of these various technologies and their corresponding annual electricity production for 2019 are outlined in Table 7, along with the annual CO_2 emissions generated by the thermal power plants.

In 2019, renewable energy sources (RES) contributed 21% of Crete's total electricity demand. The remaining 79% was largely generated by steam turbines and diesel generators, which rely on heavy fuel oil, as well as by gas turbines and the combined cycle system, both of which consume diesel oil. Despite Crete's significant potential for harnessing solar and wind energy, the use of RES remains underdeveloped. Solar thermal systems, though widely adopted for hot water production in hotels and residential buildings, are still underutilized for electricity generation. Additionally, biomass is employed for heating purposes, particularly in smaller communities, but its contribution to the island's energy mix remains limited. There is a growing recognition of the need for increased investment in renewable energy infrastructure, particularly in solar and wind energy, to capitalize on Crete's natural resources. By expanding the role of RES, Crete could significantly reduce its dependence on imported fossil fuels, lower CO_2 emissions from thermal power plants, and enhance the sustainability of its energy system. To achieve these goals, a strategic approach is necessary, focusing on increasing RES capacity and improving energy efficiency.(Katsaprakakis et al., 2022)

Table 7: Analysis of the electrical system and the annual electricity production in Crete in 2019.

Units	**Installed power (MW)**	**Annual electricity production**		**CO_2 emission (tn)**
		(MWh)	(%)	
Steam turbines	204.3	936,645	30.5	2,686,392
Diesel generators	185.9	785,273	25.6	2,252,243
Gas turbines	320.8	204,490	6.7	586,497
Combined cycle	132.3	498,542	16.2	1,429,867
Hydro plant	0.6	737	0.0	0
Photovoltaics	107.4	135,964	4.4	0
Wind parks	200.3	510,275	16.6	0
Totals	**1,151.6**	**3,071,926**	**100.0**	**6,955,000**

The Electrical Interconnection of Crete

Currently, there exist two prominent plans by the Independent Power Transmission Operator (IPTO), for the interconnection of Crete into the primary power grid of Greece and by extension of Europe. The visual representation of these strategies can be observed in Figure 18. The technical characteristics of these interconnections are described in Table 8.

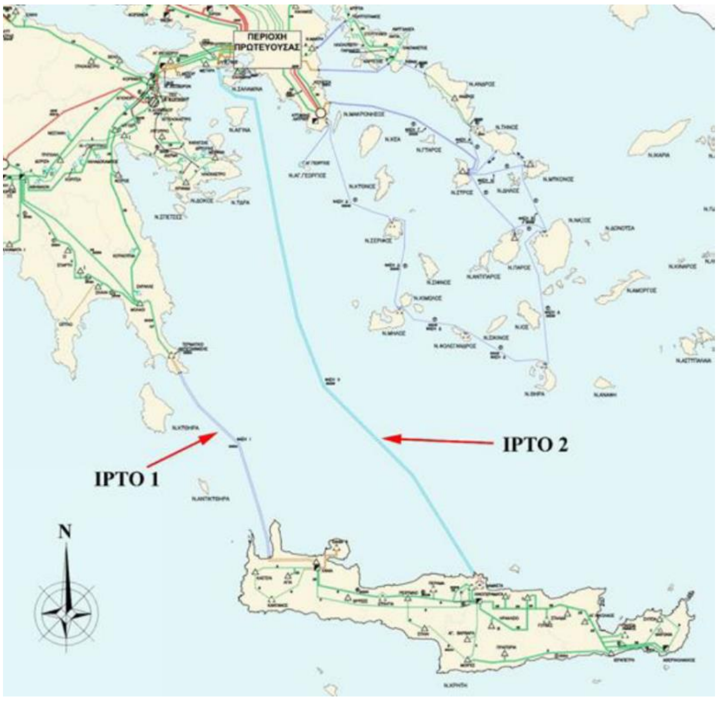

Figure 18 : Routes 1(IPTO 1) and 2 (IPTO 2) of the national electrical interconnection of Crete with the Greek mainland grid (Katsaprakakis et al., 2022)

Table 8: Technical characteristics of the planned electrical interconnections of Crete with the mainland grids of Greece (IPTO 1 and IPTO 2) (RAEEY, 2021)

	IPTO 1	IPTO 2
First operation	May 2021	N/A
Status	Completed	Under Construction
Route	Peloponesse – Western Crete (Chania Prefecture)	Attica region – Central Crete (Heraklion Prefecture)
Length	132 km	330 km
Nominal Voltage	150 kV AC	500 HV DC
Nominal Transfer Capacity	2 X 200 MVA	2 X 500 MVA

The main objectives of the electrical interconnections in Crete include:

- Increase the power grid's stability and level of energy security.
- Reduction of the high energy supply cost, aligned with the prevailing weighted average market price of the mainland grid (i.e. 132 EUR/kWh)(Independent Power Transmission Operator, 2023);
- Reduction of environmental burden on Crete throughout the gradual total or partial shut-down of the existing fossil-fuelled power plants.
- Increased and secure penetration of electricity produced exploiting local RES potential.

From a technical perspective, the feasibility of the electrical interconnections in Crete is obvious, since the existing isolated grid as interconnected will be capable of to react on energy demand stresses and potential unexpected events (power outage). In particular, the existing AC interconnection between Crete and the European grid plays a crucial role in stabilizing the island's power system, although it does not immediately position Crete as a significant producer of renewable energy sources (RES).(Paspatis et al., 2023)

Historically, damages to undersea cables, as seen in locations such as Tilos, Kasos, Aran Island, and Menorca, have demonstrated the limitations of relying solely on interconnections for the reliable provision of power to isolated grids. To ensure continuous electricity supply, fossil-fuelled power plants on Crete must be maintained in a "cold" standby mode, which inevitably increases electricity production costs, particularly when considering transmission losses. However, the installation of the HVDC (High Voltage Direct Current) interconnector is expected to significantly boost the deployment of RES units on Crete. This will enable the island to transition into a net exporter of electricity, contributing renewable energy to the European Power System. Such developments will help Crete capitalize on its substantial renewable energy potential, especially in solar and wind power, while reducing its reliance on fossil fuels.

The interconnection of Crete with the mainland grid is currently underway, managed by the Independent Power Transmission Operator (IPTO), the authority overseeing Greece's mainland grid. The first phase involves a 150 kV AC cable with a nominal capacity of 400 MW, expected to be completed by 2021 (IPTO 1). Following this, a second 400 kV DC cable, with a nominal capacity of 1 GW, is set to begin installation within the next few years (IPTO 2)(RAAEY, 2022; RAEEY, 2021). These advancements are vital steps toward modernizing Crete's energy infrastructure and integrating more renewable energy into its grid. In the broader area of the Municipality of Kissamos, the electrical infrastructure is integrated with the Public Power Corporation (PPC) network through a central substation located in Drapanias, which steps down the voltage from high to medium levels. From there, several substations convert the voltage from medium to low, ensuring the entire area is fully electrified. The substation in Drapanias is considered adequate to meet both the current and future energy needs of northern Kissamos.(RAAEY, 2022)

Replication case in Crete

In Crete, the integrated ROBINSON solution will be implemented in the community of Platanos, with a focus on the rusk bakery industry “the Manna” of “N. Tsatsaronakis S.A.” company. "The Manna" industry is among the largest bakery industries in Greece (Figure 19), with a greater than 40% market share in rusk products. The production methods include the use of ovens, dryers, and packaging automated assembly lines, while the company's R&D department proceeds with continuous tests or replacement of the mechanical equipment to improve its energy efficiency, productivity, and product quality. At the same time, a set of quality assurance systems, with constant checks, so that all products are produced under international food safety standards. The total production process takes place in a state-of-the-art plant of 9,000 m^2, with annual electricity consumption of 931 MWh and considerable diesel oil consumption equal to 398.1 tn/year. In that sense, the potential RES penetration through the ROBINSON solution could meet the large fossil-fuelled energy consumption offering a replicable plan for the industry sector in Greece (Energy Innovation, 2021; Savvakis et al., 2023).

Figure 19: The industrial processes of the Rusk bakery ("the Manna" of the N. Tsatsaronakis S.A." company)

The plant consists of two main buildings, where 16 hot air ovens and dryers, as well as a large deck oven, have been installed. Detailed data on oil consumption, as related to the hourly operation of key elements of the production plant, are summarized in Table 9. Moreover, the collected data on the energy consumption of the rusk bakery industry “the Manna” were analysed to adapt the energy flow profiles to the ROBINSON project solution. The facility consumes electricity primarily for production processes and preparatory units. Due to the increase in production during the summer, the reference industry's electric energy usage appears to be seasonal (Figure 20). More specifically, the monthly total energy consumption varied from 66,175.1 kWh (December 2020) to 121,163.1 kWh (July 2020), with 88,149.5 kWh being the mean value. Among the 1,057,794.1-kWh consumed in 2020, 41,47% were consumed from July to October(Savvakis et al., 2023).

For the other months of the reference year, the electrical consumption ranged from 66,175.1 to 79,187.6 kWh. The peak power demand fluctuated from 155.9 kW_{el} (March 2020) to 270.1 kW_{el}

(August 2020). Based on the measured energy data, May 2020 could represent the typical operation of the reference facility, as the total monthly consumption, the mean and peak power demand equalled 88,432.3 kWh, 119.1 and 205.4 kW_{el}, respectively. According to the results in Figure 20, both average power demand and total electricity consumption decreased slightly in August 2020. This finding could be related to the summer pause of rusk production. Additionally, a similar pattern will be evident by the end of December 2020. Respectively, the thermal energy usage related to the production processes taking place in the premises of the reference industry can be described in the Figure 21.(Savvakis et al., 2023)

Table 9: Annual oil consumption of the rusk bakery industry "the Manna" in 2020.(Energy Innovation, 2021)

Energy consumption sector	Diesel consumption (kg/h)
Building 1	
Rotary kiln (two-chambered)	8.6
Rotary kiln (two-chambered)	8.6
Deck surface kiln	13.0
Dryer of twelve cart	28.0
Rotary kiln (two-chambered)	8.6
Rotary kiln (two-chambered)	13.0
Rotary kiln of single cart	6.0
Total	**85.8**
Building 2	
Rotary kiln (two-chambered)	13.0
Rotary kiln (two-chambered)	13.0
Rotary kiln (two-chambered)	13.0
Rotary kiln of three cart	13.0
Rotary kiln of three cart	13.0
Rotary kiln (two-chambered)	8.6
Dryer of twelve cart	26.0
Dryer of sixteen cart	32.5
Dryer of sixteen cart	34.5
Rotary kiln of two cart	13.0
Total	**179.6**
Total	**265.4**

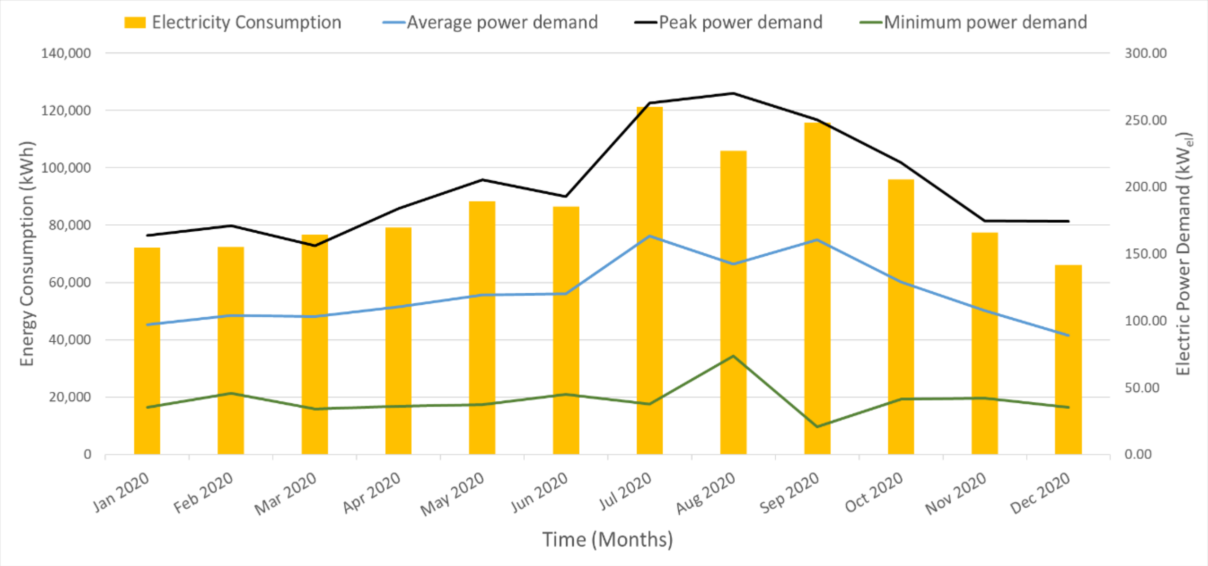

Figure 20: Variation of the total electricity consumption and average electric power demand per month (Savvakis et al., 2023)

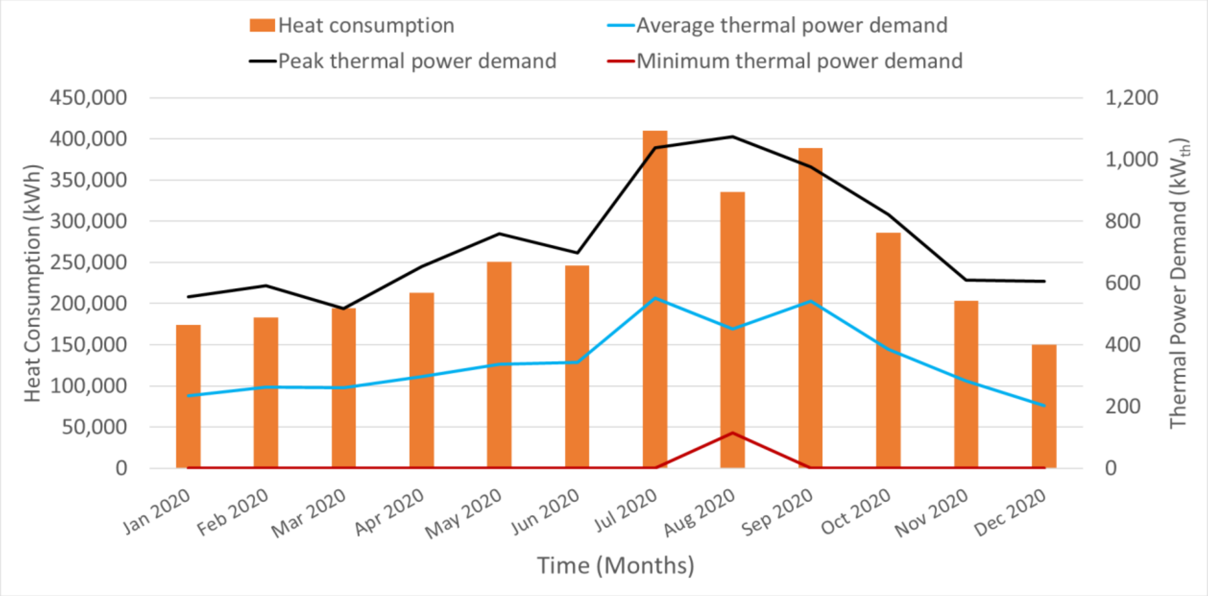

Figure 21: Variation of the total heat consumption and average thermal power demand per month (Savvakis et al., 2023)

Government policies regarding clean energy

The Integrated National Energy and Climate Plan (NECP) for 2021-2030 sets ambitious targets to increase the share of renewable energy sources (RES) in gross final energy consumption of Greece to 35% by 2030. In the electricity sector, the goal is to achieve at least 60% renewable energy. At the same time, RES is expected to cover 42.5% of the final energy consumption for heating and cooling, up from 30.6% in 2020. The transport sector is also a focus, with RES expected to rise from 6.6% in 2020 to 19% by 2030. By 2019, non-interconnected islands (NIIs) had already achieved over 18% of their total generation capacity through RES power plants. The NECP identifies two significant objectives for the Greek islands: interconnecting with the mainland grid and significantly reducing carbon emissions from thermal power plants. However, there is no detailed roadmap to guide how the clean energy transition will unfold on these islands. Ongoing efforts include accelerating the deployment of RES projects and hybrid plants on NIIs, upgrading distribution networks, and incorporating digitalisation to optimise energy efficiency. One of the significant challenges facing the electricity generation sector in NIIs is the regulated electricity price, which impedes the clean energy transition. Additionally, the need for more supportive policies for energy storage presents a significant hurdle, particularly for isolated energy systems (Apostolopoulos et al., 2020; Hellenic Republic, 2019). The Ten-Year Network Development Plan (TYNDP) of the Hellenic Electricity Transmission System (HETS) for 2022-2031 highlights islands like Crete's critical role in Greece’s energy transition. It outlines plans for connecting these islands to the mainland grid or developing self-sufficient RES systems. These actions are designed to cut electricity generation costs and provide environmental benefits by replacing fossil fuel-based thermal plants with renewable energy (Independent Power Transmission Operator, 2020). Further support for the energy transition in Greece is provided through the Territorial Just Transition Plan, which aims to channel €1.63 billion from the EU’s Just Transition Fund [4]into decarbonisation projects. The focus areas include Western Macedonia, Megalopolis, and adjacent regions and the phasing out of fossil fuel power stations on islands such as Crete and the North-South Aegean. Additionally, the National Action Plan for the Alleviation of Energy Poverty (2021-2023) offers policy measures, incentives, and subsidies to assist energy-poor households under the Territorial Just Transition Plan framework. (Hellenic Republic, 2019)

In conclusion, Crete aligns closely with national clean energy policies that focus on boosting the use of renewables, phasing out fossil fuels in thermal power plants, and improving energy efficiency across multiple sectors. Integrating RES, energy storage solutions, and enhanced grid interconnections is essential to achieving these goals. Crete's energy policies and developments are consistent with broader sustainable development goals, emphasising reducing carbon emissions and increasing energy self-sufficiency through local renewable resources. This approach not only addresses current energy demands but also positions Crete to meet future energy and environmental sustainability challenges. Overall, Crete's energy landscape is evolving with a strong focus on expanding renewable energy and modernising infrastructure to support the needs of its population and economy sustainably.

4.1.2.2. Estimation of the RES potential and possibilities for sustainable siting

Crete has substantial potential for renewable energy sources, particularly wind and solar. Current projects include wind parks and photovoltaic stations, with future for the IPTO and Euroasia Interconnector projects to connect Crete to the mainland grid, enhancing renewable energy integration. To evaluate the potential for RES in the area, an examination of renewable resources was done. Multiple datasets were compared to increase the simulations' accuracy and replicability. A clearer understanding of the economic feasibility of using olive pruning waste for energy production needs to be achieved. In the study area, the most part of agricultural land is dedicated to olive and olive oil production for the year 2021 equals 8,041.61 ha, representing a substantial biomass resource that could be used either for gasification or combustion toward sustainable energy production.(Savvakis et al., 2023)

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[4] https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/just-transition-fund_en

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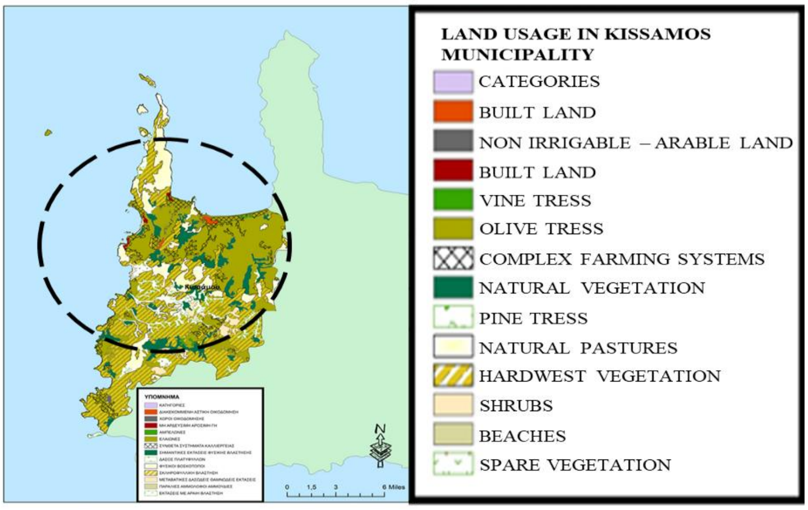

Figure 22: Agricultural activities in the municipality of Kissamos[5]

More specifically, olive pruning production per annum is estimated at 1.5 tons/ha to 3.2 tons/ha (Contreras et al., 2020; Kougioumtzis et al., 2022; Sifakis et al., 2024). Thus, considering the lower estimated olive tree pruning production and the pruning taking place only once every two years, the available biomass quantity for energy purposes will be 6,031.2 t/year. In the literature, a typical gasification ratio usually ranges from 2 to 3 Nm^3 of syngas per kg of biomass. The syngas density is about 0.9 to1.1 kg/Nm^3, while the LHV values range from 4.5 to 6 MJ/Nm^3 (Ribó-Pérez et al., 2021). Hence, the biomass potential that could be exploited through syngas production is estimated at more than 17.5 GWh/year.

In addition, the replication study in Crete is located in the western part of the island focused on the production of biogas from the exploitation of the agricultural residues coming mainly from the greenhouse tomatoes crops located at the western coastline of the island, as shown in this Figure 22. In total 800,000 m^2 of tomatoes crops are found in the specific location. In the most favourable case regarding the agricultural production, 1 tn of tomatoes residues are produced for every 1,000 m^2 of crops, while during years with extensive crops' diseases, the tomatoes residues can reach 4-5 tn for every 1,000 m^2 of cultivated land. An average biogas specific production from tomatoes residues is given at the range of 150 – 240 L/kg of volatile solids in the relevant literature, revealing the huge potential for biogas production in the area.

Figure 23 reveals the variation of the average daily radiation in the area of interest. Solar radiation is higher during the summer months (peaks on diagram), while it decreases significantly during the winter. The average solar radiation from the POWER database equals 5.36 $kWh/m^2/d$. Figure 24 demonstrates the variation of the monthly average wind speed over a year. In both the evaluated datasets, it is evident that during the winter months, the average wind speed is higher compared to the summer months. The lowest average monthly wind speeds are found during the summer months. In the study area, the prevailing Mediterranean climate with moderate winters and abundant sunshine indicates the possible implementation of sustainable energy solutions. In general, the winter lasts from December to March and can be described as slightly rainy with a total accumulated rainfall of 202.4 mm (year 2022). The average daily temperature during winter is 12.7 °C (it ranges from 0.7 °C to 21.4 °C), while during summer is 25.5 °C (varies between 18.3 and 34.9 °C) (National Observatory of Athens, 2023). During the summer, it has been observed that there is a nearly complete lack of

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[5] The circle represents a 10 km radius from exploitable waste.

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rainfall leading to an almost absolute drought climate. The solar potential in this area is considered favourable for the installation of PV systems, either in the ground or integrated into buildings, as the annual total solar irradiation on a horizontal surface is estimated equal to 5.2 kWh/m^2/d or 1,890 kWh/m^2/y (PVGIS, 2023). However, a comparable value of 4.46 kWh/m^2/d is recorded as slightly lower in related experimental results, published by (Savvakis & Tsoutsos, 2021). In 2022, the average wind speed was 4.7 m/s (National Observatory of Athens, 2023), while the corresponding value from other databases is 6.3 to 7.6 m/s (Savvakis et al., 2023).

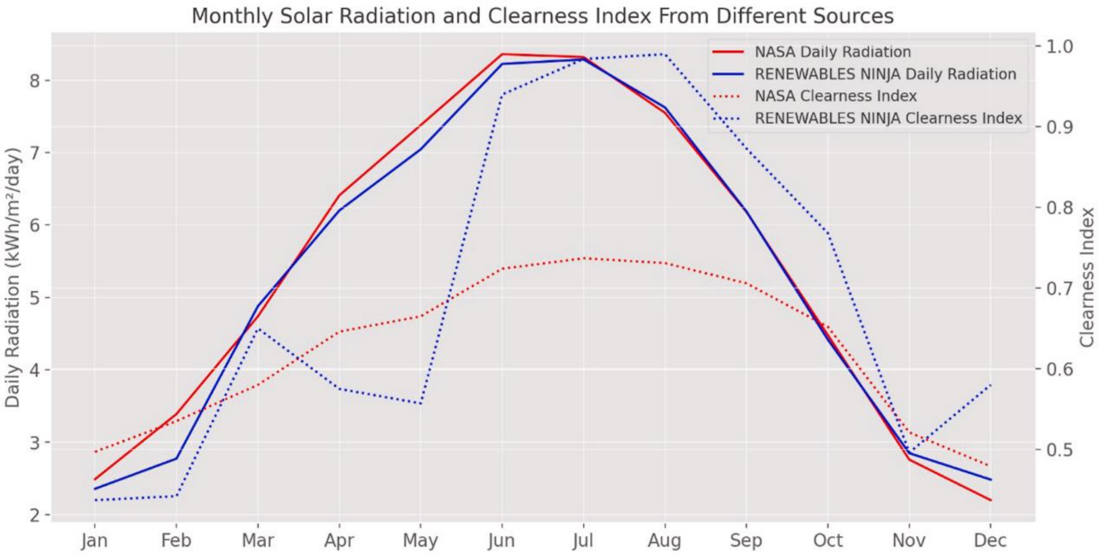

Figure 23: Average solar radiation per database (Savvakis et al., 2023)

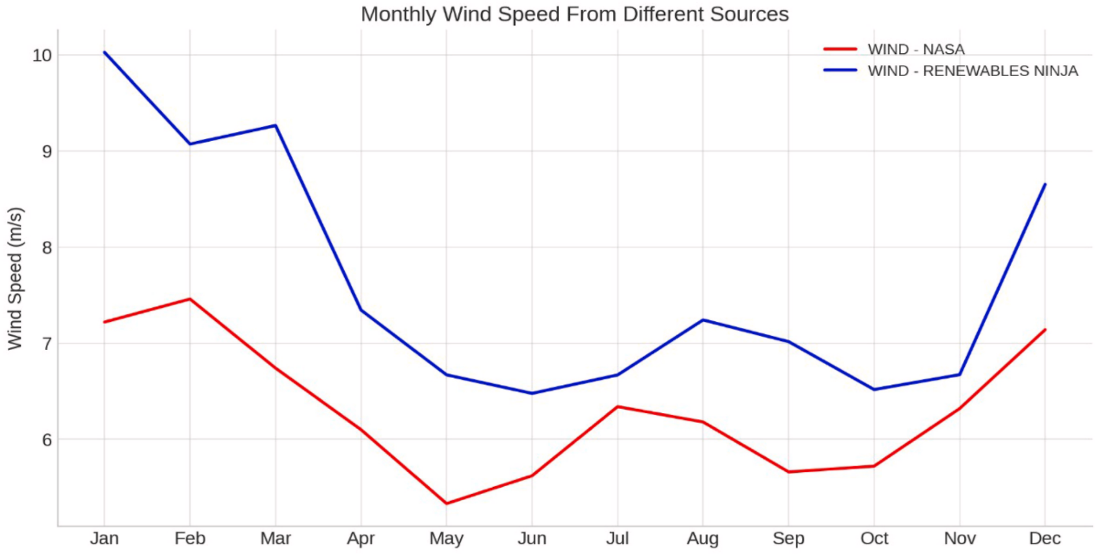

Figure 24: Monthly average wind speed at the study area (Savvakis et al., 2023)

