New Energy Solutions Optimised for Islands

NESOI

EUROPEAN ISLANDS FACILITY

D3.2: Technology Pairing – Inputs to NESOI Platform

WP3, T3.2

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List of Acronyms

AC	Alternate Current
BESS	Battery Energy Storage System
CSP	Concentrated Solar Power
DH	District Heating
DHC	District Heating and Cooling
DSO	Distribution System Operator
EC	European Commission
EV	Electric Vehicle
GHG	GreenHouse Gas
HP	Heat Pump
HVAC	Heating, Ventilation, Air Conditioning
ICT	Information and Communication Technology
LED	Light Emitting Diode
LNG	Liquefied Natural Gas
NESOI	New Energy Solutions Optimized for Islands
ORC	Organic Rankine Cycle
PHES	Pumped Hydro Energy Storage
PV	PhotoVoltaic
RES	Renewable Energy Sources
TES	Thermal Energy Storage
TRL	Technology Readiness Level
VFD	Variable Frequency Drive
VRDT	Voltage Regulation Distribution Transformer
VRF	Variable Refrigerant Flow

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1 Introduction

The EU Island Facility NESOI (New Energy Solutions Optimised for Islands) is a four-year Horizon 2020 project funded under call topic LC-SC3-ES8-2019 (European Islands Facility –Unlock financing for energy transitions and supporting islands to develop investment concepts). It began on 1 October 2019 and will finish on 30 September 2023 and is made up of a multi-disciplinary consortium consisting of 10 partners from seven EU member states. It has a total budget of €10 million of which approximately €3 million is dedicated to a cascade funding mechanism to provide direct financial support to EU Islands

Coupled to consortium capacity building activities, the facility aims to mobilise more than €100 million of investment in sustainable energy projects to an audience of 2,400 inhabited EU islands by 2023, giving the opportunity to test innovative energy technologies and approaches in a cost-competitive way and leading to an expected 440 GWh/year in energy savings.

In WP1 islands' needs will be identified based on surveys and experts' judgment and a market analysis performed. Based on the inputs from these activities, in the present D3.2 a comprehensive technology pairing is developed with the aim of identifying:

- possible technology-to-technology pairing aimed at maximizing the potential for islands' decarbonization;
- potential pairings between the islands' needs and the features of the selected technologies;
- potential pairings between the type of projects/technological solutions and the main stakeholders involved in the energy transition of islands.

In the whole deliverable, focus is placed on ready-to-implement consolidated technologies, after the first round of calls, an update of the pairings proposed in the present document will be provided to include inputs from the received applications and the technical assistance provided, as well as to include more innovative technologies in the list.

The present report is articulated into the following sections:

- Chapter 1 constitutes the introduction to the Deliverable;
- Chapter 2 describes the methodology adopted for the technology pairing;
- Chapter 3 provides an overview of the different approaches to islands' clusterization;
- Chapter 4 briefly introduces and describes the potential technologies for islands' decarbonization;
- Chapter 5 presents the pairing among different technologies, between islands' needs and decarbonization technologies and between technologies and relevant categories of stakeholders;
- Chapter 6 draws the conclusions of the analysis.

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1.1 Executive Summary

Based on the inputs from WP1 regarding technologies for islands' energy transition and creation of clusters of islands, the present D3.2 presents a comprehensive technology pairing.

The first part of the analysis focuses on the technologies for energy transition of islands and aims at identifying strengths/weaknesses and spotting potential complementarities in view of maximizing the decarbonization impact.

Then, clusters of islands are built according to their similarities with reference to: islands' size, interconnection with the mainland electricity grid and seasonal variation of population, latitude, orography, urban/rural population distribution, economic development and main productive sectors, presence of natural resources, etc.

After the analysis of technologies and clusters of islands, the pairings are defined, considering on one side the strengths/weaknesses and complementarities of technologies and, on the other hand, the availability of resources and energy demand in each cluster of islands. To conclude, the different types of stakeholders that may promote projects related to the technological solutions analyzed are also considered and potential pairings are identified.

In this version of the Deliverable, focus is placed on ready-to-implement consolidated technologies, whereas after the first round of calls, an update of the pairings proposed will be provided to include inputs from the received applications and the technical assistance provided, as well as to include more innovative technologies in the list.

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2 Methodology

The aim of the present deliverable is to identify a comprehensive technology pairing covering the following main aspects:

- possible technology-to-technology pairing aimed at maximizing the potential for islands' decarbonization;
- potential pairings between the islands' needs and the features of the selected technologies;
- potential pairings between the type of projects/technological solutions and the main stakeholders involved in the energy transition of islands

To this aim, the activities previously carried out in the NESOI project and specifically in WP1 are considered and used as sources of input.

In particular, the first step of the analysis is constituted by the analysis of the technologies identified as best suitable for the energy transition of islands as outlined in NESOI D1.3; those technologies are analyzed with the aim of identifying strengths and weaknesses and to spot their potential complementarities in view of maximizing their impact in terms of decarbonization.

In parallel, focus is placed on the islands and specifically on the creation of potential clusters of islands based on similarities in their features. The clusters created in NESOI D1.3 starting from survey results and analysis of the ASSET database of European islands, with reference to islands' size, interconnection with the mainland electricity grid and seasonal variation of population are initially considered. Then, further potential clusterizations are proposed, covering other aspects of the islands' features such as latitude, orography, urban/rural population distribution, economic development and main productive sectors, presence of natural resources, etc.