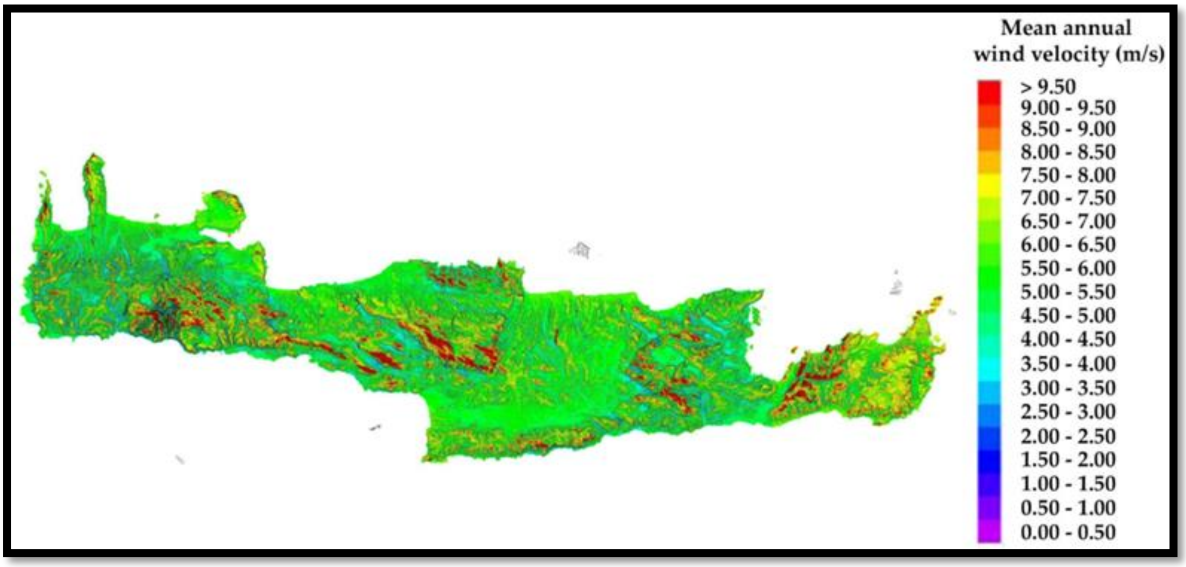

Figure 25: Annual average wind velocity on Crete Island, Greece.(Katsaprakakis et al., 2022)

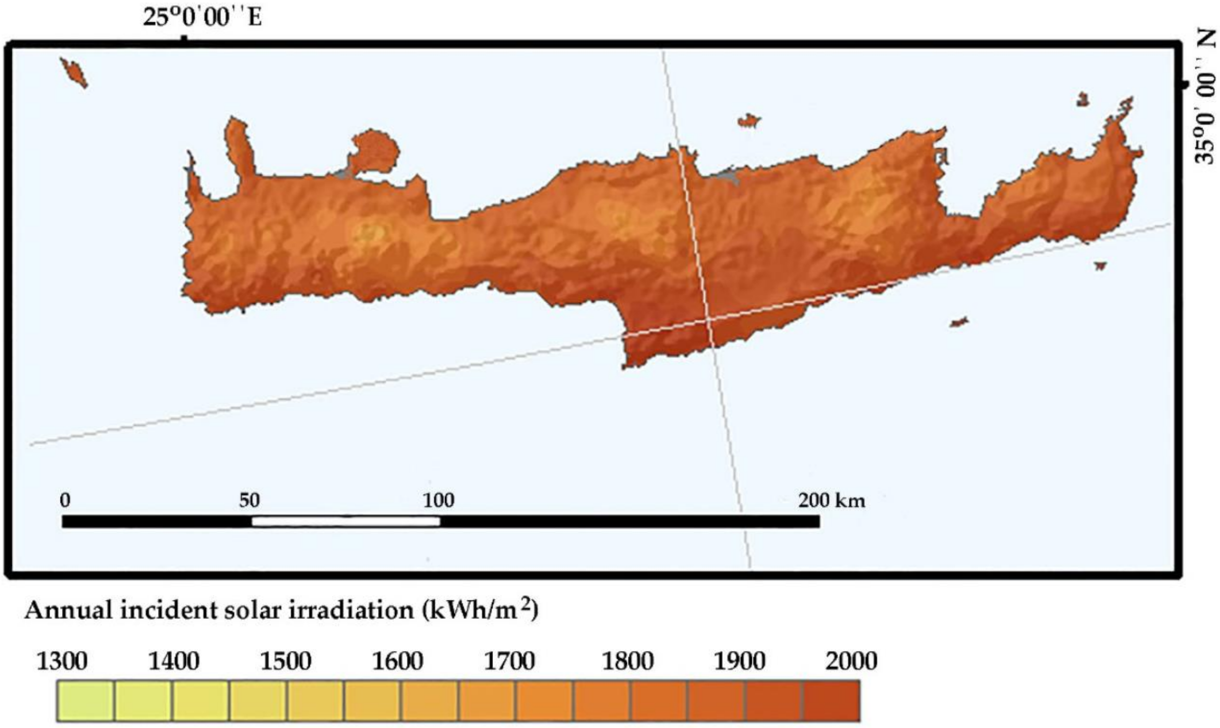

Figure 26: Annual average of global horizontal solar irradiation fluctuation in Crete Island (PVGIS, 2023)

4.1.2.3. Key Challenges addressed with the Replication Plan Development

With a clear understanding of the RES potential and sustainable siting options, we now address the key challenges that must be overcome to ensure the successful deployment of these solutions. The Replication Plan for Crete, particularly the Platanos community within the Municipality of Kissamos, addresses various critical challenges for ensuring a successful energy transition for the island and the local community. These challenges include high dependency on fossil fuels, energy infrastructure limitations, and the need for greater community engagement, all of which are intertwined within the broader context of Crete's energy strategy.

- **Dependence on Fossil Fuels:** Crete, including rural areas like Platanos, remains heavily dependent on fossil fuel-based power generation, such as diesel generators and thermal power plants. This reliance poses significant challenges regarding carbon emissions and energy costs as fuel prices fluctuate. The replication plan focuses on reducing this dependency by encouraging using renewable energy sources (RES), such as solar and wind power, which are abundant in Crete (Hellenic Republic, 2019). In Platanos, the plan promotes ROBINSON's solution, which focuses on solar panels and agricultural waste exploitation to provide cleaner, more sustainable energy for residents and the bakery industry.
- **Seasonal Energy Demand Fluctuations:** Crete experiences seasonal variations in energy demand, particularly during the summer months due to a surge in tourism. This is a challenge not only for Crete but also for smaller communities like Platanos, which rely on tourism and agriculture. The replication plan addresses these fluctuations by promoting energy storage systems and grid modernization. The ability to store excess energy during low-demand periods and redistribute it during peak times will stabilize the energy supply. This is particularly important for rural communities with less robust energy infrastructure.
- **Grid Infrastructure and Interconnection:** The existing energy infrastructure in Crete faces limitations. Interconnection with the mainland grid is a significant development for the island that will provide more reliable energy access and reduce reliance on local fossil fuel plants (RAEEY, 2021). In Platanos, developing a multi-energy system will upgrade grid stability and ensure that RES systems can be effectively integrated into the regional and island-wide energy networks.
- **Economic Constraints and Energy Poverty:** Rural communities like Platanos often face economic barriers when investing in renewable energy or improving energy efficiency. Many households may lack the financial resources to install solar panels or upgrade inefficient heating systems. The replication plan includes financial incentives and subsidies to help overcome these barriers, aligning with the national Territorial Just Transition Plan. By supporting energy upgrades, particularly for low-income households, the plan ensures that vulnerable populations can benefit from the energy transition without being left behind.
- **Stakeholder Engagement and Community Participation:** Crete and Platanos face challenges in engaging local communities in the energy transition process. The replication plan fosters greater community involvement by supporting the creation of Energy Communities, which collectively allows residents, farmers, and businesses to invest in renewable energy projects. For Platanos, local stakeholders will be directly involved in decision-making, investment, and the benefits of cleaner energy solutions.
- **Lack of Energy Storage Solutions:** The lack of energy storage infrastructure is a significant barrier to the full integration of RES in Crete and Platanos. Renewable energy generated during peak

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periods cannot be fully utilized without adequate storage. The replication plan prioritizes the development of energy storage systems, such as battery solutions and hybrid energy systems, which will enable better management of energy supply and demand fluctuations.

- **Regulatory and Financial Barriers**: The regulated electricity prices in non-interconnected islands like Crete are a significant barrier to promoting renewable energy solutions. The replication plan advocates for policy reforms that unlock financial support for renewable energy and energy storage projects. This includes exploring incentives and subsidies for local communities and businesses to invest in energy efficiency measures and renewable energy installations.(European Commission. Directorate General for Energy., 2023)
- **RES-Scale Identification**: This priority involves the identification of suitable renewable energy sources (RES) and their scale in the context of the local terrain, such as in Crete. It emphasizes the need to adapt renewable energy projects to fit the specific geography and conditions of the area, including considering small-scale RES solutions where applicable (*Rethinking Energy 2017*, 2017).
- **Adoption of WtE Approach**: This priority focuses on the adoption of a Waste-to-Energy (WtE) approach, which entails converting waste materials into usable forms of energy, such as electricity and heat. The aim is to integrate waste management with energy generation to reduce environmental impacts and enhance resource efficiency.
- **Local Energy Generation**: Prioritizing local energy generation involves the development and promotion of clean energy projects within the community. This can include initiatives like community solar installations, small-scale wind turbines, and microgrid systems, aiming to reduce reliance on non-renewable energy sources.
- **Addressing Social Acceptance**: This priority highlights the importance of addressing social acceptance issues related to clean energy projects. It involves engaging with the local community, providing education about clean energy benefits, and employing transparent communication strategies to address concerns and gain public support for these initiatives.(Wüstenhagen et al., 2007)

The replication plan for Crete and Platanos tackles the key challenges of transitioning to a sustainable energy system by addressing fossil fuel dependency, seasonal demand fluctuations, and infrastructure limitations. By promoting renewable energy adoption, fostering community engagement, and supporting energy storage solutions, the plan creates a pathway for a resilient, low-carbon future. These efforts are crucial not only for meeting Crete’s broader energy goals but also for ensuring that smaller communities like Platanos can actively participate in and benefit from the island's clean energy transformation.

4.1.3. Involving Key Stakeholders for Replicating Sustainable Energy Solutions

Given these identified challenges, the active involvement of stakeholders is crucial to effectively navigate these barriers and ensure a successful replication of energy solutions. The successful replication of sustainable energy solutions in Crete, particularly within the replication study framework, requires active involvement and engagement of various key stakeholders. These stakeholders come from different sectors, including agriculture, hospitality, education, and local government. Engaging these parties early in the process is crucial for ensuring that the energy solutions are tailored to their needs, efficiently implemented, and have a lasting impact on the community.

4.1.3.1. Key Stakeholders for Replicating Sustainable Energy Solutions

In the replication study in Crete, several important stakeholders have been identified as potential final beneficiaries. These stakeholders will directly influence and benefit from the adoption of sustainable energy practices.

- **Tomato Greenhouse Owners and Operators**: One of the primary beneficiaries includes the owners and operators of tomato greenhouses, who represent a significant part of the agricultural economy in Crete. Key organizations in this sector include Agrifal, Platanos Cooperative, Iakovos Farm, Producers Group from Falasarna, Tsatsaronakis Vasilis, Nikolakakis General Partnership, and Spiliotis. By adopting renewable energy solutions, such as solar power for heating and electricity, these stakeholders could reduce their operational costs and carbon footprint while improving the sustainability of their operations.
- **Bakery Industry**: The bakery factory “To manna Tsatsaronakis” is the central stakeholder, with high energy consumption—931 MWh annually for electricity and 398 tons of diesel oil used per year. Implementing energy-efficient technologies and transitioning to cleaner fuels, such as biogas or solar energy, could significantly reduce operational costs and emissions.
- **Residents**: The study area (Platanos Kissamos) is inhabited by approximately 1,233 people, who are mainly employed in greenhouse crops, olive oil and wine production, tourism and animal husbandry, with the average energy consumption per household amounting to approximately 3,540 kWh.
- **Technical University of Crete**: The Technical University of Crete will play a pivotal role in the scientific implementation of the study, providing expertise in energy systems, technology integration, and environmental impact assessment. Their involvement ensures that the study is grounded in research and best practices, contributing to its success and potential scalability.
- **Region of Crete**: As a supervisory body, the Region of Crete will oversee the project, ensuring compliance with regulatory frameworks and supporting the dissemination of results. Their role is crucial for facilitating collaboration among different stakeholders and ensuring that the lessons learned are applied across other regions of the island.
- **Olive Oil Cooperative in Platanos** (*candidate*): Producing 1,000 tons of olive oil annually, the Platanos Olive Oil Cooperative generates residues such as olive kernels and liquid waste. This provides an opportunity for sustainable energy solutions like biomass-based energy generation,

which can convert these residues into valuable energy resources, improving waste management and energy self-sufficiency.

- **Minoan Energy Community**: The Minoan Energy Community, the first and largest energy community in Crete, will contribute by sharing technology and methodologies that can support the transition to renewable energy. Their involvement will be key to ensuring the replication study's success and encouraging broader adoption of the solutions across Crete.

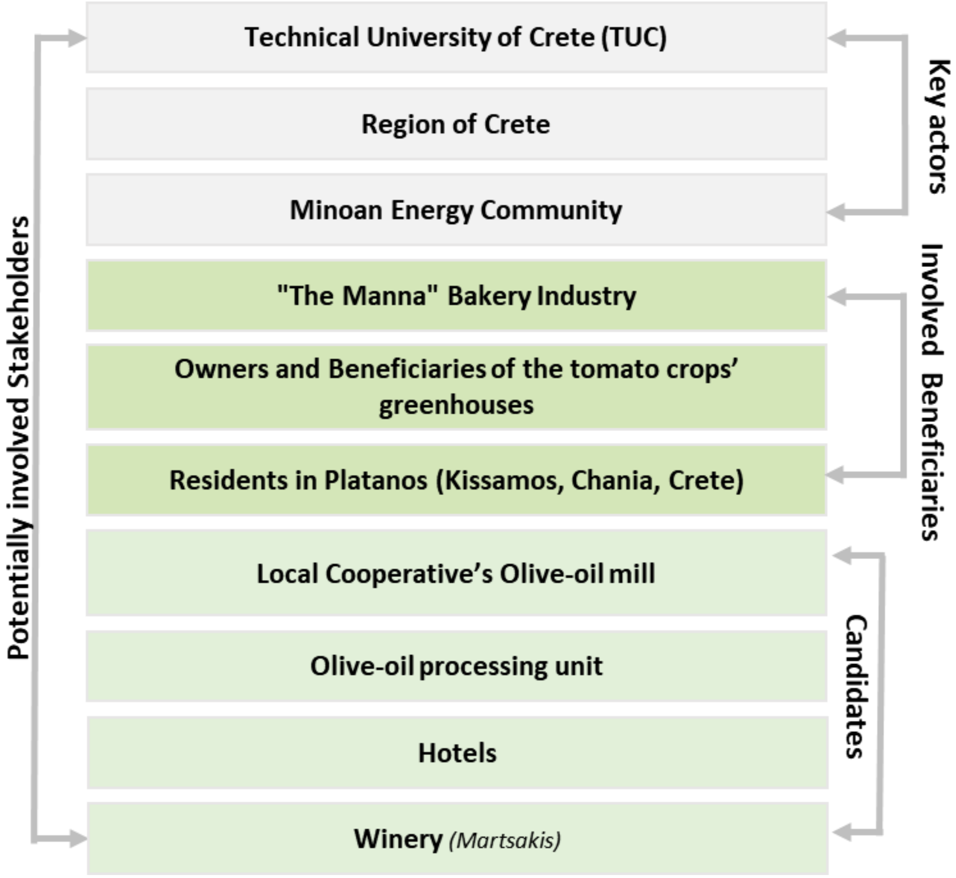

Figure 27 : Mapping of relevant local stakeholders

4.1.3.2. Engagement of all stakeholders and end-user from the beginning

To ensure the success of the replication study and the effective implementation of sustainable energy solutions, it is essential to engage all stakeholders and end-users from the outset. Early engagement fosters a sense of ownership among stakeholders and ensures that their specific needs and concerns are considered during the planning and execution phases.

- **Collaborative Workshops**: Organizing collaborative workshops with stakeholders such as greenhouse operators, hotel owners, and local cooperatives will provide a platform for discussing the challenges and opportunities associated with the adoption of renewable energy. These workshops can also serve to educate stakeholders about the potential financial and environmental benefits of transitioning to cleaner energy sources.
- **Customized Solutions**: By involving stakeholders early in the process, it becomes possible to tailor solutions to the unique needs of each group. For example, the energy requirements of a tomato

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greenhouse differ from those of a hotel, and the specific waste produced by olive oil processing may require customized biomass solutions. Early engagement helps identify these nuances, allowing for more effective and relevant energy solutions.

- **Regular Communication and Feedback Mechanisms**: Establishing channels for regular communication ensures that stakeholders can provide feedback throughout the study. This ongoing dialogue is critical for adjusting the implementation as needed and ensuring that the solutions are practical and beneficial for all parties involved.
- **Pilot Projects and Demonstrations**: Engaging stakeholders through pilot projects and demonstrations can help build trust and demonstrate the effectiveness of the proposed solutions. By showing real-world examples of how renewable energy systems can reduce costs and improve efficiency, stakeholders are more likely to embrace these technologies.
- **Support for Policy and Financial Mechanisms**: Finally, involving government authorities such as the Region of Crete ensures that the project has the necessary policy and financial support to succeed. Engaging stakeholders in discussions about incentives, grants, and financial mechanisms that make the transition to renewable energy more accessible will be key to ensuring long-term adoption.

4.1.3.3. Assignment of responsibilities to the competent stakeholders

To ensure the successful replication of sustainable energy solutions in Crete, it is crucial to clearly define and assign responsibilities to the various competent stakeholders involved. This assignment of roles will streamline the implementation process, clarify accountability, and facilitate cooperation among stakeholders from different sectors. The responsibilities will be distributed based on expertise, capacity, and influence on the relevant sectors.

Table 10: Roles and responsibilities of stakeholder groups

Stakeholder	Role	Responsibilities
Technical University of Crete	The Technical University of Crete will provide scientific oversight and technical expertise, responsible for research, data analysis, and developing frameworks for integrating renewable energy solutions.	• Designing, testing, and optimizing renewable energy systems. • Ensuring EU and local regulatory compliance. • Providing technical support and training throughout the project.
Region of Crete	**Region of Crete** will oversee the project, ensuring that the replication study aligns with regional policy frameworks and broader sustainability goals.	• Supervising the project and coordinating stakeholders. • Disseminating results and best practices across Crete. • Securing financial support from local and EU sources. • Ensuring compliance with planning and environmental regulations.
Minoan Energy Community	The Minoan Energy Community, Crete's largest energy cooperative, will play a key role in facilitating technology transfer and knowledge-sharing to scale solutions across the island.	• Providing technical expertise and sharing successful energy practices from past initiatives.

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Stakeholder	Role	Responsibilities
		• Assisting in the design and installation of renewable energy systems
Local Agricultural Cooperatives & Businesses	Agricultural cooperatives like Platanos Cooperative and other greenhouse and crop owners will be key beneficiaries of the energy solutions.	• Providing feedback on performance and challenges. • Supporting ongoing monitoring and data collection
Munipality of Kissamos	Local municipalities and administrative bodies will ensure that the project is implemented within the legal frameworks and contribute to local community outreach efforts.	• Facilitating permits and licenses for energy system installation. • Engaging local communities and informing them of the project's goals. • Monitoring compliance with environmental and planning regulations.
Private Energy Suppliers and Contractors	Private energy suppliers, such as those providing LPG, biomass, and solar energy systems, will play a crucial role in the technical deployment and servicing of the renewable energy solutions.	• Supplying, installing, and maintaining renewable energy systems for the agricultural, industrial, and hospitality sectors involved in the project. • Offering technical support and maintenance services to ensure optimal system performance. • Assisting with the training of local technicians and service providers for the long-term sustainability of the project.

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4.1.4. Replicating Sustainable Energy Solutions

The major goal of the ROBINSON project is to support islands in achieving decarbonization by maximizing the share of Renewable Energy Systems (RES) and enhancing grid flexibility through innovative energy storage solutions and other emerging clean technologies. The project not only focuses on implementing specific solutions on the Lighthouse (LH) island but also aims to explore and evaluate the feasibility of replicating these solutions on a larger scale across its Follower Islands (FIs). This approach is essential for driving long-term energy transition on the islands. Each use case within the ROBINSON project integrates both innovative and conventional technologies, targeting a common objective of enhancing the island's renewable energy capacity and impact. The replication activities are designed to identify the most effective solutions and adapt them to the unique energy landscapes of the FIs. This ensures that lessons learned and successful outcomes from the LH island can be scaled and implemented on the Fellow Islands, contributing significantly to their decarbonization goals. Through these replication activities, the ROBINSON project seeks to extend the impact of its innovations, ensuring they are applicable and beneficial to other island communities working towards a sustainable energy future.

4.1.4.1. Technical components/ infrastructure selection

The "Manna" Tsatsaronakis bakery in Crete serves as the case study for evaluating the replicability of the ROBINSON solution. Located in Kissamos, the bakery has significant electricity and heat demands, making it an ideal candidate for implementing the proposed multi-energy system (MES). Moreover, in the community of Platanos, households could benefit from an integrated energy system by participating in the ROBINSON solution.

Given the agricultural activity in the community of Platanos, particularly tomato farming, there is potential for producing biogas from tomato residues. This biogas could be utilized in Combined Heat and Power (CHP) plants, providing electricity and heat to meet the energy needs of nearby facilities, including the "Manna" bakery. The bakery's considerable demand for electricity and high-temperature heat makes it an exemplary candidate for integrating renewable energy and waste-to-energy technologies. In addition to biogas production, there is strong potential for harnessing solar and wind energy to meet local energy demands further. The preliminary techno-economic analysis conducted by the TUC, has identified key technologies and appropriate system designs that could effectively supply the energy needs of the reference industry.

However, certain regulatory limitations must be considered in the technical component selection. According to the existing legal framework, the installation of wind turbines with a nominal capacity exceeding 60 kWp is restricted (Ministry decision: ΥΠΕΝ/ΔΑΠΕΕΚ/74462/2976). Additionally, PV systems with a capacity of up to 500 kW require specific permissions. The production of biogas from agricultural residues also requires environmental permits and other authorizations as outlined in the Ministry decision Y.A. 1958/2012. Based on the analysis and current regulatory landscape, the energy system for the "Manna" bakery and surrounding local households will include a combination of biogas CHP, solar PV, and small wind turbines. These technologies will not only meet the bakery's energy needs but also contribute to the region's overall decarbonization, making the system both sustainable and economically viable.

Table 11: ROBINSON technology components (PSI, 2021; UNIVERSITA DI GENOVA, 2021)

Component	Name	Status	
CHP unit	Aurelia® A400	-	**R**
Boiler	Weishaupt WKG80/3-A ZM-NR	-	**R**
PV panels	IBC Solar 265 CS4	-	**R**
Wind turbines	V-Twin 100	-	**R**
Electrolyser	H2B2 – ELN20/***NEL – MC250***	-	**R**
Gasifier	Syncraft Gasifier.	-	**R**
AD-BES	Anaerobic Digestion Assisted by Bio-Electrochemical System (AD+BES) by Hysytech	-	**R**
Gas mixer	-	-	-
Storage systems	Hydrogen Storage/Batteries	-	**R**
EMS	ROBINSON's EMS	-	**R**
Grid	-	**D**	-
Industrial symbiosis	-	-	**R**
D: The solution is demonstrated **//** **R:** The solution is planned to be Replicated			

The initial selection of components for the ROBINSON project's replication plan in Crete was driven by the specific energy demands of the "Manna" Tsatsaronakis bakery, as well as the goal of optimizing renewable energy use to achieve decarbonization. The key components chosen for the Multi-energy System (MES) aim to balance electricity and heat generation while incorporating flexibility and regulatory compliance, as described in D3.5-Validation report of the EMS for Crete and Western Islands. In particular, the test case for Crete include:

- **Biogas-based Combined Heat and Power (CHP) Unit:** A 240 kW_{el} turbine that operates on biogas, syngas, and hydrogen has been selected as the central component for combined heat and power generation. This turbine is also capable of producing 370 kW_{th} in CHP mode, ensuring that both the electricity and heating needs of the bakery are met efficiently. The biogas will be produced from agricultural residues, such as tomato waste, making it a sustainable solution for both waste management and energy production.
- **Photovoltaic (PV) Panels**: To harness Crete's abundant solar potential, a 240 kWp PV array has been included in the system design. These solar panels will provide a significant portion of the electricity demand, particularly during peak sunlight hours, reducing reliance on external energy sources and lowering overall emissions.
- **Wind Turbine:** Six 10-kW wind turbines has been selected to complement the solar PV system. The wind turbine is sized to operate within the limits imposed by local regulations. This addition allows for continuous electricity generation, particularly during periods when solar energy is less available, providing a balanced mix of renewable energy sources.
- **Hydrogen Storage and Electrolysers:** To further enhance the flexibility of the system, two 500 kW electrolysers and a 40 m^3 pressurized hydrogen storage vessel have been integrated. The electrolysers will convert excess renewable electricity, particularly from solar PV and wind, into hydrogen, which can be stored and later used to fuel the CHP unit or for transportation needs. This hydrogen storage system not only provides a buffer for fluctuating renewable energy generation but also supports the decarbonization of the local energy system.

- **Boiler System:** A 450-kW boiler fuelled by liquefied petroleum gas (LPG) has been incorporated into the system as a backup heat source. This boiler will be utilized when renewable sources are insufficient to meet the heating demands, ensuring reliability in heat supply, particularly during peak demand periods in the winter.
- **Grid Connection and System Converter:** The system includes a 271-kW converter to handle the integration of different energy sources and manage the conversion between AC and DC power. Additionally, the system remains connected to the grid to ensure stability and flexibility, with the ability to sell excess electricity generated by the PV and wind systems back to the grid.

(NORCE, 2022)

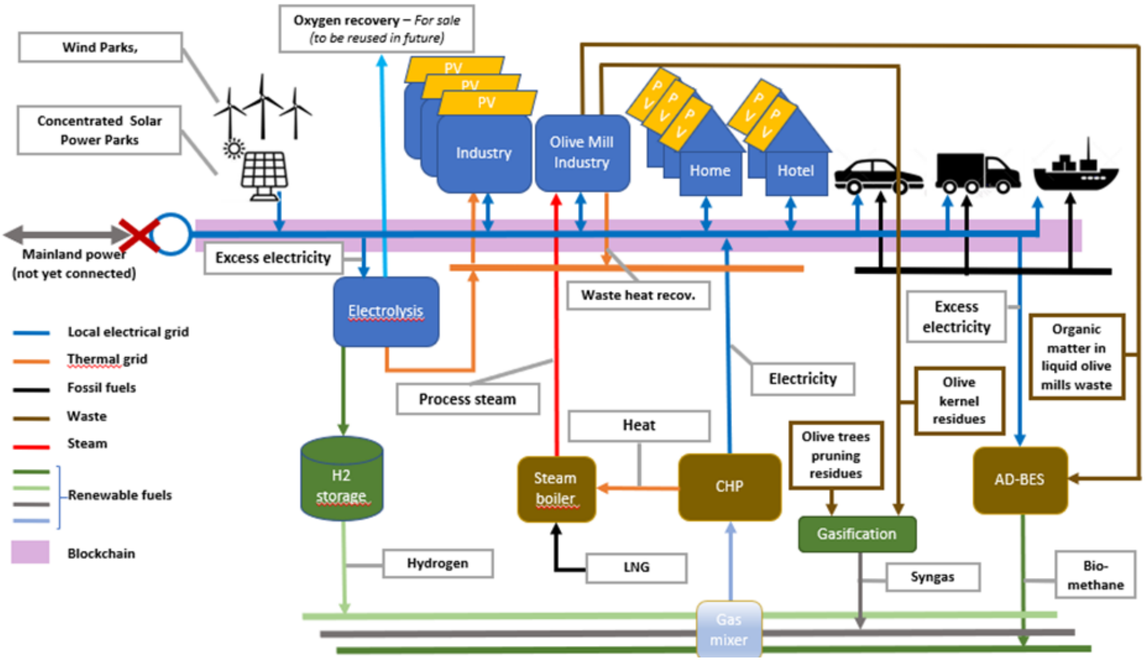

Figure 28 : Theoretical replication of ROBINSON system (UNIVERSITA DI GENOVA, 2021)

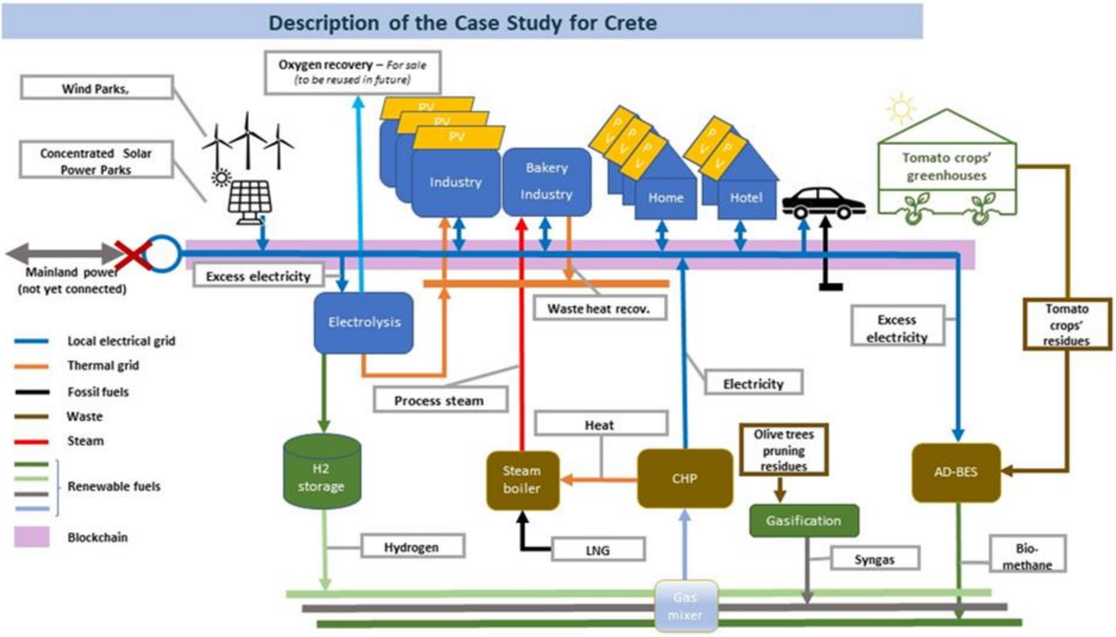

Figure 29: Proposed ROBINSON solution for application in the island of Crete (Energy Innovation, 2021)

4.1.4.2. Design and optimise the replication model

In the application of the ROBINSON solution for the island of Crete, two distinct simulation stages were carried out to model and assess the performance of the Multi-Energy Systems (MES). These simulations were crucial to evaluating both the preliminary and advanced stages of the replication model's design and optimization. The first stage involved the preliminary assessment of the MES using the software HOMER Pro. In this phase, the collected data related to energy demands, resource availability, and system configurations were inputted into the HOMER Pro model. This software enabled a simulation that incorporated key components such as solar photovoltaics (PV), wind turbines (WT), biomass gasification, and anaerobic digestion (AD), all within the context of Crete's local conditions. The objective of this initial simulation was to identify the optimal system architecture for energy generation, focusing on maximizing renewable energy penetration and minimizing costs. The HOMER Pro model allowed for the exploration of various energy scenarios, including cost minimization, renewable energy optimization, and greenhouse gas (GHG) reduction. This stage provided a preliminary understanding of the system's capabilities, highlighting the potential for significant reductions in the Levelized Cost of Electricity (LCOE) and GHG emissions.

Following the results of this initial simulation, the second stage of the simulation focused on advanced system management using the Energy Management System (EMS) approach developed within the ROBINSON project. This simulation introduced a more dynamic control of energy production and storage, particularly focusing on the integration of renewable energy sources and hydrogen storage. The EMS, utilizing a Model Predictive Control (MPC) module, was responsible for optimizing the operation of Combined Heat and Power (CHP) units, electrolysers, and hydrogen storage. This stage of simulation aimed to test the system's ability to adapt to real-time changes in energy demand and electricity prices, ensuring that renewable resources were prioritized whenever possible.

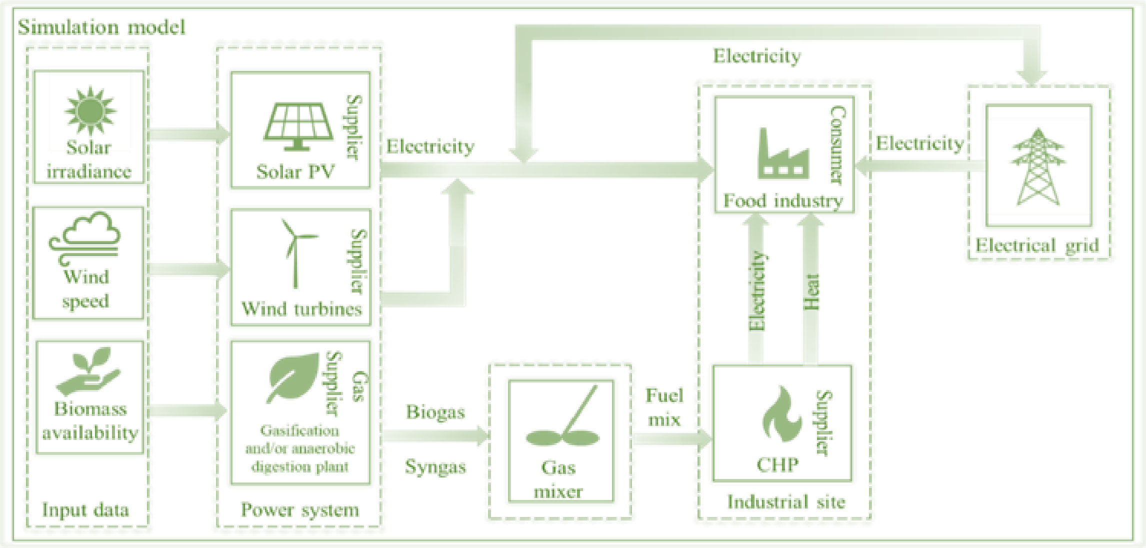

Figure 30: Schematic diagram of the initially proposed MES. The figure is obtained from Savvakis et al., 2023

The first stage of the simulation, conducted with **HOMER Pro**, focused on modelling and simulating the core components of the MES to establish a preliminary assessment of the system's architecture and its feasibility in Crete. The key Components for this simulation were:

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- **Solar Photovoltaics (PV)**: A 240 kWp solar PV array was included to capture the abundant solar energy available on the island, particularly during the peak hours of daylight.
- **Wind Turbines (WT)**: A 60 kWp wind turbine was integrated to supplement electricity generation during off-peak solar hours, especially overnight when the wind resource is more consistent.
- **Biomass Gasification and Anaerobic Digestion (AD)**: Biomass resources, particularly **olive tree prunings (OTP)** and tomato crop residues, were used for gasification to produce syngas for Combined Heat and Power (CHP) units, while the AD process allowed for biogas production, offering a renewable source of thermal and electrical energy.

The HOMER Pro software modelled several scenarios to assess the performance and economic viability of the system under different configurations. The main outcomes of the analysis summarised as follows:

1. **Business as Usual (BAU)**: This scenario simulated the current energy setup in Crete, largely reliant on fossil fuels, providing a baseline for comparison. The reliance on the carbon-intensive Cretan power grid resulted in high operational costs and CO_2 emissions.
2. **Cost-Minimization**: This scenario aimed to optimize the system purely from a cost perspective, without environmental constraints. The model revealed that a mix of PV and biomass gasification provided the most cost-effective solution, reducing the **Levelized Cost of Electricity (LCOE)** by **65%**, from 0.4362 €/kWh to 0.1533 €/kWh . This scenario demonstrated that solar PV and biomass gasification could provide significant cost savings and reduce dependence on fossil fuels.
3. **GHG-Minimization**: In this environmentally focused scenario, the simulation aimed to minimize life-cycle greenhouse gas (GHG) emissions. While this led to slightly higher costs compared to the cost-minimization scenario, it resulted in significant carbon savings. The renewable fraction of the system increased to **87.9%**, with a **63% reduction in CO_2 emissions**. The biomass gasification system proved highly effective in achieving these results, demonstrating its potential for low-carbon energy production in Crete.
4. **Constrained Scenarios (Regulatory Compliance)**: These scenarios incorporated local regulatory restrictions, such as limits on the installed capacity of solar PV and onshore wind. Despite these constraints, the system still achieved **significant cost reductions** and a renewable energy fraction of over **70%**, showing that even under regulatory limitations, the MES could deliver substantial improvements over traditional fossil fuel systems.

The HOMER Pro simulation also revealed the importance of technological flexibility. The ability to integrate various renewable energy sources, particularly the combination of PV, wind, and biomass, provided robustness in meeting the energy demands of the Bakery Industry, including both electrical and thermal loads. The simulation also identified that **solar PV** was the dominant contributor during daylight hours, while **wind turbines** provided consistent power generation at night, helping balance the energy supply throughout the day.

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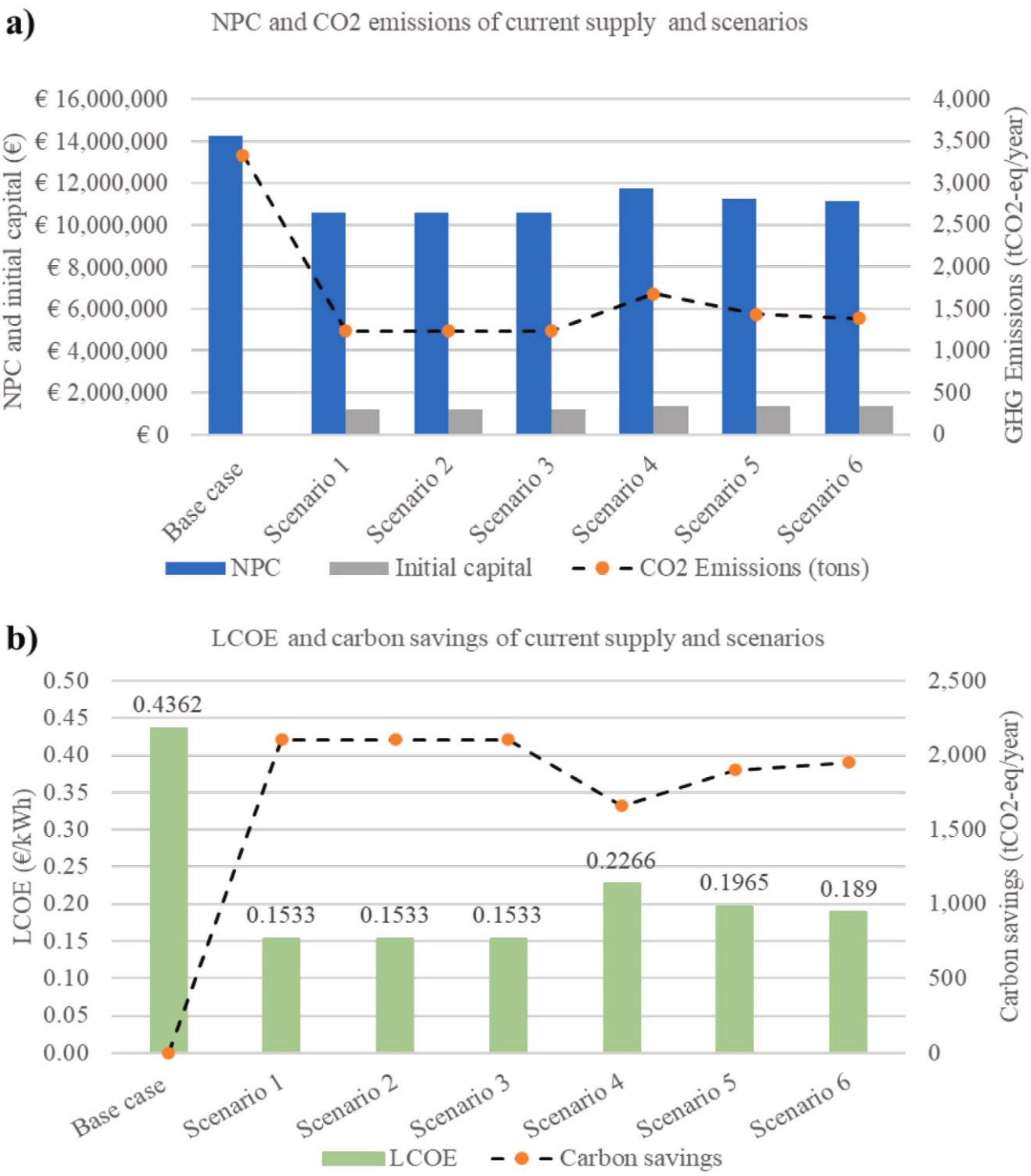

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*Figure 31: **a)** NPC, initial capital, and carbon savings of the baseline and the scenarios cases **b)** LCOE and carbon savings of the baseline and the scenarios cases. The figure is obtained from (Savvakis et al., 2023)*

Table 12: Optimal MES architecture.(Savvakis et al., 2023)

Component	Name	Size	Unit
Generator	Generic Biogas Genset (size-your-own)	120	kW
PV	Generic flat plate PV	240	kW
Wind turbine	Generic 10 kW	60	kW
Converter	System converter	271	kW
Boiler	Generic Boiler	1	quantity
Grid	Grid	1000	kW
Dispatch strategy	HOMER Cycle Charging	–	–

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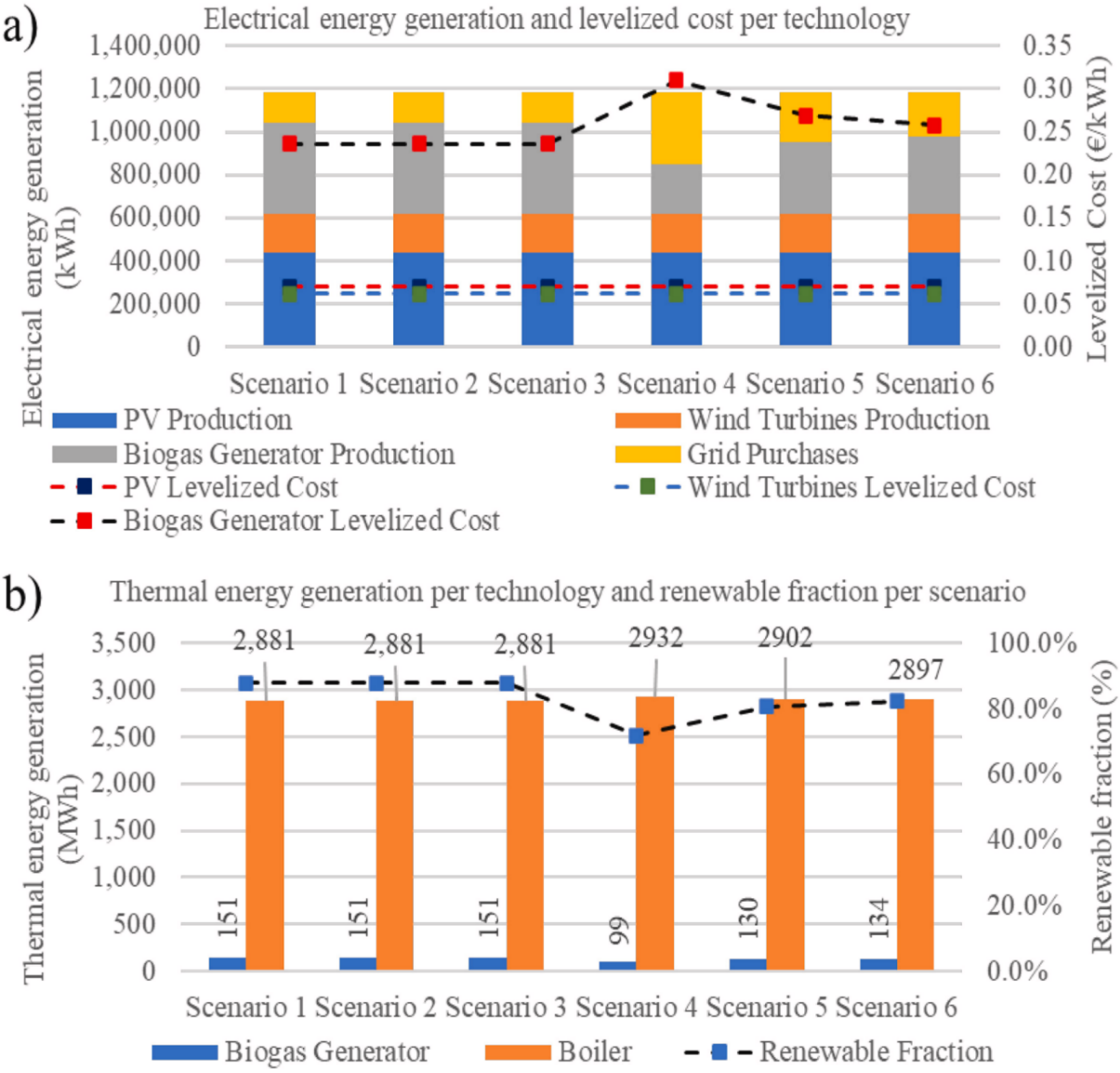

Figure 32: Electrical energy generation, and LCOE per technology, b) Thermal energy generation and RF per technology. The figure is obtained from (Savvakis et al., 2023)

Following the initial HOMER Pro simulation, the second stage introduced the **Energy Management System (EMS)** with **Model Predictive Control (MPC)**, providing a more advanced level of system optimization. This simulation focused on dynamically managing the integration of renewable energy sources, CHP units, and hydrogen storage within the MES, responding to real-time changes in energy demand and price fluctuations. The EMS aimed to optimize the system's operation by continuously monitoring energy prices, demand patterns, and resource availability.

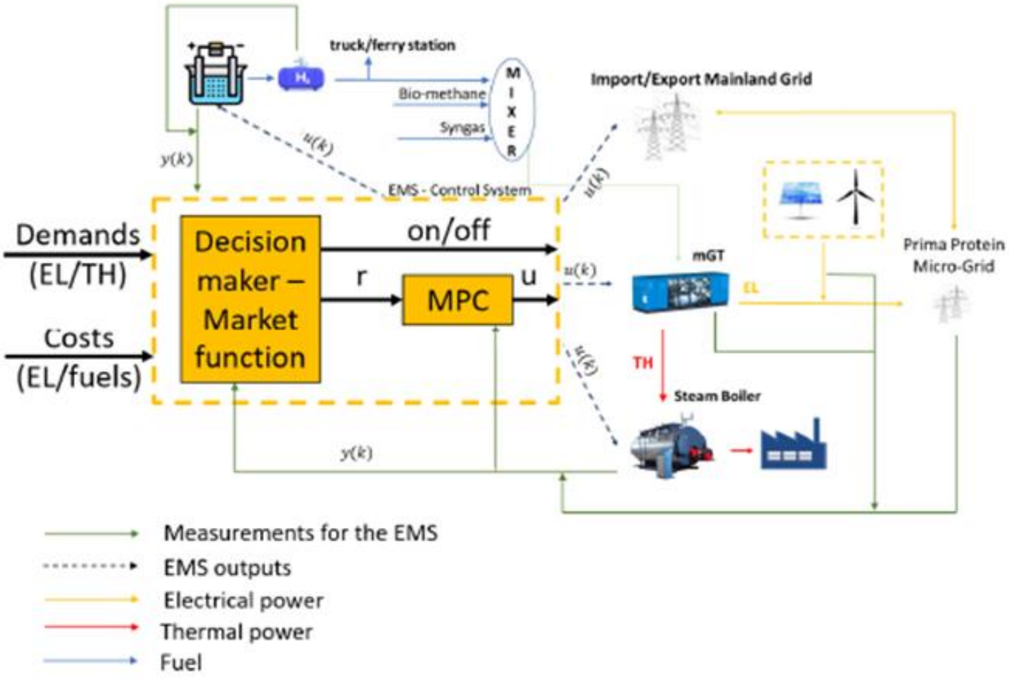

Figure 33: Energy Management System (EMS) with Model Predictive Control (MPC) simulated. (UNIVERSITA DI GENOVA, 2023)

The system prioritized renewable energy generation, particularly from PV and wind, while managing the operational flexibility of the CHP unit and hydrogen storage.

1. **Electricity Production and Management**:
    - The EMS simulation showed that **solar PV** provided the majority of the electricity during daylight hours, with peak solar generation exceeding **200 kW**. The **wind turbine** contributed significantly during the night, ensuring continuous power supply throughout the 24-hour cycle.
    - During periods of high renewable energy production, the EMS adjusted the operation of the CHP unit to avoid running it when cheaper, cleaner renewable energy was available. This dynamic control led to a reduction in CHP operation during peak solar hours, reducing reliance on fossil fuels and operational costs.
    - The EMS also demonstrated the ability to **minimize operational costs by 5.4%**, compared to a non-EMS controlled scenario. This was achieved through strategic management of electricity prices and the system's flexible response to real-time fluctuations in demand and renewable energy generation.
2. **Thermal Energy Management**:
    - The EMS improved the management of the thermal energy system by coordinating the operation of the CHP unit with the thermal load of the bakery industry. When renewable energy sources were available, the EMS reduced reliance on the CHP, instead using the backup boiler to meet the thermal demands when necessary.
    - In periods of lower renewable generation, the EMS prioritized CHP operation to provide both electricity and heat, minimizing the use of conventional energy sources.

   - The system’s ability to adjust the operation of CHP units, especially during peak energy costs, resulted in a **1.7% reduction in CO_2 emissions**, even though the reliance on the boiler (fed by LNG) somewhat limited further emissions reductions.

3. **Hydrogen Production and Storage**:
   - The simulation also focused on **hydrogen production and storage** using electrolyzers. The EMS effectively managed hydrogen production during periods of low electricity prices, storing hydrogen for later use. This helped optimize the system's operation by ensuring that hydrogen was produced when the cost was favorable.
   - A notable observation was the pressure variations in the hydrogen storage vessel. Early in the day, when electricity prices were lower, the system increased hydrogen production. Later in the day, during peak price periods, hydrogen was discharged to fuel the CHP unit, balancing energy costs and hydrogen availability.
   - During truck charging events, the system discharged hydrogen from storage, and the EMS efficiently recharged the hydrogen vessel during low-cost electricity periods, maintaining system flexibility.
4. **System Robustness**:
   - The EMS demonstrated its robustness by managing energy supply during periods of instability. For instance, when the CHP unit experienced oscillations under higher loads, the EMS dynamically adjusted operations to prevent faults and optimize system performance. Even during these challenges, the EMS maintained system stability and efficiency, preventing operational failures.
5. **No EMS Scenario**:
   - A comparison with a scenario where the EMS was not deployed revealed significant inefficiencies. Without the EMS, the CHP operated without optimization, resulting in over five hours of unnecessary operation during periods when renewable energy generation exceeded demand. This led to higher operational costs and greater reliance on fossil fuels. Additionally, hydrogen production was limited, leading to insufficient storage to meet demand.

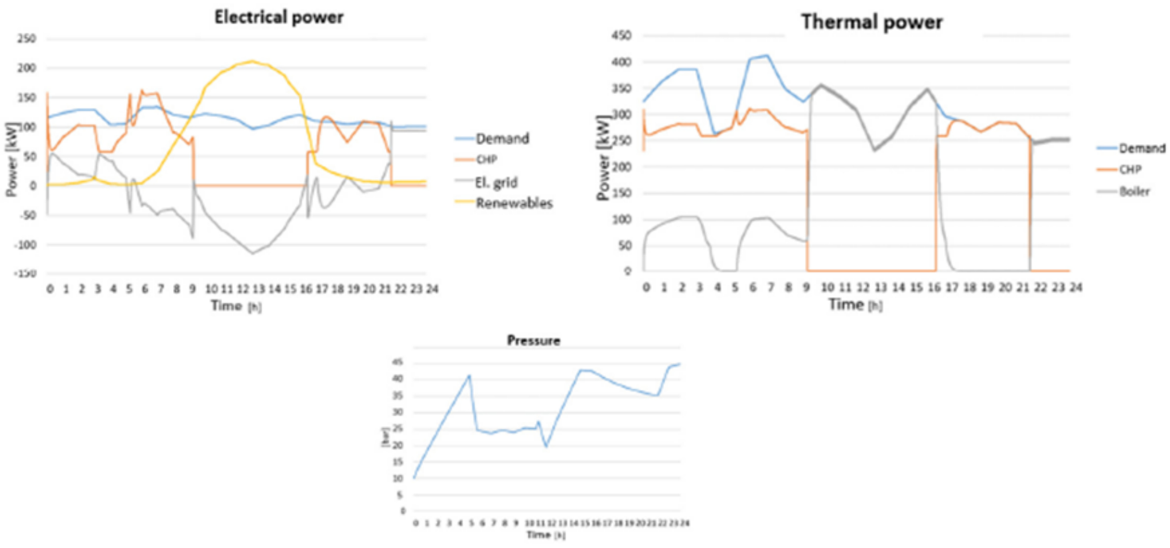

Figure 34: EMS system management in the Crete case (simulation results) (UNIVERSITA DI GENOVA, 2023)

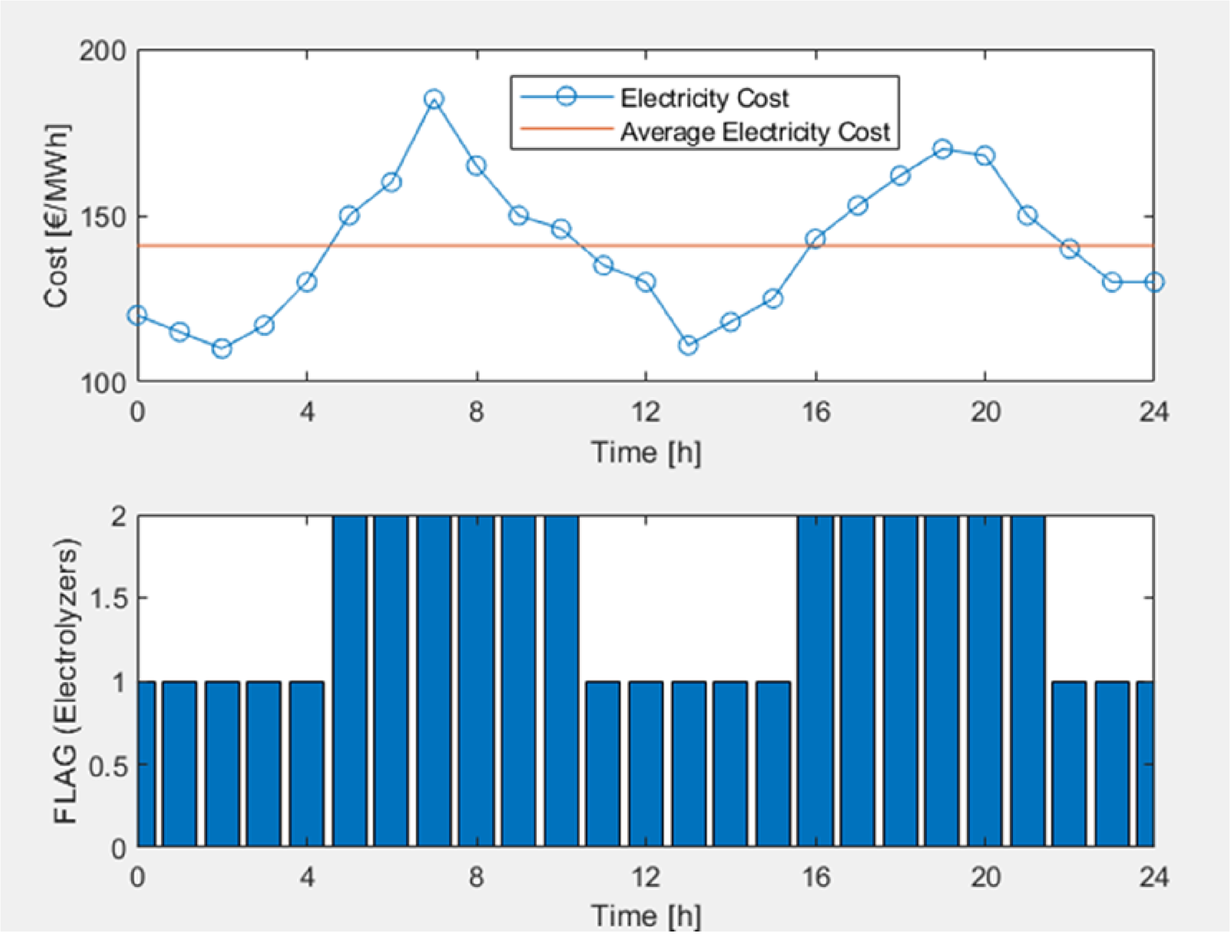

Figure 35: Electrical costs and electrolyser flags (Crete case)(NORCE, 2023)

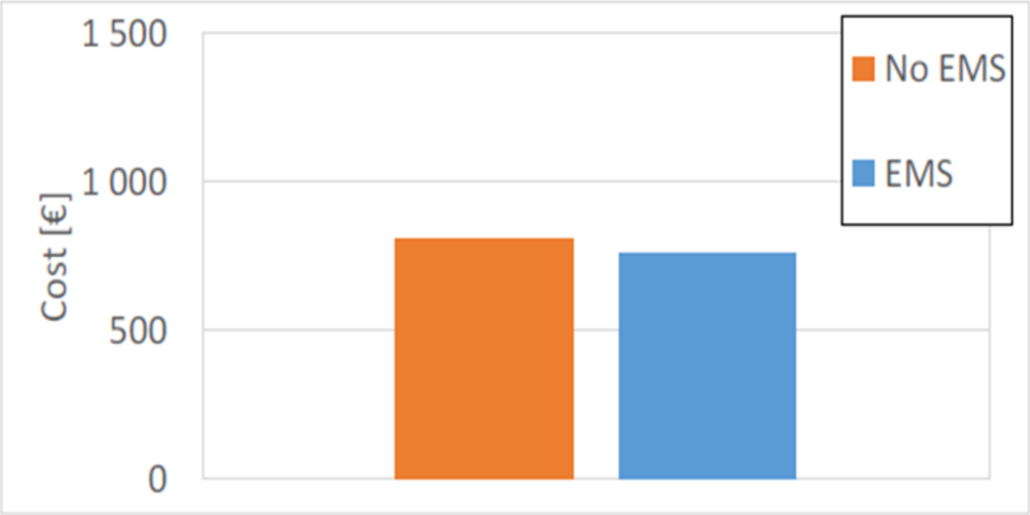

Figure 36: 24-hour test for the Crete case: global performance comparison (cost).(NORCE, 2023)

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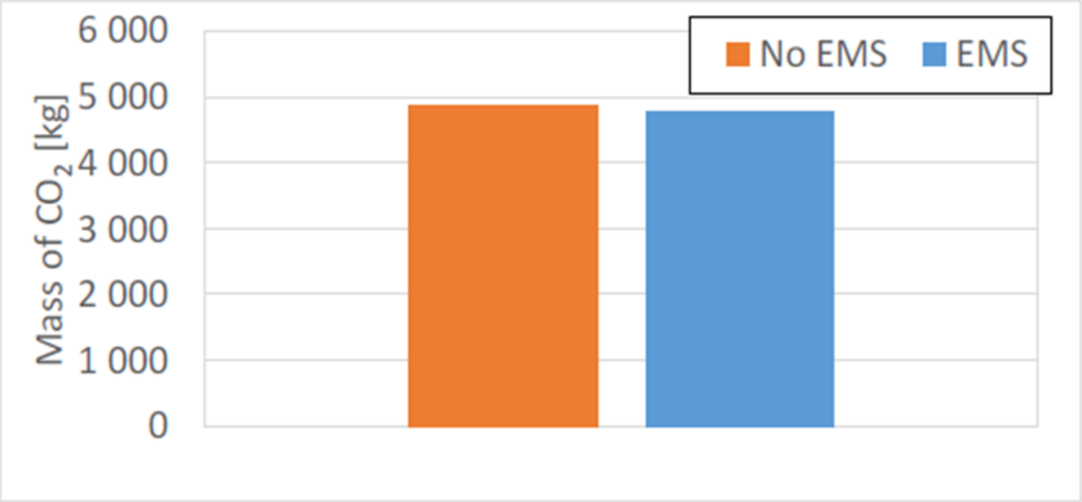

Figure 37: 24-hour test for the Crete case: global performance comparison (CO_2 emissions).(NORCE, 2023)

The combination of the two simulation stages provided comprehensive insights into the design, optimization, and real-time management of the MES for Crete. The HOMER Pro simulation established a solid foundation for understanding the system's potential in terms of cost and environmental impact, revealing that renewable energy sources, particularly PV and biomass gasification, could lead to significant cost savings and emissions reductions. The advanced EMS simulation demonstrated the system's ability to dynamically manage energy production and storage in real-time, optimizing the use of renewable energy, minimizing costs, and reducing CO_2 emissions. The integration of hydrogen storage added flexibility to the system, allowing it to respond effectively to price fluctuations and energy demand, further enhancing the MES's economic and environmental performance. Together, these simulations highlighted the feasibility and effectiveness of the ROBINSON solution in Crete and provided a replicable model for other regions with similar energy and resource conditions.

While the initial simulations were executed using PV technology, the potential for integrating Photovoltaic-Thermal (PVT) systems in Crete is a significant consideration for future replication efforts. PVT technology provides electricity and thermal energy from a single installation, making it a more efficient and space-saving alternative for regions where energy demands span electrical and heating needs. Despite not being included in the current simulations, PVT technology is considered a natural alternative to PV in contexts where maximizing energy output and space efficiency are priorities. The versatility of PVT systems makes them particularly suitable for the selected use-case with significant solar potential but constrained space for energy installations, allowing stakeholders to meet electricity and thermal energy demands with fewer resources. Additionally, adopting PVT technology can contribute to lower overall carbon emissions by reducing the need for separate heating systems, thus enhancing further the environmental and economic benefits already demonstrated by the PV simulations.

4.1.5. Ensure the application context

The successful replication of the ROBINSON concept in Crete requires a comprehensive understanding of the island's specific application context. This involves analysing regional spatial planning frameworks, environmental policies, energy regulations, and socio-economic factors that influence the feasibility and sustainability of integrating renewable energy sources (RES). By aligning the project with Crete's strategic development goals and addressing potential risks, the replication plan aims to facilitate a smooth transition towards a more sustainable and resilient energy system.

4.1.5.1. Feasibility and Strategic Business Model for RES Integration in Crete

Crete's economy is predominantly driven by tourism and agriculture, which are its main comparative advantages. Manufacturing plays a secondary role, with development strategies emphasizing the enhancement of these primary sectors. The Regional Spatial Planning and Sustainable Development Framework for Industry outlines guidelines to strengthen telecommunications, research activities, and the integration of RES, alongside improving infrastructure such as road networks and ports. From a spatial planning perspective, the main zones for industrial and energy development are designated in the broader areas of Heraklion (Gouves-Kastelli axis) and Chania, with smaller hubs in Rethymno and Agios Nikolaos. The policy advocates for the expansion of organized industrial zones to accommodate new establishments and relocations, emphasizing the need to prevent unplanned roadside developments and to avoid disrupting coastal tourist areas and high-quality agricultural lands (Ministry of Environment and Energy, 2017).

The Special Spatial Planning and Sustainable Development Framework for Renewable Energy Sources provides specific guidelines for the integration of RES, particularly wind installations and small hydroelectric projects:

- **Wind Installations**: Crete is categorized among the "inhabited islands of the Ionian and Aegean Seas," without specific classification into wind priority areas. Wind installations are prohibited in exclusion zones such as declared World Heritage sites, major cultural monuments, nature protection zones, and areas under environmental monitoring programs. Wind farm coverage must not exceed 4% of each municipality's land area, equating to approximately 0.53 typical wind turbines per 1,000 hectares.
- **Small Hydroelectric Projects**: Potential exists in mountainous areas with favourable water resources and elevation differences. Similar exclusion zones apply as with wind installations, ensuring that projects do not adversely affect protected areas or significant natural habitats.(Region of Crete, 2020)

he feasibility of integrating RES in Crete is further supported by national legislation promoting energy communities. The Greek legal framework allows for the forming of energy communities that can participate in EU projects, own RES plants, and operate virtual net-metering schemes (Hellenic Republic, 2023). This enables local stakeholders, such as farmers and business owners, to contribute resources like biomass and participate actively in the energy transition. The business model proposed for this approach can be seen in Figure 39. In parallel, subsidies and financial incentives are available for RES technologies used by autonomous producers for self-consumption and other supporting measures. After conducting energy audits, Islanders can benefit from energy efficiency funds, with financial support ranging between 30% and 70% of total intervention costs. (Hellenic Republic, 2021)

The special framework for RES does not set commitments or priority activities for RES in the area of the plan and does not include Crete in the wind priority areas. According to data from RAE, there are no areas with licenses for electricity generation from RES in the immediate area of the property. An evaluation is underway for a Wind Power Station with a capacity of 24 MW in the broader study area.

Figure 38: Proposed location for a 24 MW wind power station within the overall study area (RAAEY, 2024)

In a nutshell, the revised framework The Regional Spatial Planning and Sustainable Development Framework 260/A.A.P./2017 (Region of Crete, 2020) aims for Crete's spatial integration into broader national and international contexts with the following objectives:

- Institutional and financial support for research and technology activities.
- Development of a major telecommunications hub serving businesses.
- Promotion of export-oriented and knowledge-sharing activities.
- Active participation in EU maritime strategies and climate change mitigation efforts, particularly for coastal zones.
- Joint efforts for protecting Crete's natural and cultural environment.
- Completion and enhancement of trans-European transport infrastructure.
- Strengthening the polycentric model of spatial organization to support balanced territorial development.

Partners

- *Technical University of Crete*
- *Region of Crete*
- *Energy Community*
- *Technology providers and suppliers incl. RES and energy storage*
- *Industrial companies & technical staff*
- *Electricity regulators and grid operators*
- *Financial partners*
- *Citizens associations*
- *Industries representatives*

Activities

- *CHP unit*
- *Steam boiler*
- *Electrolyser*
- *AD-BES system*
- *Gasifier, ?*
- *Gas fuel mixer ?*
- *PV systems*
- *EMS*
- *Energy storage*

Resources

- *Experienced consortium*
- *Crete business innovation platform*
- *Financial instruments*

Values

- *Reduce dependency on imported fossil fuels.*
- *Energy saving solutions to local community.*
- *Energy efficiency and renewable energy business opportunities.*
- *Renewable biomass sources (e.g. agricultural waste) ensure stable energy supply and storage (TES, H_2, etc.)*
- *Lower power capacity requirements.*
- *General energy use awareness from users.*
- *Lower carbon emissions from RES and energy storage.*
- *Energy management system to control and optimize energy usage.*

Relationships

- *Personal assistance*
- *Co-creation*
- *Retailers*
- *Companies and other municipal utilities to incorporate.*
- *Consultants*
- *Energy cooperatives to stimulate local RES investment.*

Channels

- *Local/regional authorities*
- *Municipal or regional companies*
- *Other stakeholders-chambers, associations*
- *Financial partners (ESCOs, banks private funds, other funds)*
- *Citizens associations*

Customers

- *Local industries (energy intensive e.g. other food industries, etc.)*
- *Existing residents who will benefit from energy savings or see increased access to energy.*
- *Local Cooperative's Olive Oil Mill*
- *Hotels*
- *Prosumers*

Cost structure

- *Costs of equipment*
- *Cost of expanding infrastructure*
- *Technical support*

Revenue structure

- *Public and private investment*
- *Improve energy efficiency leads to cost savings.*

Figure 39: Business Model Canvas for Crete Case (STRATAGEM, 2023)

4.1.5.2. Addressing Key Risks for Successful RES Implementation

Implementing RES projects in Crete entails addressing several technical, regulatory, financial, and social risks to ensure successful replication:

1. **Technical and Grid Infrastructure Risks**: The ongoing interconnection of Crete's grid with mainland Greece presents technical challenges, including potential grid instability and delays in infrastructure projects (ENTSO-E, 2023). To mitigate these risks, the replication plan emphasizes infrastructure upgrades, the deployment of energy storage systems, and the integration of smart grid technologies to enhance grid stability and accommodate peak demand periods, especially during the tourist season (RAAEY, 2022).
2. **Regulatory and Financial Barriers**: Regulated electricity prices on non-interconnected islands and a lack of financial incentives for RES adoption pose significant challenges (European Commission. Directorate General for Energy., 2023). The plan addresses these barriers by adopting the cooperative model approach that is supported by Greek legal framework and incentivizes local renewable energy projects, particularly in rural areas like the Platanos community. Leveraging funding opportunities from the European Union's Just Transition Fund can alleviate financial constraints and support the scaling of RES projects.
3. **Stakeholder Engagement and Cooperation**: Effective management of multiple stakeholders across government, local municipalities, and the private sector is crucial. The replication plan adopts a multi-stakeholder participatory approach, facilitated by entities like the Regional Energy Agency of Crete, to ensure alignment of goals and collaborative problem-solving. Engaging local communities through energy communities helps to mitigate resistance and fosters a sense of ownership among residents (Skaloumpakas et al., 2024).
4. **Environmental and Climate Risks**: Crete's vulnerability to climate change and extreme weather events necessitates the incorporation of environmental resilience measures in RES projects. The plan prioritizes sustainable energy solutions that reduce greenhouse gas emissions and enhance the island's resilience to climate impacts. Environmental impact assessments and adherence to ecological protection guidelines ensure that RES developments do not adversely affect sensitive ecosystems. (Intergovernmental Panel On Climate Change (Ipcc), 2023)

By proactively addressing these risks through comprehensive planning and stakeholder collaboration, the replication plan aims to facilitate the successful implementation of RES projects in Crete, contributing to the island's sustainable energy transition.

4.1.5.3. Assessing Long-term Sustainability and Socio-economic Impact of RES on Crete

The replication plan for Crete’s energy transition focuses on ensuring the long-term sustainability of renewable energy solutions and their impact on the local environment, economy, and community. The main goal is to reduce reliance on fossil fuels and increase the use of RES while addressing local challenges such as seasonal energy demand fluctuations, economic constraints, and environmental preservation.

1. **Environmental Sustainability:** A significant part of the sustainability strategy focuses on reducing carbon emissions and minimizing the island’s environmental footprint. The adoption of solar,

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wind, and biomass energy will replace carbon-intensive power generation methods, resulting in a cleaner energy system. Additionally, the life-cycle environmental impact assessments of these technologies ensure that their deployment considers long-term sustainability, from raw material extraction to energy generation and waste management. This life-cycle approach is crucial to ensure that the shift to renewable energy has a positive, lasting environmental impact without unforeseen ecological side effects (Calvin et al., 2023).

2. **Economic Sustainability:** The replication plan for Crete integrates economic sustainability by promoting energy efficiency and renewable energy adoption, which will lead to lower energy costs over time. By reducing dependence on expensive imported fossil fuels, local communities, such as Platanos, will experience direct economic benefits, including reduced energy bills and the creation of local jobs in the renewable energy sector. Moreover, the focus on energy cooperatives allows for community-led renewable energy projects, which empower residents to participate in and benefit from the island's energy transition.(Stamopoulos et al., 2021)
3. **Social Impact and Energy Poverty Reduction:** Ensuring that the energy transition is equitable and benefits all communities is a key component of long-term sustainability. The Territorial Just Transition Plan allocates funding to support vulnerable populations and alleviate energy poverty by offering subsidies and incentives for energy-efficient upgrades. This plan ensures that low-income households can access renewable energy solutions, reducing their energy costs and improving living standards (European Union, 2022). Involving local stakeholders through Energy Communities and participatory governance structures strengthens social cohesion and ensures that the benefits of the energy transition are widely shared across Crete.

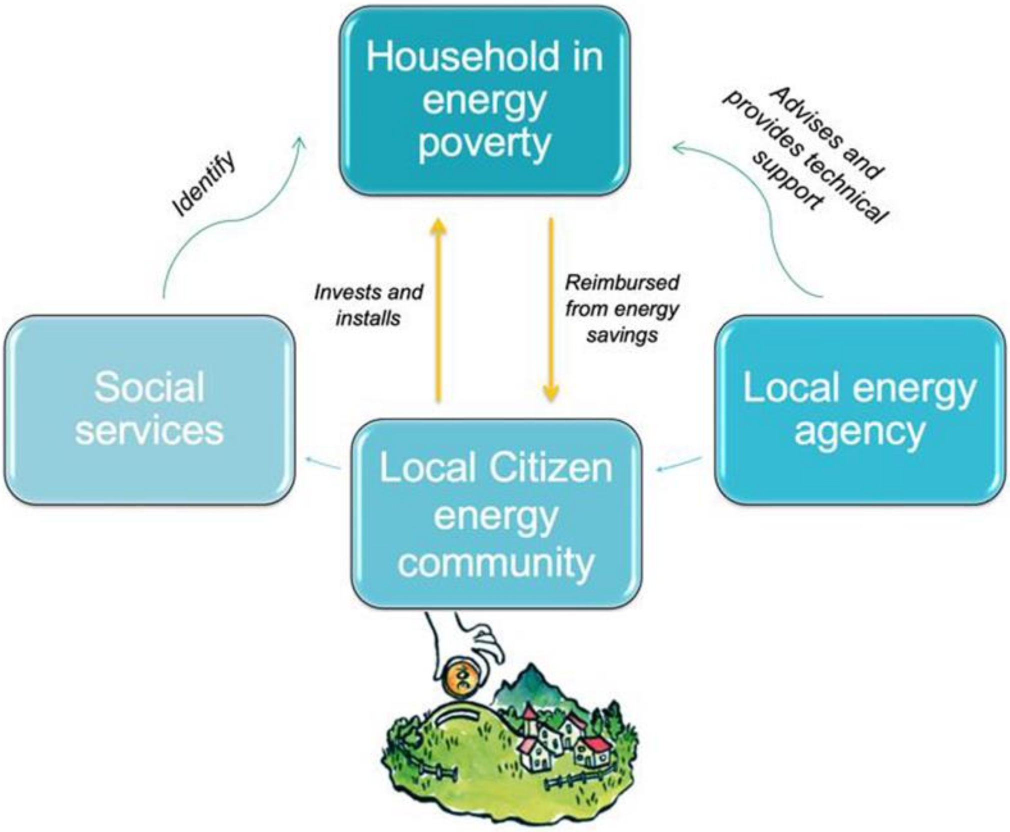

Figure 40: Interaction model between citizen energy communities and vulnerable households. (European Union, 2022)

4. **Long-term Impact and Resilience:** The interconnection of Crete's grid with the mainland, coupled with the increased penetration of RES, strengthens the island's long-term energy resilience. The replication plan includes measures to enhance grid stability and accommodate fluctuations in energy demand, particularly during peak tourist seasons. Additionally, the integration of energy storage systems ensures that Crete can store excess renewable energy, thus improving grid reliability and preparing the island for future energy challenges (Uyar, 2020).

Table 13: List of indicative KPIs for the selected use case in Crete (adapted from (Clercq et al., n.d.)

KPI/Metric	Description	Target (Indicative)
CO_2 Reduction Over Time	Total carbon emissions reduction	40% reduction by 2030
Energy Poverty Alleviation	Reduction in energy poverty for low-income households	15% reduction in rural areas by 2026
Economic Growth	Increase in economic output due to renewable energy projects	€3 million increase over 5 years
Sustainable Energy Production	Growth in renewable energy production capacity	50% increase by 2027

In summary, the sustainability and long-term impact assessment of the replication plan for Crete emphasizes reducing environmental impact, boosting local economic growth, enhancing social equity, and building resilience against future energy demands. These goals align with broader EU targets for clean energy and sustainability, ensuring Crete's successful transition to a renewable energy future.

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4.1.6. Adaptation analysis

4.1.6.1. Diagnosis of the customisation level needed

To effectively implement the Multi-Energy Systems (MES) in Crete, a detailed diagnosis of the required customization is essential. This involves considering local industry requirements, regulatory frameworks, and energy consumption patterns. For instance, the local bakery industry (BI) necessitates high-temperature heat, which is a significant factor in determining the energy system's customization. Additionally, a broader MES design must encompass energy needs across residential households, transportation, and industrial sectors. These two scopes—BI and the entire MES—are distinct in their system boundaries and should be adapted accordingly.

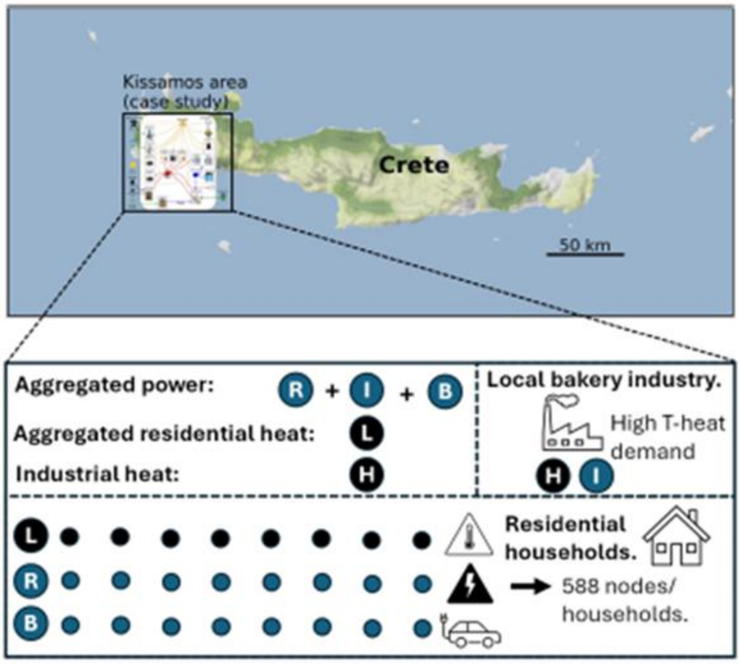

Figure 41: Illustration of the case study in Crete and sectors with (aggregated) energy demands. The figure is obtained from (Terlouw et al., 2025)

Scenarios have been defined to assess various design configurations of the MES, allowing for a comparison of cost, environmental impact, and adherence to local regulations:

1. **Business-as-Usual (BI)**: Reflects the current state of the BI's energy system, largely dependent on fossil fuels, such as diesel boilers, and utilizing the carbon-intensive electricity from the Cretan power grid.
2. **Cost-Min (BI)**: Optimizes for minimum cost without environmental concerns, disregarding local regulatory constraints on renewable installations like solar PV and wind turbines.
3. **Cost-Min-Constr (BI)**: A cost-focused scenario that integrates local regulatory limits, such as the 0.5 MW solar PV and 0.06 MW micro wind turbine capacity restrictions.
4. **Business-as-Usual (Entire MES)**: Models the current energy system of the entire MES (including BI, households, and transport) reliant on fossil fuels and grid electricity.
5. **Cost-Min (Entire MES)**: Optimizes the entire system for minimum cost, ignoring both environmental factors and regulatory constraints on renewable energy installations.

6. **Cost-Min-Constr (Entire MES)**: A cost-minimized solution for the MES that respects local regulations on renewable energy capacity.
7. **GHG-Min (Entire MES)**: Optimizes the system based on minimizing greenhouse gas emissions, disregarding both cost and local renewable energy capacity restrictions.
8. **Off-Grid Scenario**: Evaluates the feasibility of an off-grid system for the entire MES, eliminating connections to the power and gas grids and banning the export of electricity and hydrogen.
9. **Balanced Autonomy**: Strives for a balance between local renewable energy production and consumption, ensuring the system can operate autonomously while being connected to the power and gas grids. Hydrogen exports are restricted.

Each scenario examines different levels of customization and adapts to varying regulatory frameworks and energy demands. The results of these scenarios will guide further adaptation requirements for the optimal MES design.(PSI, 2024b, 2024a; Terlouw et al., 2025)

4.1.6.2. Replication plan updates

An optimization model was developed to design the MES for Crete, focusing on minimizing both annual costs and life cycle greenhouse gas (GHG) emissions. The model, structured as a Mixed Integer Linear Program (MILP), provides a flexible framework that could be adapted to other regions while maintaining the ability to focus on key environmental and economic metrics. In this analysis, the primary objectives were cost minimization and GHG reduction, although other environmental factors could be integrated depending on regional needs. The MILP model has been fine-tuned for Crete’s specific energy demands and infrastructure, incorporating detailed considerations of local climate data, renewable energy potential, and industry-specific energy needs.
Key updates to the replication approach include:

1. **Technology Integration**: The model now includes additional energy conversion technologies such as diesel boilers and electric boilers to meet high-temperature heat demands in the bakery industry, reflecting local industrial needs.
2. **System Complexity**: Only two out of three high-temperature technologies—CHP, electric, and diesel boilers—are considered for installation, reducing the complexity of system integration.
3. **Residential Energy Demand**: The model now incorporates cooling demand into residential energy consumption, reflecting Crete’s Mediterranean climate and the resulting higher power usage during summer months.
4. **Advanced Technologies**: The advanced CHP unit and wood gasifier are modelled with specific operational constraints, including minimum up- and downtimes, ensuring that system design aligns with practical deployment.

This updated replication plan ensures that the MES framework can be adapted for other regions, considering local regulations, industrial requirements, and climatic conditions. It is also capable of addressing energy demands across multiple sectors while optimizing for cost and environmental impact. This adaptation reflects the required modifications for Crete’s energy systems and provides a pathway for replicating this approach in other regions with similar customization needs. (PSI, 2024b, 2024a; Terlouw et al., 2025)

4.1.7. Evaluation of replication plan

4.1.7.1. Review of results and recommendations

The analysis of Crete's energy system in the ROBINSON project shows that implementing Multi-Energy Systems (MES) could reduce overall energy costs by up to 30%. Specifically, the bakery industry in Platanos could achieve up to 81% cost reductions by using electric boilers and combined heat and power (CHP) units powered by renewables.

Figure 42 compares the cost and life cycle greenhouse gas (GHG) emissions across eight scenarios, with the left subplot focusing on the industrial sector and the right illustrating the entire MES. Each scenario includes two stacked bars: annual cost on the left and annual GHG emissions on the right. The coloured segments represent contributions from different technologies and energy carriers. Dashed lines with percentages indicate changes in cost due to location-specific regulations versus unconstrained conditions. The environmental benefits of MES are also substantial. It has the potential to reduce GHG emissions by up to 87%. This reduction is achieved by optimizing the use of solar PV, wind, and battery storage, thereby decreasing reliance on fossil fuel-based power generation. Decarbonizing industries requiring high-temperature heat, such as the bakery sector, can be fully realized by adopting advanced CHP units powered by biomass gasification or hydrogen. However, the analysis highlights several challenges that must be addressed to unlock the full potential of these energy systems. Crete faces regulatory constraints that limit the capacity of onshore wind and solar PV installations. For example, regulations restrict autonomous solar PV systems to 500 kW and wind turbines to 60 kW under the net metering scheme. These limitations hinder the island's ability to fully utilize its renewable energy resources, particularly regarding exporting excess energy to the grid. The study shows that removing these export restrictions could lead to further cost reductions of over 67%.

Figure 43 presents six spider graphs illustrating the environmental trade-offs of the optimal MES designs across six scenarios. The impacts are normalized against the scenario with the highest impact in each category. The BAU scenario exhibits the worst overall environmental performance—represented by the most prominent dark blue area—driven by substantial fossil fuel utilization and GHG-intensive grid electricity. In contrast, scenarios permitting energy export, especially those allowing grid connection and hydrogen export, show avoided environmental burdens (negative impacts depicted as zero impact). Optimization scenarios generally reduce environmental burdens due to the increased implementation of cost-effective solar PV and onshore wind, resulting in lower impacts across most environmental categories. However, the "Cost-Min-Constr" scenario faces trade-offs in land use, mainly due to the biomass needed for advanced CHP to generate high-temperature industrial heat. Off-grid MES configurations exhibit trade-offs in material use, water consumption, and human toxicity because of the oversizing of renewables (and curtailment) and energy storage installations.

The MES designs for Crete integrate renewable energy generation with battery and hydrogen storage solutions to balance energy demand and supply, especially in off-grid scenarios. Off-grid MES configurations promise near-total decarbonization but require higher upfront investments, particularly for storage infrastructure. The analysis also highlights environmental trade-offs, such as increased land use and material consumption, from large-scale solar PV installations and battery storage. Despite these trade-offs, the overall environmental benefits, particularly in greenhouse gas reductions, are significant. (PSI, 2024b, 2024a; Terlouw et al., 2025)

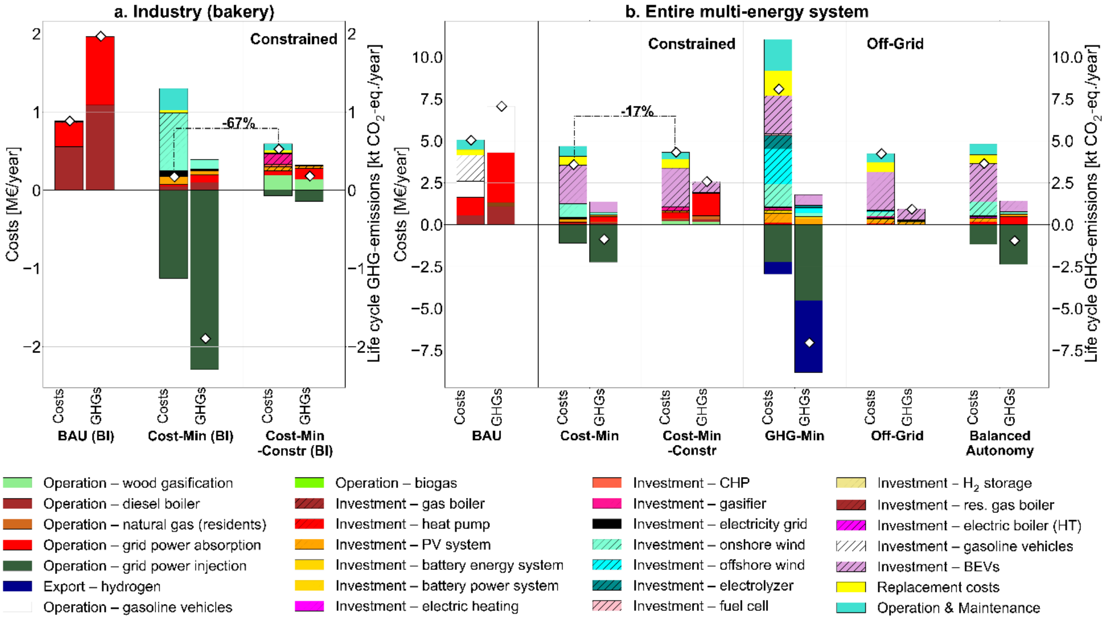

Figure 42. Overall results: annual cost and life cycle GHG emissions of optimal MES designs in Crete. The diamond markers represent the net annual costs and GHG emissions. The figure will be published in (Terlouw et al., 2025).

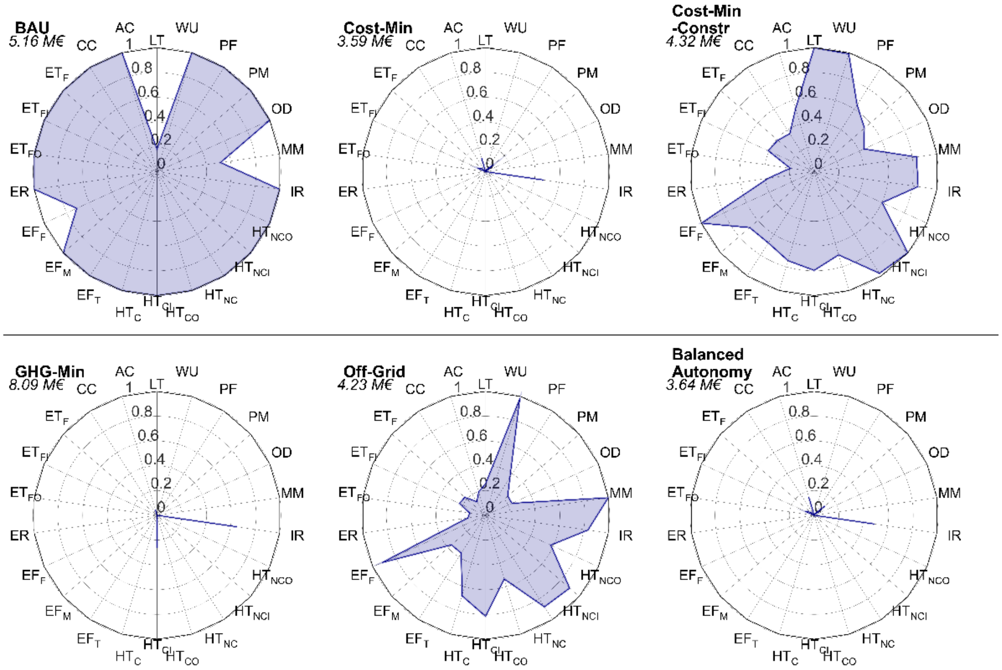

Figure 43. Spider graph with the different scenarios considered for the entire MES in Crete, and associated life cycle environmental burdens on selected normalized environmental impact categories[6]. The figure will be published in (Terlouw et al., 2025).

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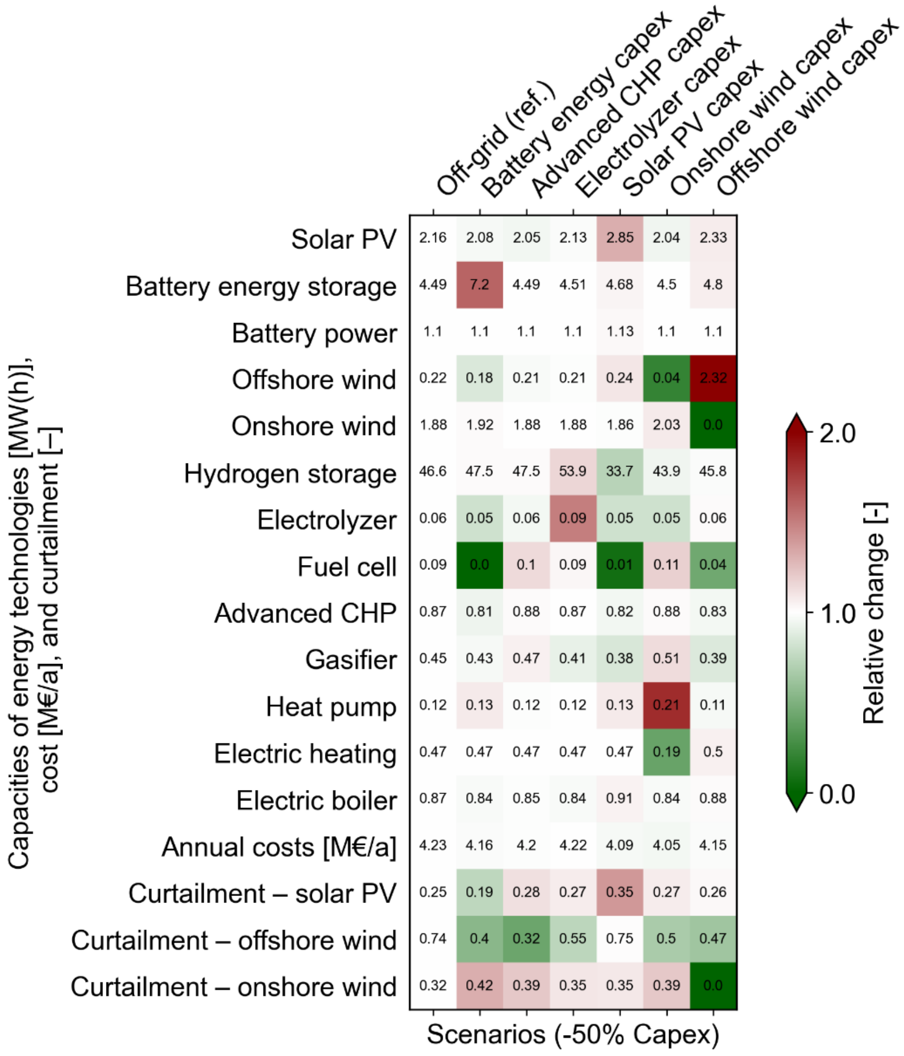
[6] LT = land transformation. AC = acidification. CC = climate change. ETF = ecotoxicity: freshwater. ETFI = ecotoxicity: freshwater, inorganics. ETFO = ecotoxicity: freshwater, organics. ER = energy resources: non-renewable. EFF = eutrophication: freshwater. EFM = eutrophication: marine. EFT = eutrophication: terrestrial. HTC = human toxicity: carcinogenic. HTCI = human toxicity: carcinogenic, inorganics. HTCO = human toxicity: carcinogenic, organics. HTNC = human toxicity: non-carcinogenic. HTNCO = human toxicity: non-carcinogenic, organics. HTNCI = human toxicity: non-carcinogenic, inorganics. IR = ionizing radiation: human health. MM = material resources: metals/minerals. OD = ozone depletion. PM = particulate matter formation. PF = photochemical oxidant formation: human health. WU = water use

4.1.7.2. Interventions’ follow-up and correction mechanisms

A sensitivity analysis highlights that capital expenditures (capex) for renewable energy technologies are pivotal in determining the cost-effectiveness of Multi-Energy System (MES) designs. Reductions in capex for technologies such as solar photovoltaic (PV), wind turbines, and battery storage can significantly lower overall system costs and enhance efficiency. Conversely, the study demonstrates that increasing grid connection costs shifts the system's reliance toward solar PV and storage solutions, which reduces the capacity for onshore wind installations and diminishes the profitability of energy exports.

Figure 44 illustrates how the optimal design of these technologies changes relative to the baseline off-grid MES in Crete when their capex is reduced by 50%. In this figure, red areas indicate an increase in relative installed capacity, total costs, and curtailment, while green areas represent a relative decrease.. (PSI, 2024b, 2024a; Terlouw et al., 2025)



	Off-grid (ref.)	Battery energy capex	Advanced CHP capex	Electrolyzer capex	Solar PV capex	Onshore wind capex	Offshore wind capex
Solar PV	2.16	2.08	2.05	2.13	2.85	2.04	2.33
Battery energy storage	4.49	7.2	4.49	4.51	4.68	4.5	4.8
Battery power	1.1	1.1	1.1	1.1	1.13	1.1	1.1
Offshore wind	0.22	0.18	0.21	0.21	0.24	0.04	2.32
Onshore wind	1.88	1.92	1.88	1.88	1.86	2.03	0.0
Hydrogen storage	46.6	47.5	47.5	53.9	33.7	43.9	45.8
Electrolyzer	0.06	0.05	0.06	0.09	0.05	0.05	0.06
Fuel cell	0.09	0.0	0.1	0.09	0.01	0.11	0.04
Advanced CHP	0.87	0.81	0.88	0.87	0.82	0.88	0.83
Gasifier	0.45	0.43	0.47	0.41	0.38	0.51	0.39
Heat pump	0.12	0.13	0.12	0.12	0.13	0.21	0.11
Electric heating	0.47	0.47	0.47	0.47	0.47	0.19	0.5
Electric boiler	0.87	0.84	0.85	0.84	0.91	0.84	0.88
Annual costs [M€/a]	4.23	4.16	4.2	4.22	4.09	4.05	4.15
Curtailment – solar PV	0.25	0.19	0.28	0.27	0.35	0.27	0.26
Curtailment – offshore wind	0.74	0.4	0.32	0.55	0.75	0.5	0.47
Curtailment – onshore wind	0.32	0.42	0.39	0.35	0.35	0.39	0.0

Figure 44: Impact of reducing capex of selected low-carbon energy technologies by 50% on the optimal design. The absolute numbers are provided, while the colours indicate relative changes (refer to the colour bar). The figure published in (Terlouw et al., 2025)

In conclusion, the replication plan for Crete indicates that MES can deliver substantial environmental and economic benefits by integrating local renewable resources. Realizing this potential, however, requires addressing regulatory barriers, optimizing system configurations, and securing necessary

investments for infrastructure upgrades. Crete could serve as a model for sustainable island energy systems, contributing to both national and European Union clean energy goals. Detailed findings of this analysis, including the techno-economic performance and environmental impacts of the proposed systems, are comprehensively presented in Deliverables 5.2 and 5.3.
Finally, the following key take-aways from the case study in Crete summarised as follows:

- **Significant Cost and Emissions Reductions**: Substantial reductions in costs (up to 30%) and greenhouse gas (GHG) emissions (up to 87%) can be achieved in Mediterranean regions through the cost-effective integration of solar PV and wind energy. The local bakery industry, for example, can be fully decarbonized using electric boilers and advanced combined heat and power (CHP) units.
- **Regulatory Challenges**: Current and future location-specific regulations, especially those targeting local renewables, can significantly limit cost savings and decarbonization potential. This underscores the necessity of practical policy guidelines to facilitate further decarbonization efforts.
- **Potential of Off-grid MES**: Off-grid MES configurations offer promising potential for enhanced decarbonization due to reduced reliance on the current GHG-intensive power grid. However, they may lead to trade-offs concerning material utilization and land use.
- **Sensitivity to Capital Costs**: Off-grid MES designs are highly sensitive to capex and discount rates of low-carbon technologies since they require substantial upfront investments.

To effectively monitor and evaluate the implementation of the Multi-Energy Systems (MES) in Crete, specific Key Performance Indicators (KPIs) have been established. These KPIs are designed to measure progress towards the project's environmental, economic, and social objectives, ensuring that interventions are on track and allowing for corrective actions if necessary.

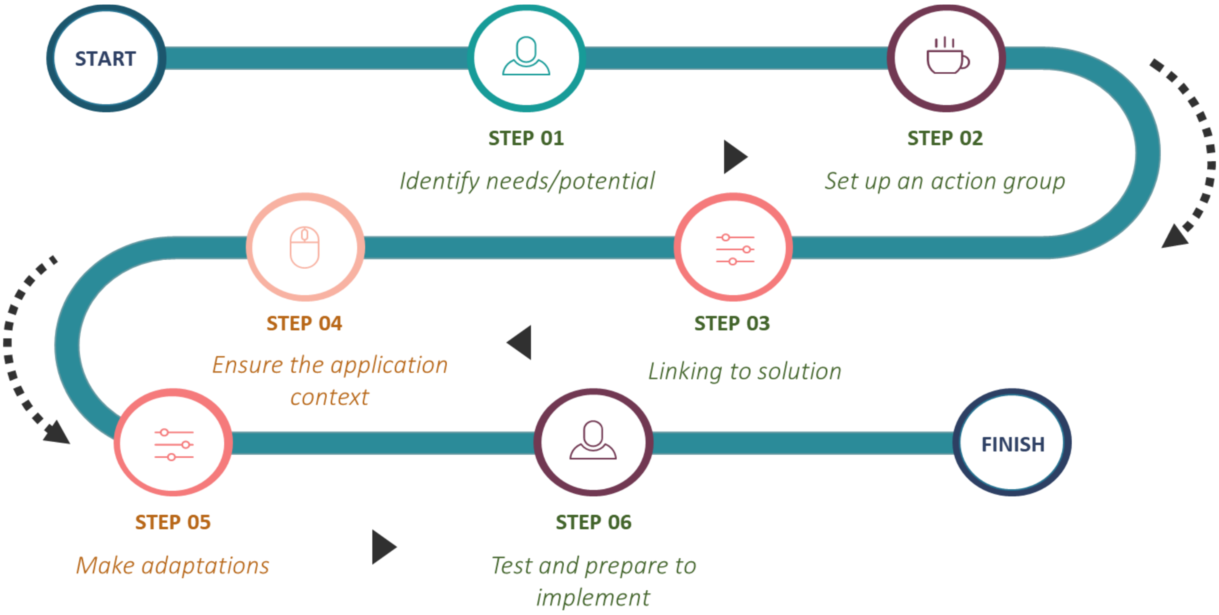
Table 14: Indicative KPIs for mentoring and evaluating Multi-Energy Systems (MES) in Crete

KPI/Metric	**Description**	**Target (Indicative)**
CO_2 Emissions Reduction	Reduction in carbon emissions by using RES	20% reduction by Year 3
Renewable Energy Penetration	Proportion of energy demand met by RES	50% of total energy consumption by 2025
Energy Cost Savings	Overall reduction in energy costs for industry and households	15% cost savings for the bakery industry by 2024
System Reliability	Improvement in grid stability and reduced downtime	Reduce system downtime by 25% over 3 years
Local Job Creation	Jobs created in the renewable energy sector	50 new jobs by 2026
Performance of Renewable Energy Systems	Efficiency and operational output of RES installations	85% operational efficiency for Solar PV annually
Energy Demand and Supply Balancing	Meeting energy demands, especially during tourist season	100% energy coverage during peak summer months
Compliance with Local Regulations	Adherence to local energy regulations	100% regulatory compliance in Crete

4.2. Replication plan for Western Isles

4.2.1. Replication in a nutshell

The replication plan for the Western Isles, specifically the Creed Waste Management Facility in Stornoway, is an integral part of the ROBINSON project, aimed at decarbonizing island energy systems. The replication strategy involves several key steps to adapt and apply the successful methodologies and technologies demonstrated on Eigerøy Island to the local context of the Western Isles.



4.2.2. Analysis and diagnosis of the status, needs and potential for sustainable/flexible energy solutions.

4.2.2.1. Determination of the local energy needs and conditions

The Western Isles (Outer Hebrides), located off Scotland's west coast, are home to around 26,000 residents, with a significant proportion of the population residing in and around Stornoway, the principal town on the Isle of Lewis. Comhairle nan Eilean Siar, the local authority for the Outer Hebrides, provides a broad range of statutory and non-statutory services to benefit the islands' residents and communities. As a Follower Island in the ROBINSON Project, the Replication Plan focused on implementing an Energy Management System (EMS) at the Creed Waste Management Facility, located just outside Stornoway. Comhairle nan Eilean Siar is committed to unlocking the islands' renewable energy potential for economic growth and to support its goal of achieving net-zero greenhouse gas emissions. The council was particularly interested in assessing whether the proposed EMS through the ROBINSON Project could be adapted to the islands’ energy systems to meet decarbonization targets and address the significant issue of energy poverty. Local governance is critical in promoting renewable energy development through strategic policies and incentives that foster community involvement and attract necessary investments. A vital aspect of this governance is creating sustainable financial models and securing both public and private investments—an essential component of the broader energy transition.

Meeting the Western Isles' energy needs requires a strategic approach that leverages the region's renewable energy potential, enhances community engagement, and effectively addresses infrastructural and economic challenges. This comprehensive approach shapes policies and strategies that deliver sustainable, flexible energy solutions tailored to regional needs. By addressing immediate energy demands and aligning with long-term sustainability objectives, the Western Isles are well-positioned to adapt to the evolving energy landscape. According to the Outer Hebrides Local Development Plan, the facility is in an 'Outwith Settlement' area. These areas serve as buffers between settlements, preserving their distinct character and supporting diverse activities, including agriculture, recreation, mineral extraction, energy development, and waste management. Development in such areas is generally dispersed across open landscapes and mainly focuses on resource-based or tourism-related activities. While there may be limited development opportunities, siting and design are crucial to mitigate the impact on the surrounding landscape. The 'Outwith Settlement' classification refers to areas between mapped settlement boundaries and Remote Areas, as defined in the Outer Hebrides Local Development Plan.(Energy Innovation, 2021)

Figure 45: Location of the Western Isles relative to Scotland (Energy Innovation, 2021)

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The energy system in Westerns Islands

The electricity in the Western Isles is supplied through an alternating current (AC) cable from a modular integrated transportable substation (MITS) at Fort Augustus. This cable travels through Skye and then divides at Ardmore into two subsea cables: one connecting to Stockinish in Harris, extending to Stornoway, and the other running to Lochcarnan in South Uist. This setup effectively provides the islands with two independent electricity supplies – one for Lewis and Harris (the North Island Group) and another for North Uist, Benbecula, South Uist, and Barra (the South Island Group). The peak electricity demand across the Western Isles is about 30 MW, but the current AC supply is limited to 22 MW in its subsea sections. During times of peak demand, additional electricity is generated locally by diesel plants in Stornoway and Lochcarnan. The distribution network for the Western Isles currently connects 34.3 MW of renewable energy, much of which operates on a non-firm connection basis. However, the 30-year-old AC link, rated at 22 MW in its subsea section, was originally designed to supply electricity to the islands, not to accommodate the export of locally generated power. Once the new high-voltage direct current (HVDC) link is operational, the electricity supply for Lewis and Harris will be shifted to this new system, and the existing 34.3 MW of constrained renewable generation will be transferred to the new transmission link. Electricity supply in the Western Isles is frequently disrupted by adverse weather conditions and spikes in demand. The region experiences seasonal fluctuations in electricity usage, with lower demand during the summer and higher demand in the heating season, likely due to variations in lighting loads and the prevalence of electric heating systems. The backup power supply for the Western Isles generates approximately 5 GWh of electricity annually, with demand concentrated during the winter months of November to February, aside from July. These seasonal interruptions are often caused by poor weather and the widespread use of electric heating.

According to data from the 'Western Isles Energy Audit' by Element Energy (2014) and the report on total final energy consumption at regional and local levels (2018), fossil fuels made up 75% of the total energy consumption in 2013. Liquid fuel sources constituted a significant proportion of the energy supply, with gas oil alone contributing 25% of the total energy in 2013. That year, the total non-electric fuel supply to the Western Isles was 583 GWh. By 2018, fossil fuels still accounted for 74.1% of the total energy consumed, with liquid petroleum fuels making up 63.4% of that supply. The non-electric fuel supply in 2018 was 512.2 GWh. Outside of a small gas network serving around 1,500 households in the Stornoway area, there is no access to natural gas across the islands.

As a result, households heavily rely on oil and electricity for heating. The domestic sector is the largest energy consumer in the Western Isles, making up 43% of total energy consumption in 2018. Residents of the Western Isles consume 25% more energy per capita compared to the Scottish mainland, and their per capita carbon dioxide emissions are 3% higher than the mainland average. Based on data from SSE, the load profile of electricity demand in the Western Isles shows that electricity consumption peaks around 4 p.m., with the highest demand reaching approximately 30 MW on peak days. The average daily peak demand is 24 MW during winter and 22 MW in summer. Energy consumption patterns in the Western Isles differ from those in the rest of the UK. While the domestic sector remains the largest consumer, accounting for 37% of the total energy supply, the industrial and commercial sectors show similar energy consumption levels to the UK average. However, transport energy consumption is notably lower in the Western Isles.(Community Energy Scotland, 2021; Energy Innovation, 2021)

Replication Case in Westerns Islands

The Creed Waste Management Facility, located on the outskirts of Stornoway, has been identified as the site for the EMS replication study. Creed Waste Management employs a comprehensive waste-to-energy system (Figure 46). This system processes organic waste to generate biogas, which is then used to produce electricity and heat. The facility incorporates advanced anaerobic digestion technology, ensuring efficient conversion of waste to energy, thereby reducing landfill use and lowering greenhouse gas emissions. The facility has already been the site of the innovative Outer Hebrides Local Energy Hub (OHLEH) – an award-winning circular economy project which shows the scope offered by renewable energy technologies to bring about tangible business benefits around energy use and waste reduction. (Community Energy Scotland, 2021; Energy Innovation, 2021)

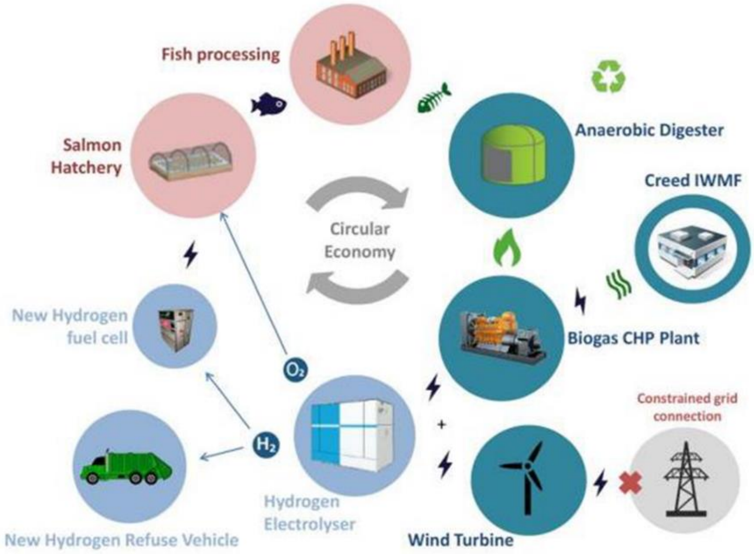


Figure 46: Industrial symbiosis and flows of energy, heat and waste at the Creed site (Community Energy Scotland, 2021; Energy Innovation, 2021)

The project incorporates two sites on the Isle of Lewis – the Creed Integrated Waste Management Facility (IWMF) just outside Stornoway, owned and operated by Comhairle nan Eilean Siar (the Local Authority for the Western Isles) and a salmon hatchery at Barvas, operated by The Scottish Salmon Company. OHLEH integrates Scottish Salmon's fish waste with household and garden waste in an anaerobic digester at the Creed IWMF. The Biogas produced is used to fuel the on-site Combined Heat and Power (CHP) plant. The heat is used for the buildings at the Creed site, and electricity generated by an on-site wind turbine (Figure 47) and by the CHP is used to produce hydrogen and oxygen. Hydrogen is being used to fuel a dual-fuel refuse collection vehicle which, in turn, collects household and garden waste for the anaerobic digester. This hydrogen will also be used to power a hydrogen fuel cell at the salmon hatchery to provide power for lighting and feeding units for outdoor cages. Oxygen will be delivered to the hatchery to be used for oxygenation of the fish. The project aimed to address challenges faced by many island and rural locations – weak electricity grid, underutilised bio-waste resources, high on-island oxygen prices and an unreliable energy supply. Solutions provided by OHLEH include the diversion of fish waste from landfill, the integration of fish waste with domestic waste (which is believed to be a first), the production of hydrogen for power and transport, and the production of oxygen at lower-than-market price.

Figure 47: Wind turbine at Creed IWMF (Energy Innovation, 2021)

Government policies regarding clean energy

The *Scottish Government's Energy Strategy and Just Transition Plan* outlines a comprehensive approach to transforming Scotland's energy sector in pursuit of net-zero goals by 2045. The plan, presented in a ministerial statement, reflects the urgency of reducing dependence on oil and gas while leveraging the nation's vast renewable energy resources.

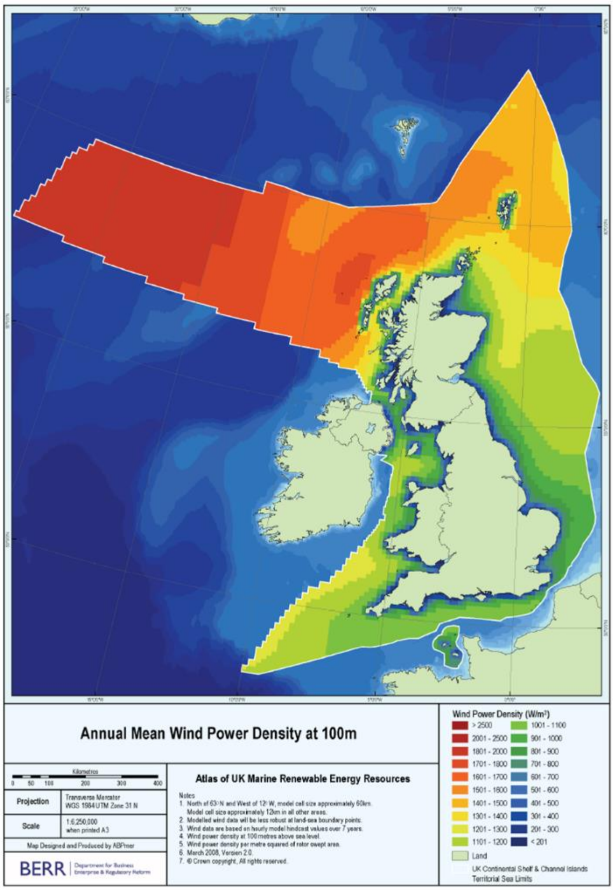
Key points from the plan include:

- **Renewable Energy Expansion**: Scotland aims to deliver over 20 GW of additional renewable electricity capacity by 2030, focusing on onshore and offshore wind, solar, tidal, and hydro energy. Wind power is viewed as a low-cost, scalable solution to meet energy needs and generate surplus for export.
- **Hydrogen Development**: The strategy envisions hydrogen playing a significant role, with a production target of 5 GW by 2030, rising to 25 GW by 2045. Hydrogen production, especially from surplus renewable energy, is central to decarbonizing industry and supporting Scotland’s energy exports.
- **Just Transition**: The plan emphasizes fairness, ensuring that the transition benefits all communities and workers. Key measures include the creation of new jobs in the renewables sector, particularly for regions reliant on fossil fuel industries, and the provision of skills and training for workers. By 2050, the number of low-carbon jobs is expected to quadruple from 19,000 to 77,000.
- **Energy Market Reform**: The strategy calls for UK Government action to reform the energy market, specifically decoupling electricity prices from gas and ensuring affordable energy for consumers. Scotland seeks increased autonomy over energy regulation to optimize the renewables sector's growth.
- **Investment in Energy Infrastructure**: Investment in infrastructure, such as hydrogen hubs and renewable energy projects, will support economic growth and energy security. The Scottish Government has allocated £500 million towards a Just Transition Fund to support the Northeast and Moray regions in this transformation.
- **Carbon Capture and Storage (CCS)**: The strategy also underscores the importance of CCS technologies, particularly the ACORN project, in achieving Scotland’s decarbonization targets.

(Scottish Government, 2023)

4.2.2.2. Estimation of the RES potential and possibilities for sustainable siting

The Western Isles possess a wealth of renewable energy resources, but their exploitation has been limited compared to their vast potential. Currently, domestic and non-domestic renewable energy projects across the islands generate around 74 GWh. However, the installation of a proposed high-voltage subsea interconnector (HVSC) would significantly increase capacity, enabling the delivery of energy from newly approved wind farms and transforming the region’s energy landscape. The energy dynamics of the Western Isles are characterized by a complex interplay of challenges and opportunities, shaped by the islands' geographic isolation and distinct environmental conditions. These factors contribute to a unique energy profile, with consumption patterns varying across the region. While the islands' infrastructure still relies heavily on traditional energy sources, a shift towards renewable energy integration is well underway, as evidenced by the Western Isles Connection Project. This initiative seeks to harness Scotland’s renewable energy potential while promoting sustainable economic growth.

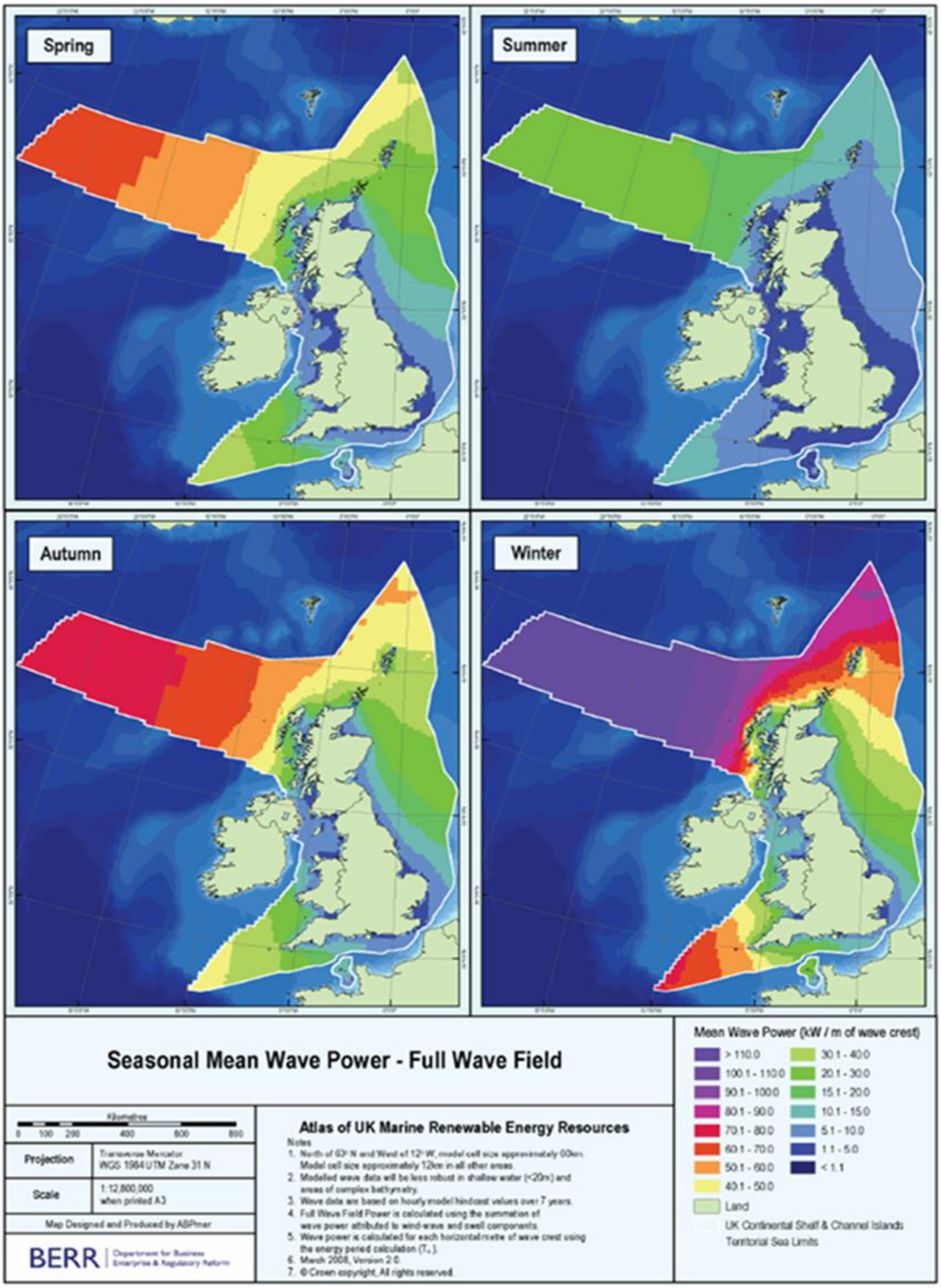


Notes
1. North of 63° N and West of 12° W, model cell size approximately 60km. Model cell size approximately 12km in all other areas.
2. Modelled wind data will be less robust at land-sea boundary points.
3. Wind data are based on hourly model hindcast values over 7 years.
4. Wind power density at 100 metres above sea level.
5. Wind power density per metre squared of rotor swept area.
6. March 2008, Version 2.0.
7. © Crown copyright. All rights reserved.

Figure 48: Wind Power Potential in Western Islands

(BERR, 2008)

One of the key factors driving this transition is the islands’ heavy reliance on heating oil for domestic use, stemming from the absence of a natural gas network and the harsh local climate. Electricity consumption also fluctuates significantly, largely due to seasonal tourism and the demands of the fishing industry. Wind energy plays a central role in the region’s energy strategy, given the area's abundant wind resources. Several small to medium-sized wind farms are already operational, with considerable potential for expansion. Beyond wind power, the surrounding seas offer significant, yet largely untapped, potential for marine energy generation, including tidal and wave energy. The shift towards renewable energy in the Western Isles is largely community-driven, with many community-owned projects boosting local energy production. These initiatives not only strengthen economic resilience by creating jobs and reducing energy costs—currently inflated due to the high reliance on imported fuels—but also contribute to the region’s transition to a more sustainable energy system. However, the transition to renewable energy is not without its challenges. One of the primary obstacles is the intermittency of renewable sources like wind and marine energy, highlighting the need for advanced energy storage solutions. In addition, the existing grid infrastructure requires modernization to manage the increased input from renewables and to improve energy efficiency in both residential and commercial sectors. Despite these challenges, the Outer Hebrides remain rich in renewable resources, particularly wind, wave, and tidal energy Historically, the exploitation of these resources has been constrained by limited local demand and insufficient capacity to export electricity to the mainland. However, driven by the need to address energy supply challenges that impact the local economy and quality of life, there is growing momentum within the island communities to fully harness these renewable resources.(Energy Innovation, 2021; Hulme, 2023; SUSTAINABLE DEVELOPMENT COMMITTEE, 2024)



Notes

1. North of 63° N and West of 12° W, model cell size approximately 60km. Model cell size approximately 12km in all other areas.
2. Modelled wave data will be less robust in shallow water (<20m) and areas of complex bathymetry.
3. Wave data are based on hourly model hindcast values over 7 years.
4. Full Wave Field Power is calculated using the summation of wave power attributed to wind-wave and swell components.
5. Wave power is calculated for each horizontal metre of wave crest using the energy period calculation (T_e).
6. March 2008, Version 2.0
7. © Crown copyright, All rights reserved.

Figure 49: Wave Potential in Western Islands (BERR, 2008)

4.2.2.3. Key Challenges addressed with the Replication Plan Development

The development of the Replication Plan for the Western Isles aims to address several significant energy challenges unique to the region. These challenges stem from a combination of geographic isolation, reliance on imported fuels, and environmental conditions that complicate energy management and sustainability efforts. Key issues include:

- **Exorbitant Energy Costs and Fuel Poverty**: Due to the reliance on imported liquid and gaseous fuels, the Western Isles face some of the highest energy costs in the UK. Being situated at the end of the supply chain further inflates these costs, contributing to high levels of fuel poverty. The Replication Plan will focus on mitigating these costs by promoting local renewable energy generation and reducing the islands' dependence on imported fuels.
- **Extreme Weather and Energy Efficiency**: Harsh winter weather conditions significantly increase energy consumption, particularly for heating. The private housing stock on the islands often lacks adequate energy efficiency measures, further exacerbating energy use and costs. The Replication Plan will target improved energy efficiency, integrating renewable energy systems that are better suited to the islands' environmental conditions and encouraging retrofitting programs for housing.
- **Supply Interruptions**: The Western Isles experience frequent disruptions to their electricity supply, both from the grid and in fuel imports, due to their remote location and extreme weather. By fostering local renewable energy production and enhancing energy storage solutions, the Replication Plan aims to reduce the islands' vulnerability to supply interruptions, ensuring a more stable and resilient energy network.
- **High Energy Consumption and Emissions**: The high use of liquid and solid fuels, along with inefficient appliances, contributes to elevated energy consumption and carbon emissions per capita in the Western Isles. Addressing these inefficiencies, the Replication Plan will facilitate the integration of more efficient energy systems and appliances, while leveraging the islands' abundant renewable energy resources, including wind, wave, and tidal energy.
- **Reducing Carbon Emissions**: In alignment with the Comhairle nan Eilean Siar's Corporate Strategy (2020), the Replication Plan will be a key element in the islands' pathway to achieving net zero carbon emissions by 2035. By enhancing the deployment of renewable energy technologies and improving the overall energy infrastructure, the plan will support the long-term goal of drastically reducing carbon emissions across the islands.

The Replication Plan seeks to address these challenges by harnessing the vast renewable energy potential of the Western Isles, improving energy efficiency, and building a more resilient and sustainable energy infrastructure. This holistic approach will not only reduce energy costs and improve reliability but will also help meet the ambitious goal of achieving net zero by 2035. (Comhairle nan Eilean Siar, 2028; Community Energy Scotland, 2021; Energy Innovation, 2021 ; Hulme, 2023; SUSTAINABLE DEVELOPMENT COMMITTEE, 2024)

4.2.3. Involving Key Stakeholders for Replicating Sustainable Energy Solutions

4.2.3.1. Key Stakeholders for Replicating Sustainable Energy Solutions

The successful replication of sustainable energy solutions at the Creed Site depends on the collaboration of a diverse group of key stakeholders. Stakeholder mapping, conducted during the design phase, identified all relevant parties necessary for developing green energy generation technologies at the local level. This process specifically focused on the Creed Site, where the Energy Management System (EMS) was replicated. The Comhairle nan Eilean Siar plays a central role in providing strategic oversight and coordinating the efforts of all involved. They ensure that the project aligns with the region's broader energy and sustainability goals, including the objective of achieving net zero emissions by 2035. The Creed Waste Management Facility operators are responsible for the day-to-day technical implementation, ensuring the EMS system integrates seamlessly with the facility’s existing operations. Community Energy Scotland plays a vital role in fostering community engagement and ensuring the local population benefits from the initiative. Their involvement helps to build local support for the project by promoting community ownership of renewable energy initiatives. The University of the Highlands and Islands (UHI) contributes through research and skills development, supporting the technical aspects of the project and fostering long-term capacity building within the region. Scottish and Southern Electricity Networks (SSEN) is responsible for managing the integration of the renewable energy generated at the Creed Site into the regional grid. Their expertise ensures that the system contributes to grid stability and overall energy efficiency. Additionally, local businesses, political representatives, and funding bodies play key roles in ensuring the project meets the energy needs of the region while securing the necessary financial and political support for successful implementation. Each of these stakeholders brings unique expertise and resources, ensuring that the Creed Site project not only meets the immediate energy demands of the Western Isles but also supports the region's long-term sustainable energy goals.

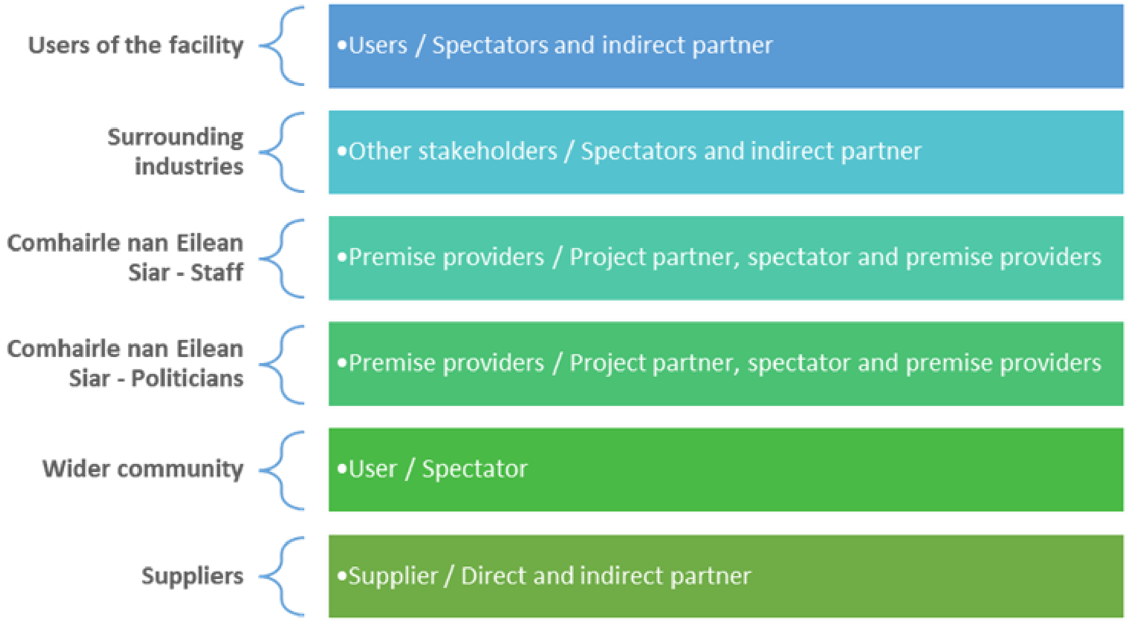


Figure 50: Main stakeholders for Western Isles (TUC, 2022)

4.2.3.2. Engagement of all stakeholders and end-user from the beginning

From the outset of the project, it has been essential to engage all relevant stakeholders and end-users to ensure a collaborative and inclusive approach to the development and implementation of sustainable energy solutions at the Creed Site. Early engagement helps foster trust, encourages active participation, and ensures that the various perspectives and needs of each stakeholder group are considered in the project's development. A detailed analysis was conducted to assess each stakeholder's level of interest, willingness to cooperate, and general attitude toward the replication of the Energy Management System (EMS) at the Creed Site. Stakeholders were mapped based on their roles and categorized into four levels of interest: neutral, positive, medium, and high.

	Expectations and attitudes to the project	Interest and willingness / ability to cooperate	Influence and power / willingness to influence
Users of the facility	Neutral	Medium	Medium
Surrounding industries	Neutral positive	Medium	Medium
Comhairle nan Eilean Siar - Staff	Positive	High	High
Comhairle nan Eilean Siar - Politicians	Positive	High	High
Wider community	Neutral	Medium	Medium
Suppliers	Positive	High	High

Figure 51: Interest analysis of Western Isles stakeholders (TUC, 2022)

A significant portion of stakeholders demonstrated a positive attitude from the outset. This group includes organizations and individuals with a strong interest in sustainability and renewable energy, many of whom have been involved in previous green energy initiatives. Their enthusiasm is driven by the recognition of the economic, environmental, and social benefits that the EMS could bring to the Western Isles, enhancing both the local energy landscape and broader sustainability efforts. Stakeholders with a medium level of interest were primarily those with moderate involvement or influence in the project. While supportive, these groups may require additional engagement to fully grasp the project's scope and benefits. Their involvement is crucial, as they represent sectors or communities that stand to benefit significantly from the initiative. A more structured communication approach will be employed to address their concerns and questions, ensuring they remain actively engaged throughout the project. Key factors such as Comhairle nan Eilean Siar personnel, local politicians, and community energy advocates exhibited the highest level of interest. These stakeholders are highly motivated to see the project succeed, as it aligns with their long-term goals of promoting energy independence, reducing carbon emissions, and fostering local economic development. Their involvement is expected to be active throughout the planning, decision-making, and execution phases, contributing leadership and support both at policy and operational levels. High-level support is crucial to the project's success, and it is anticipated that key figures within Comhairle nan Eilean Siar and local political representatives will continue to advocate for the EMS project. Their influence will be essential in securing funding, aligning policies, and ensuring the project's progress aligns with the region's broader sustainability goals. Their involvement from the early stages will also help address any potential legislative or regulatory challenges, facilitating a smooth project timeline. To maintain ongoing engagement, regular communication channels will be established, including newsletters, project updates, and community meetings. These efforts will ensure all parties remain informed about progress, challenges, and key milestones. Additionally, feedback mechanisms will be introduced to collect input from both stakeholders and end-users, ensuring that the project continues to address the evolving needs of the community.

4.2.3.3. Assignment of responsibilities to the competent stakeholders

The successful replication of sustainable energy solutions at the Creed Site hinges on the clear assignment of roles and responsibilities to the most competent and relevant stakeholders. To ensure that the project progresses smoothly and efficiently, responsibilities must be aligned with each stakeholder's expertise, authority, and capacity to deliver on specific tasks. This section outlines the key responsibilities assigned to the primary stakeholders involved in the development and deployment of the EMS system at the Creed Site.

1. **Comhairle nan Eilean Siar (Western Isles Council)**: As the local authority, Comhairle nan Eilean Siar plays a pivotal role in overseeing the entire project. The council is responsible for ensuring that the EMS system aligns with the region's strategic goals, including the drive towards net zero by 2035. The Comhairle will coordinate between different stakeholders, manage regulatory and planning procedures, and secure necessary public funding and support. In addition, the council will monitor compliance with environmental regulations and ensure that the EMS integration meets local policy requirements.
2. **Creed Waste Management Facility Operators**: The operators of the Creed Waste Management Facility will have direct responsibility for the day-to-day management and technical implementation of the EMS system. They will ensure that the system is integrated effectively into the facility's existing infrastructure and that it operates efficiently in meeting energy demands. Additionally, they will work closely with other stakeholders to optimize the system's performance and contribute to broader sustainability goals.
3. **Technical and Engineering Teams**: The technical and engineering teams, composed of experts in energy management systems, renewable energy, and grid integration, will be responsible for the design, installation, and maintenance of the EMS system. They will ensure that the system is tailored to the specific energy needs of the Creed Site and the broader region. Furthermore, they will address any technical challenges that arise during the implementation phase and contribute to long-term operational sustainability.
4. **Community Energy Scotland**: As a key advocate for community-led renewable energy projects, Community Energy Scotland will play a crucial role in fostering local engagement and ensuring that the benefits of the EMS system are realized at the community level. Their responsibilities will include facilitating communication between the community, the council, and technical teams, as well as identifying opportunities for community ownership or co-management of renewable

energy resources. They will also help raise awareness about the EMS system and its potential benefits for local energy security and cost reduction.

5. **University of the Highlands and Islands (UHI)**: UHI will contribute to the project through research, innovation, and skills development. The university will collaborate with the technical teams to optimize the EMS system's efficiency and support the development of innovative solutions to the challenges posed by renewable energy integration. UHI will also provide educational opportunities for students and local workers, creating pathways for training in renewable energy management and supporting the growth of a skilled workforce in the region.
6. **Scottish and Southern Electricity Networks (SSEN)**: As the primary grid operator for the region, SSEN will play an essential role in managing the interface between the EMS system and the wider electrical grid. Their responsibility includes ensuring that the increased energy production and renewable integration from the Creed Site does not disrupt the stability of the regional grid. SSEN will also help develop strategies for managing peak demand and supporting energy storage solutions, ensuring that excess renewable energy can be efficiently stored or distributed.
7. **Political Representatives and Policy Makers**: Local politicians and policymakers will be responsible for advocating for the project at higher government levels, securing additional funding, and shaping supportive policies that promote renewable energy development. Their role will include liaising with national bodies such as the Scottish Government to ensure that the EMS replication aligns with broader national energy strategies and receives the backing it needs to succeed.
8. **Local Businesses and End-Users**: Local businesses, particularly those involved in energy-intensive industries such as fishing and tourism, will be key beneficiaries and stakeholders in the EMS system. Their involvement is crucial for ensuring that the system meets real-world energy needs and delivers tangible cost savings. Businesses will provide feedback on the system's performance and collaborate with the council and technical teams to identify areas for improvement.
9. **Funding Bodies and Investors**: Securing the necessary financial resources for the project will require the involvement of both public and private sector funding bodies. These stakeholders will be responsible for providing the capital needed for infrastructure development and long-term maintenance of the EMS system. Investors will also play a role in assessing the project's financial viability and ensuring that it delivers a return on investment through cost savings, energy efficiency, and improved sustainability.

By clearly defining the roles and responsibilities of each stakeholder, the project will benefit from a coordinated approach that leverages the strengths and expertise of all parties involved. This structured framework will support the successful replication of sustainable energy solutions at the Creed Site and contribute to the long-term energy goals of the Western Isles.

4.2.4. Replicating Sustainable Energy Solutions

The ROBINSON project aims to support islands in their journey toward decarbonization by maximizing the use of Renewable Energy Systems (RES) and enhancing grid flexibility through innovative energy storage and clean technologies. By focusing on both Lighthouse (LH) islands and Follower Islands (FIs), the project not only implements specific renewable energy solutions but also evaluates their potential for wider application across similar island communities. Each use case within the project combines innovative and traditional technologies to enhance renewable energy capacity. Through replication activities, ROBINSON aims to adapt successful models to the unique energy landscapes of the Follower Islands, driving long-term energy transitions and contributing to the global push for sustainable, low-carbon island communities.

4.2.4.1. Technical components/ infrastructure selection

The ROBINSON concept will be considered at the Creed Waste Management Facility (IWMF). The facility already operates a multi-energy system, integrating several advanced technologies designed to meet local energy needs, reduce carbon emissions, and promote long-term sustainability. The system includes a CHP, an anaerobic digester, a wind turbine, and an electrolyser, each playing a crucial role in energy generation, storage, and distribution. Together, these technologies form a resilient and scalable energy system that can serve as a model for further energy infrastructure development throughout the Western Isles. However, ROBINSON's Energy management system will be tested towards the integrated approach to ensure efficient energy use, reduce dependency on external energy sources, and lay the groundwork for replicating the system across the region, supporting the broader goal of achieving net-zero emissions.(University of Flensburg, 2018)

Table 15: ROBINSON technology components (PSI, 2021; UNIVERSITA DI GENOVA, 2021)

Component	Name	Status	
CHP unit	N/A	**D**	**-**
Boiler	N/A	**D**	**-**
PV panels	260 W BenQ Green Triplex	**D**	**-**
Wind turbines	Enercon E-33 300 kW	**D**	**-**
Electrolyser	N/A	**D**	**-**
Gasifier	Syncraft Gasifier	**-**	**-**
AD-BES	N/A	**D**	**-**
Gas mixer	-	**-**	**-**
Storage systems	Hydrogen Storage/Batteries	**D**	**-**
EMS	ROBINSON's EMS	**-**	**R**
Grid	-	**D**	**-**
Industrial symbiosis	-	**D**	**-**
D: The solution is demonstrated **//** **R:** The solution is planned to be Replicated			

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In particular, the key technical components of at the Creed site include:

1. **Combined Heat and Power (CHP) Unit**: The CHP unit at Creed plays a central role in the facility's energy system. Powered by biogas generated through the anaerobic digestion (AD) of organic waste, the unit has a capacity of **240 kWe** for electricity and **370 kWth** for thermal energy. The electricity produced is used for on-site operations, while the thermal energy is stored for future use. This system helps to optimize energy use, lowering operating costs and minimizing CO_2 emissions.
2. **Anaerobic Digester (AD)**: The AD unit processes organic waste, such as household refuse and fish by-products, to produce biogas with a high methane content. The biogas is then fed into the CHP unit to generate renewable electricity and heat. Over time, the system has been adjusted to better handle the ammonia content from fish waste by incorporating cow slurry as a buffer, improving biogas quality and operational efficiency.
3. **Wind Turbine**: The facility features a **300-kW wind turbine**, which provides renewable electricity directly to the Creed facility’s microgrid. This wind energy not only supports daily operations but also powers the production of green hydrogen via an on-site electrolyzer. The wind turbine helps ensure that the site remains energy-independent and can reduce its reliance on external energy sources.
4. **Electrolyzer and Hydrogen Storage**: A **50 kW electrolyzer** converts excess wind power into **green hydrogen**, which is stored in a **1.25 m^3 pressurized hydrogen vessel**. The hydrogen produced is used for various applications, including potentially powering local vehicles and supporting operations at nearby fish hatcheries by supplying oxygen. The production of green hydrogen is expected to expand in the future, as demand for clean energy grows across the islands.
5. **Thermal Energy Storage**: The system includes a **30 m^3 thermal energy storage unit**, which captures excess heat from both the CHP and electrolyzer processes. This stored heat is available for use during periods of low energy production, ensuring that the facility has a reliable supply of thermal energy for heating and operational needs. This storage system allows for greater flexibility and improves overall energy efficiency.
6. **Energy Management System (EMS)**: The entire energy infrastructure will be managed by an advanced **Energy Management System (EMS)**, designed to optimize the use of renewable resources, reduce operational expenditures (OPEX), and minimize carbon emissions. The EMS integrates electricity, thermal energy, and gas, balancing generation and demand. This ensures that energy flows efficiently within the facility, and any excess can be used or stored as needed. (UNIVERSITA DI GENOVA, 2021; University of Flensburg, 2018)

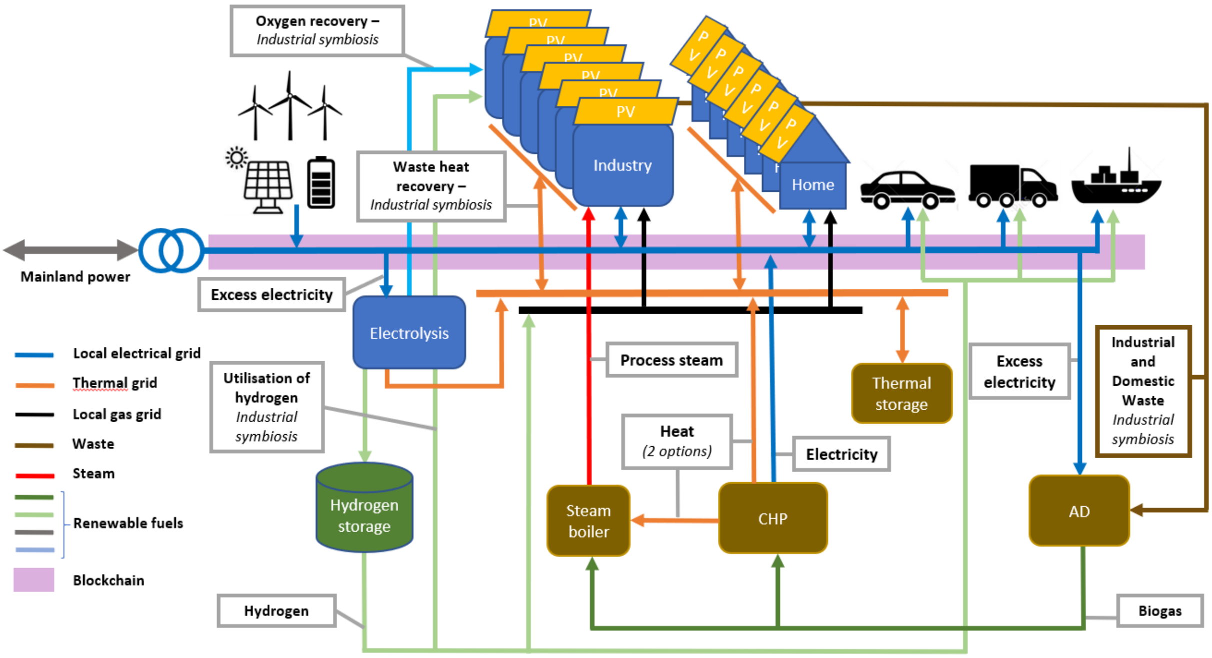

Figure 52: Theoretical replication of ROBINSON system(UNIVERSITA DI GENOVA, 2021)

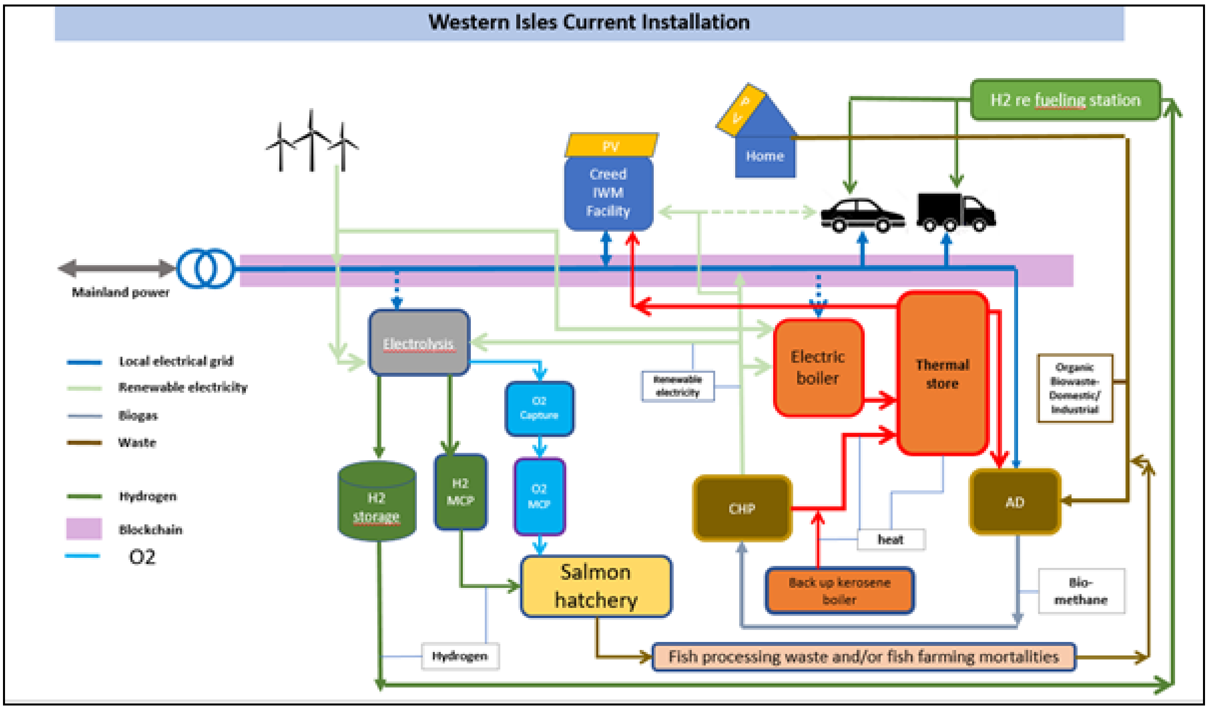

Figure 53: Proposed ROBINSON solution for application in Western Islands (Energy Innovation, 2021)

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4.2.4.2. Design and optimise the replication model

The EMS replication at the Creed Waste Management Facility (IWMF) is a foundational demonstration of the ROBINSON energy concept, matching renewable energy sources and advanced technologies to meet local energy needs while reducing carbon emissions. The facility's energy infrastructure incorporates several key technologies, including an anaerobic digester, a CHP unit, a wind turbine, and a hydrogen electrolyser, all interacting seamlessly to optimize energy generation, storage, and distribution. The biogas produced by the anaerobic digester is fed into the CHP, providing electricity and thermal energy to the site. The heat generated is stored in a thermal storage reservoir, ensuring that demand is met efficiently, even when generation fluctuates. One of the critical aspects of the Creed system is the integration of multiple energy vectors, such as electricity, thermal energy, and hydrogen, which interact to create a reliable and resilient system. The wind turbine generates electricity that powers the site and supplies the electrolyzer, which produces green hydrogen. This hydrogen is stored and used as a flexible energy source, while the oxygen byproduct is directed to nearby hatcheries, demonstrating the system's circular approach.

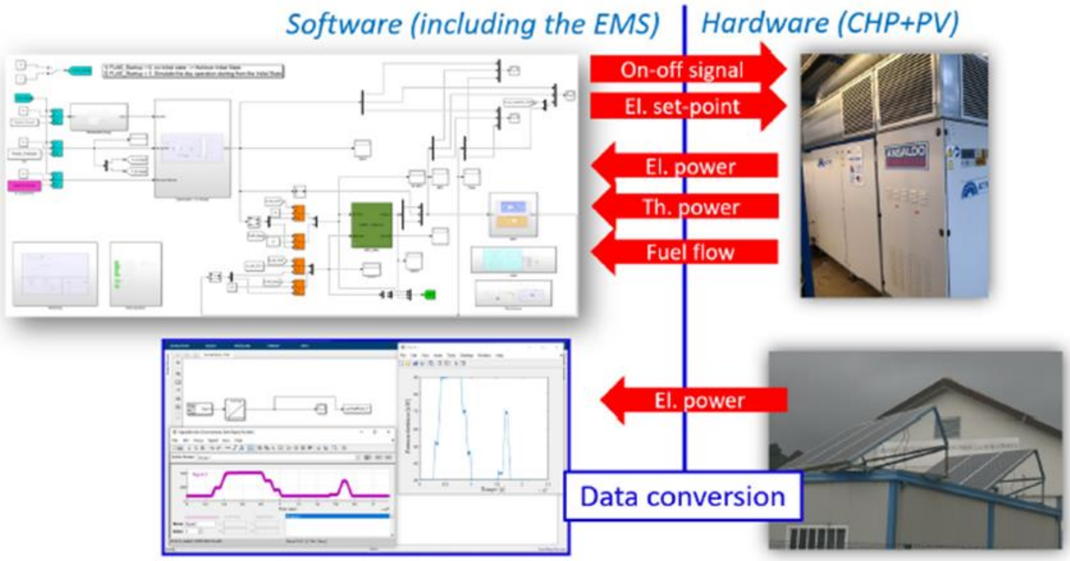

Figure 54: Details for the software-hardware communication (UNIVERSITA DI GENOVA, 2023)

ROBINSON's project's EMS was able to control and optimise these components, balancing energy generation with demand (Figure 54). The EMS is designed to manage the intermittent nature of renewable sources, ensuring the system can operate efficiently and cost-effectively. For example, during low-demand periods, excess energy is stored in the thermal reservoir or used to produce hydrogen, which can be utilised later. The EMS also supports hydrogen management, allowing for recharging operations and replenishing hydrogen storage after it is used or exported. The system's modularity and flexibility make it suitable for adaptation to other locations where additional renewable sources like wind and tidal energy can be incorporated. The scalability of the system, including potential future additions such as gasification units, ensures that it can meet varying energy needs across the region. Figure 55 shows schematically the current and expected energy fluxes, to visualise the interaction of the various prime movers.

An example of the WI system management with the EMS is reported in Figure 56. Except the initial 30 minutes when the software performed the necessary iterations to be aligned with the system initial conditions, the EMS was able to manage the system to satisfy the load demands. The initial oscillation, although different from the previous cases where the simulation started from a stable condition, demonstrated the EMS robustness and the possible easy connection with the system. In comparison with the previous results for the Eigerøy case, here the contribution of renewable sources is very important. Moreover, the system includes also a thermal storage that was managed to uncouple the electrical generation (the CHP was operated to minimize the costs) with the thermal demand matching. On the hydrogen side, the simulation included a truck/trailer recharging operation (as described for the Eigerøy case) that generated the vessel pressure decrease. This is due to an important amount of hydrogen discharged from the pressure vessel. This was followed by the 40-bar restoring thanks to the operation of the electrolyzer. As performed for Eigerøy, the results obtained with the EMS were compared with the no EMS simulations in terms of global variable costs. Also, in this case the cost saving is significant (-33.3% as shown in Figure 57) thanks to a CHP utilization increase that allowed to avoid the switch on of the boilers).(UNIVERSITA DI GENOVA, 2023)

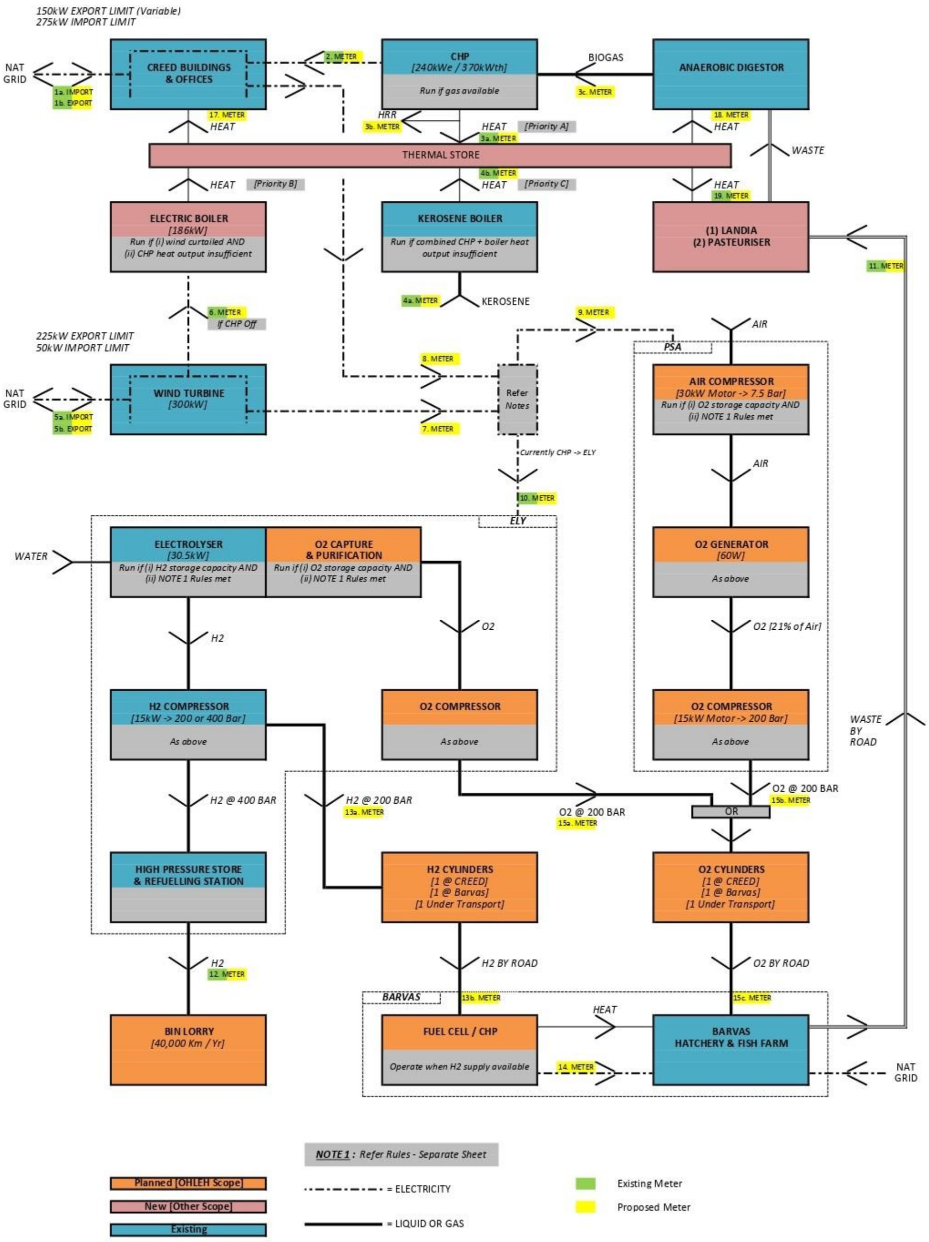

Figure 55 : Existing and proposed meters in Western Isles (NORCE, 2022)

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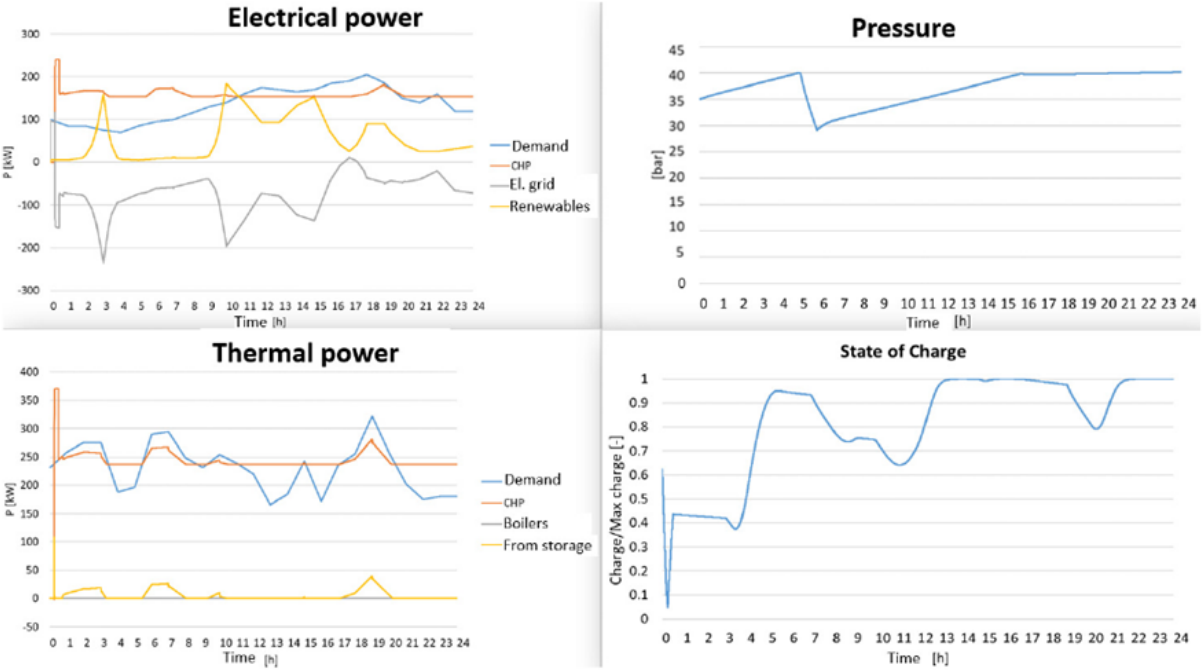

Figure 56: EMS system management in the WI case (simulation results)(UNIVERSITA DI GENOVA, 2023)

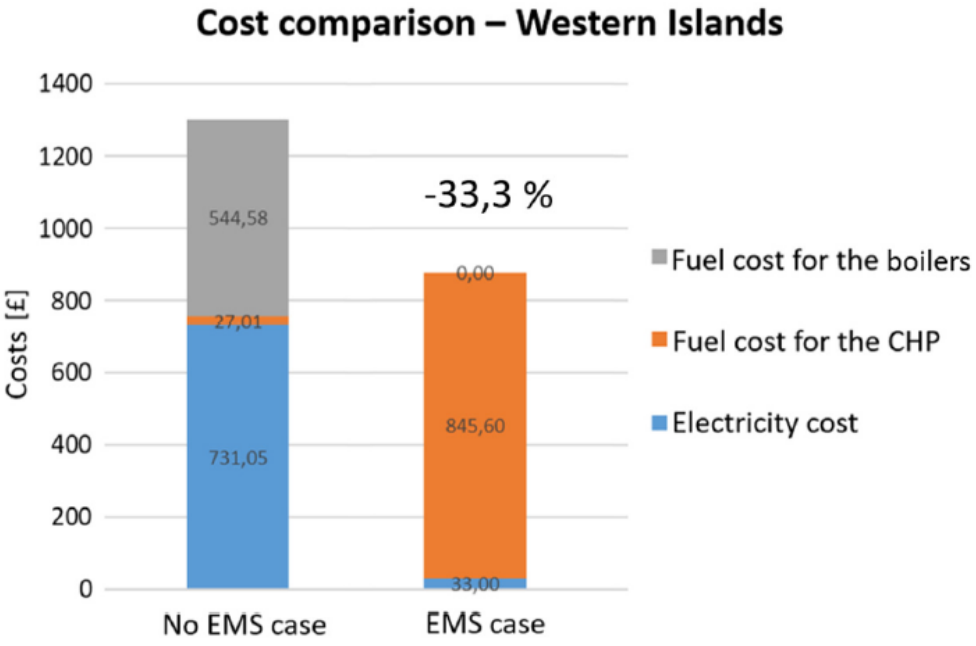

Figure 57: Generation cost comparison for the WI case (UNIVERSITA DI GENOVA, 2023)

4.2.5. Ensure the application context

The successful replication of the ROBINSON concept in the Western Isles requires a detailed understanding of the region’s unique energy landscape and socio-economic context. The Outer Hebrides, with its abundant renewable energy potential, presents both opportunities and challenges. A thorough analysis of regional spatial planning frameworks, environmental policies, and energy regulations is crucial to ensure the project's alignment with the Outer Hebrides' strategic development goals. The replication plan must consider the latest developments outlined in the Energy Developments Update Report and the initiatives driven by the Islands Centre for Net Zero (ICNZ) as part of the Islands Growth Deal.

4.2.5.1. Feasibility analysis and business model development

The **Energy Developments Update Report for the Outer Hebrides** provided a detailed overview of major renewable energy projects and plans, highlighting the region's transition to a renewable energy hub. Key energy developments include:

1. **Major Projects**: A 1.8GW HVDC transmission link, approved by Ofgem, is expected to be operational by 2030, and several onshore wind projects (Stornoway, Uisenis, Druim Leathann) with a combined capacity of 429.9MW are slated for construction by 2026. Additionally, offshore wind projects totalling 2.835GW are under development, with construction anticipated between 2027 and 2028, subject to licensing approvals. An innovative hydrogen production facility (Outer Hebrides Energy Hub) is also being explored, with local demand production aimed for 2026.
2. **Economic Impact**: These projects are expected to provide substantial economic benefits through job creation and local supply chain engagement, while boosting community wealth. The synergy with initiatives like the Islands Growth Deal and the Levelling-Up Partnership will enhance regional development.
3. **Governance and Coordination**: A Major Developments Forum (MDF) has been established to coordinate stakeholders, developers, and the local community. The forum will focus on supply chain integration, workforce accommodation, and environmental sustainability. The report also suggests forming a Major Developments Oversight Board to provide strategic leadership and manage operational challenges.
4. **Challenges and Resources**: The Comhairle is facing significant capacity challenges in managing the scale of these projects, particularly in infrastructure and planning services. Efforts are underway to bolster resources, seek national support, and enhance coordination across agencies to manage these challenges effectively.

The Islands Centre for Net Zero (ICNZ) is a significant part of the Islands Growth Deal, which aims to drive sustainable growth and decarbonization in Shetland, Orkney, and the Outer Hebrides. Highlights from the ICNZ and related energy developments include:

1. **Net Zero Initiatives**: The ICNZ, receiving £16.5 million in funding, is aimed at positioning the islands as global leaders in the energy transition. The Outer Hebrides will receive £5 million to support local projects focused on decarbonization, community engagement, and innovation. Tools such as Data Exchange, Transition Labs, and Demonstration Zones will trial and showcase new technologies.
2. **Focus on Uist and Barra**: Uist and Barra are identified as key areas for decarbonization demonstrations, focusing on energy efficiency measures and reducing fuel poverty. Scottish and

Southern Electricity Networks (SSEN) has proposed infrastructure upgrades, including subsea cables to enhance grid reliability and support renewable energy exports.

3. **Hydrogen and Green Energy**: ICNZ is developing a Hydrogen Skills and Innovation Centre in Lewis, which could expand hydrogen production to Uist and Barra. There are also long-term prospects for exporting green hydrogen powered by offshore wind.
4. **Future Plans**: The ICNZ remains committed to supporting domestic energy decarbonization, peatland restoration, and waste reduction projects. Strategic alignment with community energy forums and SSEN's planned infrastructure upgrades will ensure the energy resilience and sustainability of Uist, Barra, and the broader Outer Hebrides.

In summary, the Energy Developments Update Report and the ICNZ initiatives reflect a transformative vision for the Outer Hebrides. The region is poised to become a leader in renewable energy, with significant economic, environmental, and social benefits, if coordination, governance, and resource management are efficiently addressed.(Hulme, 2023; SUSTAINABLE DEVELOPMENT COMMITTEE, 2024)

4.2.5.2. Risk Management and Mitigation Strategies

The system is designed to be resilient to harsh weather conditions, and regular maintenance of infrastructure is essential to prevent damage. Installing robust, weather-resistant components and ensuring that backup systems, such as biogas-powered CHP, are available during extreme weather events, will further minimize disruptions.

Table 16: Risk Management and Mitigation Strategies for the selected use case in Western Islands

Condition	Risk	Mitigation Strategy
Technical	*The integration of multiple energy technologies (anaerobic digestion, wind turbines, CHP, electrolyzer, and storage systems) presents potential challenges in terms of system compatibility, efficiency, and operational reliability.*	*The Energy Management System (EMS) plays a critical role in optimizing the interaction between these components. Rigorous testing, simulation, and phased implementation can help identify and address technical incompatibilities early on. Continuous monitoring and the use of predictive maintenance technologies will help system failures.*
Intermittency of Renewable Energy Sources	*Wind energy, a major component of the system, is inherently intermittent, which could lead to periods of low power generation.*	*The system is designed with flexibility in mind, utilizing thermal storage and hydrogen production to store excess energy for periods of low wind output. The integration of multiple energy vectors—such as electricity, heat, and hydrogen—helps balance generation and demand, reducing the impact of intermittent renewable energy sources. Additionally, exploring complementary energy sources, like tidal energy, can further mitigate this risk.*
Fuel Supply and Biogas Production Variability	*the anaerobic digestion process relies on a steady supply of organic waste to produce biogas. Variability in feedstock quality or supply interruptions could reduce biogas production and impact the operation of the CHP system*	*Establishing diverse and reliable feedstock sources (e.g., household waste, agricultural waste, fish waste) is key to maintaining consistent biogas production. Regular adjustments to the feedstock composition and system calibration (e.g., cow slurry buffering to manage ammonium buildup) will help ensure the stability of biogas generation. A contingency plan for alternative fuel supply or temporary energy imports may be implemented during supply interruptions.*

Condition	Risk	Mitigation Strategy
Regulatory and Compliance Risks	*Changes in local, national, or European energy regulations or environmental policies could impact the feasibility or legality of certain components of the energy system*	*Continuous engagement with regulatory bodies and alignment with current policy frameworks are critical. The Creed facility should maintain regular communication with local authorities and policymakers to ensure compliance and to take advantage of any incentives or regulatory changes that support renewable energy initiatives. Additionally, flexible system design allows for adaptation to future regulatory changes.*
Financial and Economic Risk	*High upfront capital costs, potential cost overruns during installation, and fluctuations in energy prices could pose financial risks to the project.*	*A thorough cost-benefit analysis during the planning stages, combined with securing public and private funding through sustainable financial models, is crucial. Mitigation strategies include exploring government grants, subsidies, and private investment to offset high upfront costs. Ongoing financial assessments and the use of the EMS to optimize operational costs will help maintain economic viability in the long term.*
Community and Stakeholder Engagement Risks	*Lack of community support or engagement could delay implementation and reduce the overall effectiveness of the energy system.*	*Early and continuous engagement with stakeholders, including residents, businesses, and policymakers, is essential to building support and addressing any concerns. Community outreach programs, public consultations, and educational initiatives should be prioritized to highlight the benefits of the project, such as reduced energy costs, job creation, and environmental sustainability*
Environmental conditions	*Environmental factors, such as extreme weather events, could disrupt the operation of renewable energy technologies, particularly wind turbines and hydrogen storage systems.*	*The system is designed to be resilient to harsh weather conditions, and regular maintenance of infrastructure is essential to prevent damage. Installing robust, weather-resistant components and ensuring that backup systems, such as biogas-powered CHP, are available during extreme weather events, will further minimize disruptions.*

4.2.5.3. Assessing Long-term Sustainability and Socio-economic Impact of RES on Western Islands

Integrating RES in the Western Isles is crucial for sustainability and development. This transition will reduce reliance on fossil fuels, cut carbon emissions, and enhance energy security while addressing social issues like poverty and job creation. The Western Isles can significantly decrease CO_2 emissions and contribute to Scotland's goal of achieving net-zero emissions by 2035 using RES. From a socio-economic perspective, RES projects will bring substantial benefits, including creating local jobs and increased economic output. Projects like the planned Outer Hebrides Energy Hub and the construction of large-scale wind farms are expected to generate jobs during the construction and operational phases, helping alleviate unemployment in the region.

A virtual power plant (VPP) business model could be a transformative tool for the Western Isles to maximise the benefits of renewable energy (Figure 58). By connecting various decentralised energy sources, such as individual wind turbines, small-scale solar panels, and hydrogen storage systems, the VPP can optimise energy production and consumption across the islands. The VPP allows individual

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households and businesses to become part of a flexible energy network. Through intelligent control, the VPP can manage energy generation and consumption to minimise costs and maximise the use of locally generated renewable energy. For instance, during periods of high demand or peak energy prices, the VPP could discharge stored energy (from batteries or electric vehicles) and adjust the consumption of flexible consumers, providing lower energy bills for participants while ensuring grid stability.

This approach can also provide opportunities for local energy trading, where prosumers (energy producers and consumers) can sell excess energy generated by wind, solar, or hydrogen back to the grid or the balancing market. This increases profitability for local producers and makes the overall energy system more resilient and efficient. Adopting RES in the Western Isles, supported by innovative business models like the VPP, can lead to long-term sustainability by reducing carbon emissions and promoting energy self-sufficiency. Simultaneously, it offers significant socio-economic benefits, such as job creation, reduced energy poverty, and opportunities for local energy trading. Through intelligent energy management and integration, the region can maximise the benefits of its renewable energy resources, contributing to a more sustainable and resilient future.

Table 17: List of indicative KPIs for the selected use case in Western Islands (adapted from (Clercq et al., n.d.))

KPI/Metric	Description	Target
CO_2 Reduction Over Time	Total carbon emissions reduction	40% reduction by 2030
Energy Poverty Alleviation	Reduction in energy poverty for low-income households	15% reduction in rural areas by 2026
Economic Growth	Increase in economic output due to renewable energy projects	€10 million increase over 5 years
Sustainable Energy Production	Growth in renewable energy production capacity	50% increase by 2027

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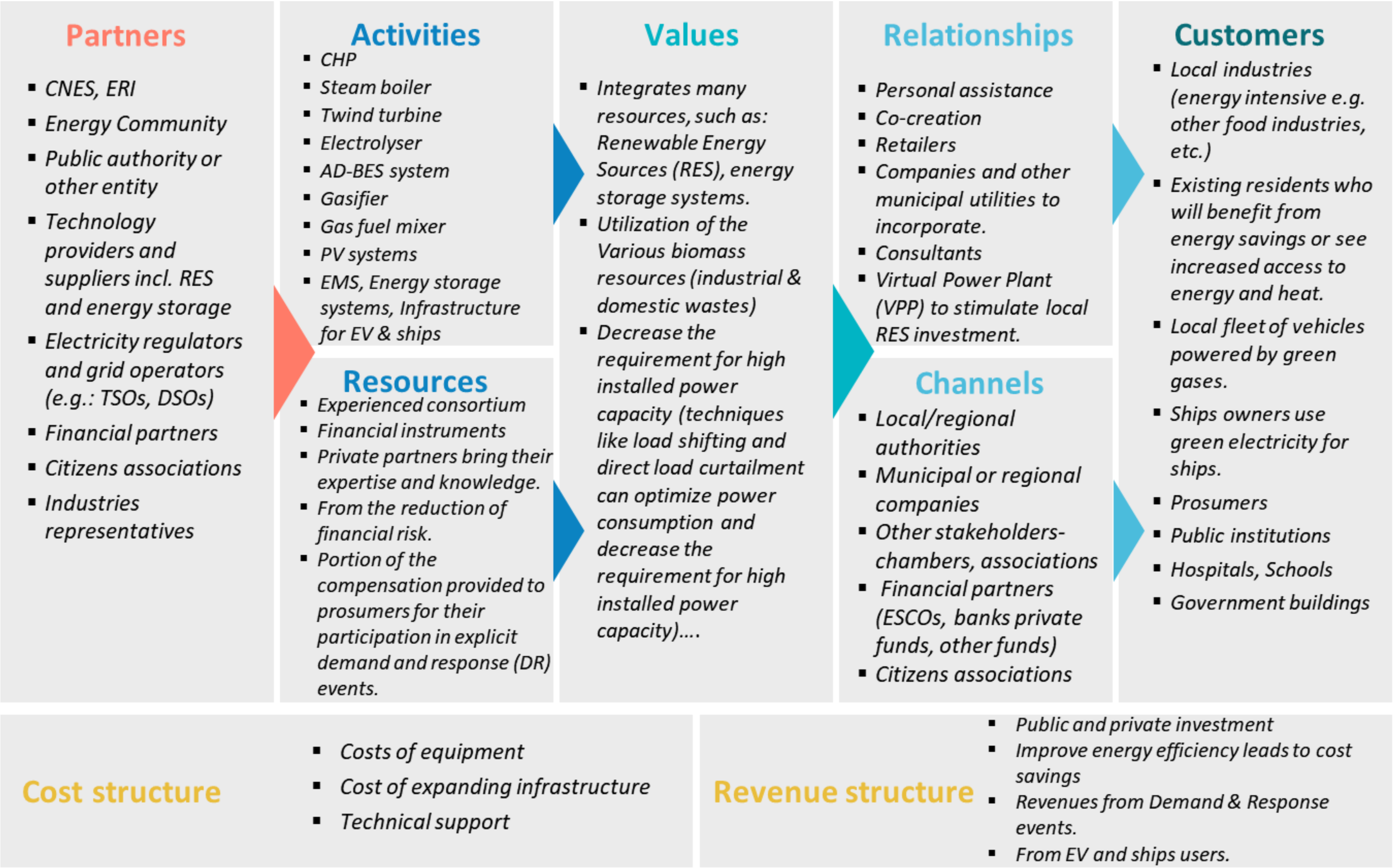

Partners

- *CNES, ERI*
- *Energy Community*
- *Public authority or other entity*
- *Technology providers and suppliers incl. RES and energy storage*
- *Electricity regulators and grid operators (e.g.: TSOs, DSOs)*
- *Financial partners*
- *Citizens associations*
- *Industries representatives*

Activities

- *CHP*
- *Steam boiler*
- *Twind turbine*
- *Electrolyser*
- *AD-BES system*
- *Gasifier*
- *Gas fuel mixer*
- *PV systems*
- *EMS, Energy storage systems, Infrastructure for EV & ships*

Resources

- *Experienced consortium*
- *Financial instruments*
- *Private partners bring their expertise and knowledge.*
- *From the reduction of financial risk.*
- *Portion of the compensation provided to prosumers for their participation in explicit demand and response (DR) events.*

Values

- *Integrates many resources, such as: Renewable Energy Sources (RES), energy storage systems.*
- *Utilization of the Various biomass resources (industrial & domestic wastes)*
- *Decrease the requirement for high installed power capacity (techniques like load shifting and direct load curtailment can optimize power consumption and decrease the requirement for high installed power capacity)….*

Relationships

- *Personal assistance*
- *Co-creation*
- *Retailers*
- *Companies and other municipal utilities to incorporate.*
- *Consultants*
- *Virtual Power Plant (VPP) to stimulate local RES investment.*

Channels

- *Local/regional authorities*
- *Municipal or regional companies*
- *Other stakeholders-chambers, associations*
- *Financial partners (ESCOs, banks private funds, other funds)*
- *Citizens associations*

Customers

- *Local industries (energy intensive e.g. other food industries, etc.)*
- *Existing residents who will benefit from energy savings or see increased access to energy and heat.*
- *Local fleet of vehicles powered by green gases.*
- *Ships owners use green electricity for ships.*
- *Prosumers*
- *Public institutions*
- *Hospitals, Schools*
- *Government buildings*

Cost structure

- *Costs of equipment*
- *Cost of expanding infrastructure*
- *Technical support*

Revenue structure

- *Public and private investment*
- *Improve energy efficiency leads to cost savings*
- *Revenues from Demand & Response events.*
- *From EV and ships users.*

Figure 58: Business Model Canvas for Crete Case (STRATAGEM, 2023)

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4.2.6. Adaptation analysis

The Adaptation analysis for the ROBINSON project at the Creed Waste Management Facility in the Western Isles must carefully examine how the project can be tailored to the unique conditions of the site and the region. The main objective of this assessment is to verify that the suggested Energy Management System (EMS) and renewable energy elements are both functionally efficient and compatible with the local energy environment, regulatory guidelines, infrastructure capabilities, and socio-economic conditions. Additionally, the EMS is intended to be adaptable to fluctuations in the market and environmental factors.

To successfully replicate the ROBINSON concept, the Energy Management System (EMS) must be adapted to manage the inherent intermittency of RES, particularly wind power. Ensuring efficient storage of excess energy through systems like hydrogen and thermal storage is critical. As renewable energy generation increases in the Western Isles, the EMS should remain adaptable to future technological developments, such as the potential integration of gasification units and expanded wind or solar installations. This adaptability will maintain flexibility and ensure the system can handle the evolving energy demands of the region.

In addition to the technical aspects, several risk mitigation and resilience planning considerations should be addressed. The Western Isles experience frequent weather-related disruptions and seasonal variability in energy demand, which pose a risk to the stability of energy supplies. The EMS must be optimized to balance energy storage, demand response, and backup generation systems, such as the on-site diesel generators, particularly during periods of grid stress. Long-term resilience strategies need to consider changes in local energy needs, innovations in technology, and modifications in policies, guaranteeing that the system stays strong and ready for the future.

Moreover, the project must align with the critical policy and regulatory frameworks governing the Western Isles. It is essential that the EMS complies with regional policy documents, such as the Outer Hebrides Local Development Plan, and integrates seamlessly into broader initiatives like the Islands Centre for Net Zero (ICNZ). Achieving decarbonization by 2035 is a crucial strategic goal for the region, and the Creed energy system must be part of this more comprehensive net-zero strategy. The EMS must also adhere to national Scottish Government renewable energy targets, ensuring compliance with evolving regulations related to green hydrogen production, wind projects (both onshore and offshore), and the capacity of local infrastructure to accommodate increased renewable energy outputs. By aligning with these policies and incorporating technological resilience, the project can effectively contribute to the sustainable energy future of the Western Isles.

4.2.7. Evaluation of replication plan

4.2.7.1. Review of results and recommendations

The simulation and validation of the Energy Management System (EMS) for the Western Isles case, conducted in a cyber-physical mode as outlined in Deliverable D3.5, provided important insights into the system's performance, efficiency gains, cost savings, and reduction in carbon emissions. The testing, which replicated a 24-hour operating period under real-time conditions, demonstrated the viability and effectiveness of the EMS in managing the complex energy flows at the Creed Waste Management Facility. The layout of the Creed district It includes the following components: a 240 kW (electrical power) engine fed by biogas from waste and able to produce also 370 kW of thermal power in CHP mode, a 150 kW kerosene boiler, a 180 kW electrical boiler, 9.75 kWp photovoltaic panels, a 300 kW wind turbine, a 50 kW electrolyser, a 30 m^3 thermal energy storage (hot water vessel) and a 1.25 m^3 pressurized hydrogen storage vessel. The EMS, which was developed and validated by UNIGE, demonstrated its ability to optimize energy generation, leading to a 40.8% reduction in operational costs compared to the "No EMS" scenario (Figure 61). This cost reduction was primarily achieved by prioritizing the use of biogas and renewable energy sources such as wind power, while reducing reliance on more expensive fuels like kerosene. The EMS improved the overall energy efficiency of the system by 23.2% (Figure 61), due to the effective management of the CHP unit, photovoltaic panels, and wind turbine. Surplus thermal energy was stored in the 30 m^3 thermal storage tank, allowing the system to meet demand during periods of low energy production, thereby reducing waste and enhancing overall operational efficiency. A particularly impactful outcome of the EMS implementation was the dramatic reduction in CO_2 emissions, which decreased by over 97.5% compared to the "No EMS" case (Figure 62). This significant reduction was driven by the shift from a system that relied heavily on kerosene and external electricity to one primarily powered by biogas and locally generated renewable energy. The EMS successfully integrated intermittent renewable energy sources, especially the wind turbine and solar panels, by effectively managing energy flows through the thermal storage and hydrogen production systems. This ensured stable energy output, even during periods of low renewable generation, contributing to the system's reliability and flexibility. Additionally, the EMS proved highly effective in managing hydrogen generation and storage. During periods of low electricity prices, the system optimized hydrogen production, storing it in the 1.25 m^3 pressurized storage vessel. When demand peaked, the stored hydrogen was used to power local systems. Furthermore, the EMS efficiently handled the recharging of hydrogen trucks, ensuring that pressure levels in the storage vessel remained stable throughout the process. Despite some initial oscillations in power generation, which were corrected through adjustments to the Model Predictive Control (MPC) system, the EMS demonstrated its robustness and stability. It effectively managed the complex interactions between different energy sources and storage components, maintaining stable operation and ensuring energy balance throughout the entire 24-hour test period. In conclusion, the EMS system at Creed Waste Management Facility has proven its capacity to significantly reduce costs, enhance efficiency, and minimize carbon emissions, making it a crucial tool for advancing renewable energy integration and sustainability across the Western Isles.(NORCE, 2023)

Based on these simulation results, several recommendations are made for replicating and optimizing the EMS across the Western Isles:

1. **Expand EMS Deployment**: The cost and efficiency benefits demonstrated by the EMS suggest that it should be deployed at additional sites across the Western Isles. The system's ability to integrate renewable energy sources and optimize local generation can provide similar benefits to other facilities.
2. **Increase Renewable Energy Capacity**: The test showed that the EMS is capable of effectively managing intermittent renewable energy sources. Expanding the capacity of wind and solar installations, as well as integrating other renewable resources like tidal energy, would further enhance the region's energy independence and sustainability.
3. **Prioritize Hydrogen Infrastructure**: The successful management of hydrogen production and storage suggests that hydrogen can play a vital role in the energy mix. Expanding hydrogen infrastructure across the Western Isles will further improve energy flexibility and provide additional energy storage solutions.
4. **Long-term Efficiency Focus**: The improvements in overall efficiency underscore the importance of optimizing the EMS to continue reducing energy waste. As the system is expanded, continuous monitoring and fine-tuning will be essential to maintain these efficiency gains.

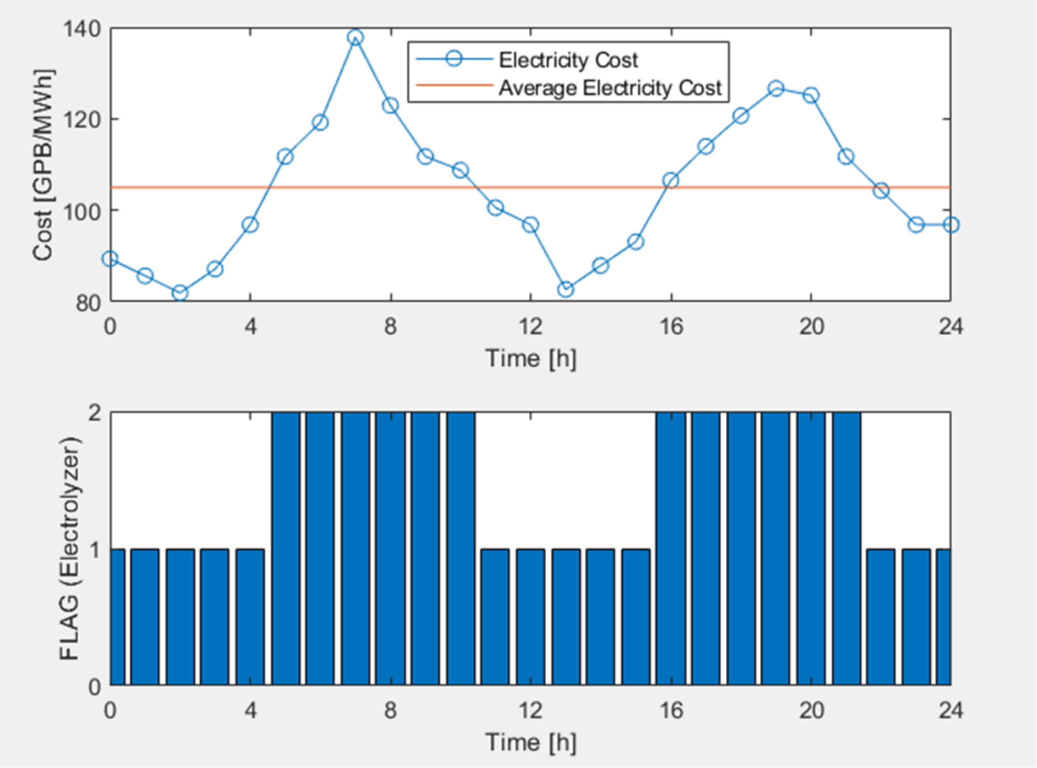

Figure 59: Electrical costs and electrolyser flags (WI case)(NORCE, 2023)

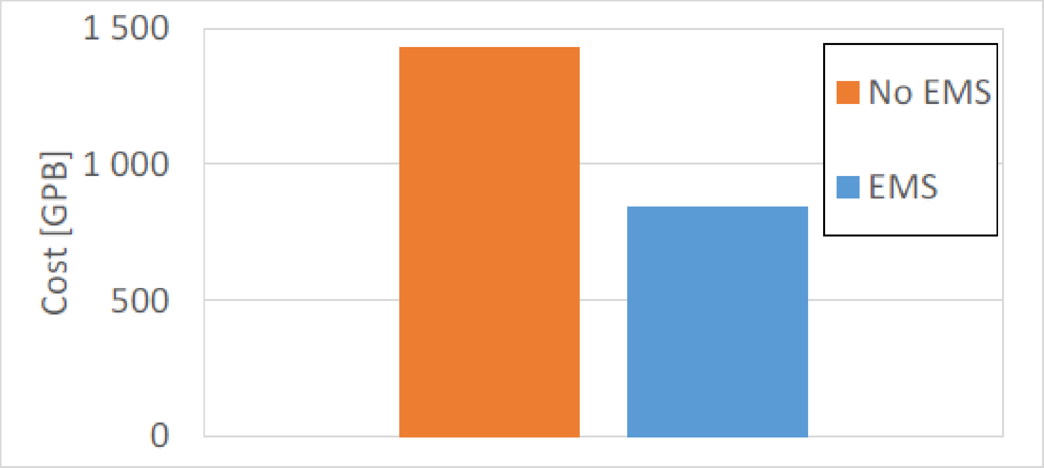

Figure 60: 24-hour test for the WI case: global performance comparison (cost).

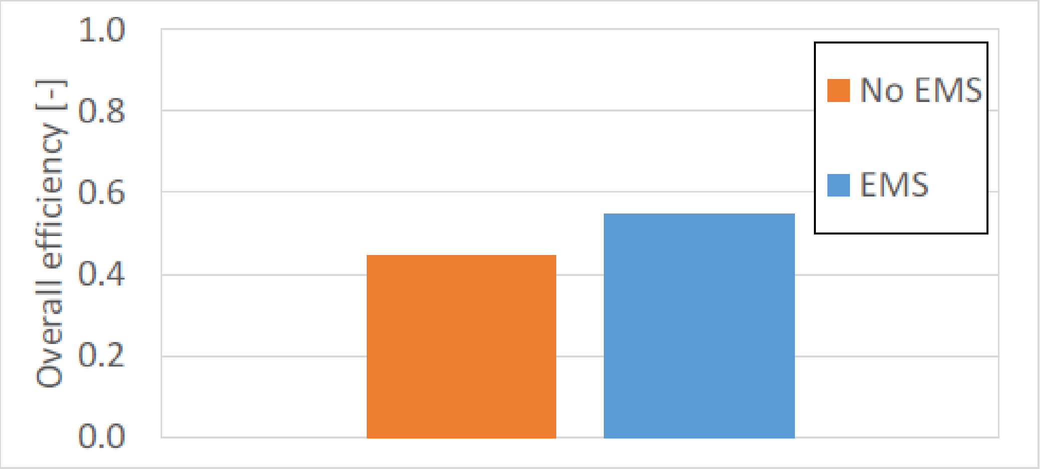

Figure 61: 24-hour test for the WI case: global performance comparison (overall efficiency).

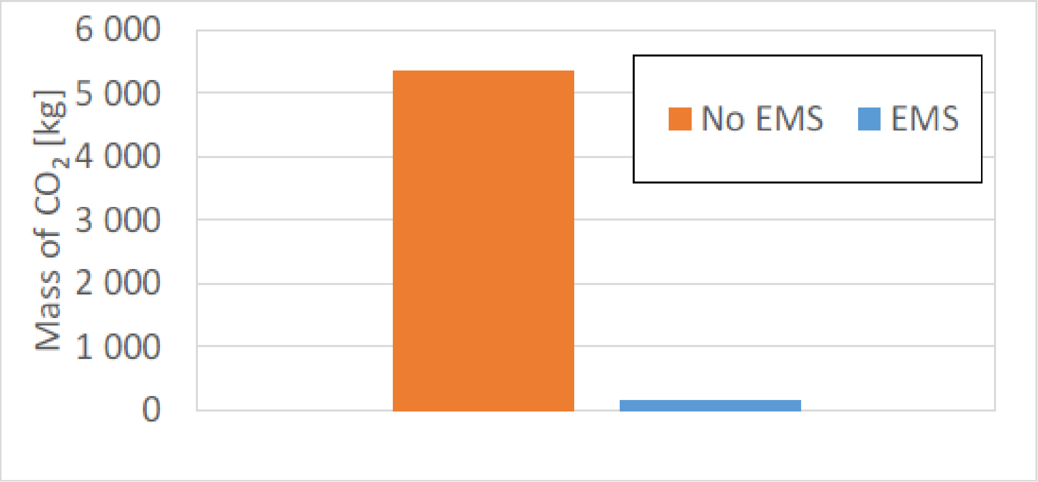

Figure 62 : 24-hour test for the WI case: global performance comparison (CO2 emissions).

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4.2.7.2. Interventions’ follow-up and correction mechanisms

Effective follow-up and correction mechanisms are essential to ensure the long-term success and optimization of the **Energy Management System (EMS)** and its associated components at the Creed Waste Management Facility and other replication sites. Establishing robust follow-up and correction mechanisms is crucial to ensuring the long-term success and optimization of the Energy Management System (EMS) at the Creed Waste Management Facility and other replication sites. These mechanisms enable the system to adapt to changing conditions, address unforeseen challenges, and continuously enhance performance.

These processes allow the system to adjust to evolving circumstances, tackle unexpected obstacles, and perpetually improve efficiency. Devices from optimal performance can be detected early using sensors and automated systems, enabling rapid interventions to prevent disruptions. This ability is essential due to the intricate nature of combining different renewable energy sources, including biogas, wind, and thermal storage. The EMS also has automatic fault detection systems that identify early signs of underperformance, ensuring operational stability. In addition, a regular maintenance and inspection schedule is essential for minimizing the risk of system failures. Maintenance plans are developed for critical components, such as the CHP unit, electrolyzer, and wind turbines, with predictive algorithms helping determine the most appropriate times for servicing. Cyber-physical testing is also periodically performed to simulate potential stress scenarios and assess system resilience under various conditions.

The EMS incorporates feedback loops for continuous optimization, ensuring the system learns from operational data and refines its performance over time. Using Model Predictive Control (MPC), the EMS forecasts future energy demand and adjusts operational strategies accordingly. This enables the system to optimize energy generation, storage, and consumption based on real-time conditions, ensuring ongoing efficiency improvements. Moreover, the EMS is designed to be flexible in its response to market and environmental changes. It can adjust its operation to fluctuating electricity prices and environmental factors like wind or solar energy availability. For example, during high electricity prices, the EMS can prioritize stored energy, while in low-cost periods, it can increase hydrogen production or recharge energy storage systems. This adaptability is crucial for maintaining balance and performance across various scenarios.

Periodic system audits and performance reviews are conducted to ensure accountability and track progress. These audits focus on key performance indicators (KPIs) such as cost savings, CO_2 emissions reductions, and energy efficiency. The reviews also evaluate whether the system aligns with long-term net-zero emissions goals for the Western Isles. Based on these assessments, further adjustments may be made, including system enhancements or the integration of new technologies. Finally, community and stakeholder feedback play a vital role in the EMS's ongoing success. Regular consultations with local stakeholders, such as residents, businesses, and government entities, ensure the system aligns with community needs. This open dialogue allows for prompt responses to any concerns and helps the system remain responsive to technical and social factors over time. The EMS can continuously adapt and improve by combining real-time monitoring, maintenance schedules, feedback loops, flexibility to market and environmental changes, periodic audits, and stakeholder engagement, ensuring a sustainable energy future for the Western Isles.

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Conclusions

The replication of the ROBINSON energy solutions in Crete and the Western Isles underscores the critical importance of integrating renewable energy sources (RES), energy storage systems, and advanced Energy Management Systems (EMS) to address the specific challenges faced by islands and isolated regions. Both Crete and the Western Isles offer unique opportunities for renewable energy deployment, and the replication plans outlined demonstrate that, with careful adaptation, these islands can transition to sustainable, low-carbon energy systems. For the Western Isles, the selected use case focused on wind energy, hydrogen production, and anaerobic digestion to create a resilient energy system exploiting EMS functionalities to face the islands' significant challenges related to weather-related disruptions, seasonal demand variability, and energy poverty. The planned integration of the HVDC transmission link is expected to enhance further the Western Isles' ability to export renewable energy to the mainland, significantly contributing to Scotland's and the EU's broader net-zero goals. In Crete, the replication plan emphasized the potential of solar energy and biomass as the main parts of a designed MES for the selected use case (Bakery Industry & Community of Platanos). Given Crete’s geographical location and prominent levels of sunlight, solar energy presents an ideal opportunity to reduce the island's dependency on fossil fuels. In addition to traditional PV systems, Photovoltaic-Thermal (PVT) technology can be explored to maximize energy generation by producing electricity and thermal energy from a single installation, making it a highly efficient solution for Crete's energy landscape. This dual-output approach would further enhance the island's ability to meet its energy needs, particularly in sectors requiring significant power and heat. Developing biomass energy systems also aligns with Crete's agricultural landscape, offering a sustainable way to convert organic waste into energy while reducing CO_2 emissions. The replication strategies for these islands are not simply about technology implementation; they focus on a comprehensive approach, considering regulatory frameworks, local socio-economic conditions, and community engagement. Stakeholder involvement in Crete and the Western Isles is crucial to ensuring that the energy transition is inclusive and beneficial to local communities. Public consultation, awareness campaigns, and local partnerships will ensure that the deployment of RES has long-term positive impacts on local economies and employment.

Moreover, the projects demonstrate that renewable energy integration is an environmental necessity and an economic opportunity. Expanding renewable energy infrastructure will create new jobs, stimulate local supply chains, and generate revenue from energy exports. The economic models developed for these replication plans project a significant return on investment in energy savings and economic growth, making a solid case for continued investment in RES. In addition, the long-term sustainability of the ROBINSON project is enhanced by using feedback mechanisms and real-time monitoring systems that ensure continuous optimization of energy flows. These mechanisms will allow the system to adapt to changing environmental, economic, and policy conditions, ensuring that Crete and the Western Isles can meet their net-zero targets by 2035. While this target is ambitious, it is realistic if the islands continue to rapidly scale their renewable energy infrastructure, implement smart energy management, and leverage emerging technologies like PVT to boost efficiency further. By building flexibility into the EMS, the project ensures that the energy systems will remain future-proof, capable of incorporating innovative technologies and expanding capacity as demand grows.

In conclusion, replicating the ROBINSON project in Crete and the Western Isles sets a clear pathway for transforming island energy systems into sustainable, self-reliant, and resilient networks. This project addresses immediate energy challenges and provides a scalable and adaptable model for other European islands and isolated regions. The successful implementation of these strategies will contribute to the EU's broader climate objectives while providing significant socio-economic benefits to local populations. The ROBINSON project represents a critical step forward in the global transition to renewable energy, demonstrating how targeted innovation and careful planning can lead to sustainable energy futures.

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