As soon as the technologies and the main islands' clusters are defined, the pairings are carried out, by considering on one side the strengths and weaknesses of the technologies and their potential complementarities and, on the other hand, the availability of resources and energy demand in each cluster of islands. The different types of stakeholders that may promote projects related to the technological solutions under analysis are also considered and potential pairings presented.

As also outlined in the Introduction, the focus of the analysis is on consolidated technologies; after the first round of NESOI calls, an update of the pairings proposed in the present document will be provided to include inputs from the received applications and the technical assistance provided, as well as to include more innovative technologies in the list.

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3 Creation of Island Clusters

In this chapter, criteria for grouping islands into clusters are highlighted, based on their characteristics from different points of view (size, grid interconnection, seasonality, geographical features, economic development and resources availability); they will then be coupled in Chapter 5 to the different technologies presented in Chapter 4, taking into account their needs and characteristics.

3.1 Clusters by Size and Grid Interconnection

These clusters, named from C1 to C6, are those defined in NESOI T1.2 starting from survey results and analysis of the ASSET database of European islands.

C1 – Large Islands

These islands are very populated like Sicily or Sardinia and count more than 500,000 inhabitants. Large islands are advanced in terms of transition status, mainly in renewable energy and public lighting projects and have plans in order to fulfil their goals. Their main drivers are the national regulation/objectives they have to comply with and the environmental benefits of the actions, while their most perceived limitations are economical barriers and funds, also with problems encountered in the definition of roles between public entities. The need for an energy transition in this case can be less severe, as these islands have high efficiency processes, being able to count on the electricity grid of the continent.

C2 – Medium-Sized Islands

These islands count from about 150,000 to 500,000 inhabitants. Medium-sized islands have also developed energy transition projects, with renewable energy integration as the most advanced aspects, and have plans to further these efforts. Their main driver is the reduction of the environmental impact of their activities, and the limitations and needs are similar to the ones for the large islands (economical and organizational).

C3 – Small Non-Connected Islands with High Seasonality

Small islands count no more than 150,000 inhabitants; these ones are not electrically connected to the mainland, and present a high seasonality, which means that the number of inhabitants increase in specific times of the year. The reason is that they are generally a tourist destination, such as some islands of Greece or Croatia. Small non-connected islands with high seasonality still have a long way to go in their energy transition, with renewable energy as the most developed aspect, but are developing concrete plans to advance. Their main driver is the reduction of living costs in the island, because they use energy systems with low efficiencies that have difficulty in supporting the variation of energy demand linked to seasonality. The energy transition should aim at the implementation of systems that generate electricity in a flexible manner taking into account the seasonality.

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C4 – Small Interconnected Islands with High Seasonality

These islands have the same characteristics as the previous ones, except that they are electrically connected to the mainland. Small interconnected islands with high seasonality are behind the average in their energy transition besides public lighting projects and still do not have concrete plans to advance. Their main driver is the reduction of living costs in the island, taking into account that, being able to count on the electricity grid of the continent can support the variable energy demand due to seasonality.

C5 – Small Non-Connected Islands without Seasonality

Contrary to the previous islands, these ones are not affected by seasonality, which means that the number of inhabitants may not vary. Small non-connected islands without seasonality are room for improvement in their energy transition status and mainly do not have transition plans to advance. Their main driver is the reduction of environmental impact as it happens in C3 islands.

C6 – Small Interconnected Islands without Seasonality

Small interconnected islands without seasonality have potential to advance their energy transition but do not have concrete plans to do so. Their main driver is the reduction of environmental impact. Small islands (clusters 3 to 6) coincide with the lack of a skilled workforce, legal complexity and location of funds are their most common barriers. They share similar criticalities with C4 islands.

3.2 Clusters by Geographical Features

Clusters by Latitude

This classification helps to identify the energy needs of islands related to their geographical location and therefore to their climate; this can result, for example, in a greater efficiency of one technology rather than another.

- Mediterranean Europe Islands (between 30° and 45° of Latitude). These islands have a Mediterranean climate, characterized by hot summers and mild and rainy winters.
- Northern/Central Europe Islands (between 45° and 70° of Latitude). Here we can distinguish two types of climates: temperate oceanic climate and cold continental climate. The first one interests the UK and the northern part of France and features cool summers (relative to their latitude) and cool but not cold winters, with a relatively narrow annual temperature range and few extremes of temperature. The second one interests the northern part of Germany and Scandinavia and features long and cold winters, while summers are short and cool.

Clusters by Orography

This classification helps to understand the feasibility of implementing a certain technology based on the orographic characteristics of the island.

- Mountainous Islands. Mostly located in the Aegean Sea and in the Atlantic Ocean.
- Flat Islands. They are located in front of Croatia, near the UK and in the Baltic Sea.

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Clusters by Population Distribution

This classification helps to understand the energy demand of the islands in relation to the lifestyle of the inhabitants.

- Concentrated in towns/cities.
- Distributed in villages over the territory.

3.3 Clusters by Economic Development

Clusters by Economic Activities

This classification helps to understand the demand for resources (for example water) and energy of the islands in relation to the economic activities they carry out.

- Mainly Tourism. These islands are mainly identifiable in clusters affected by seasonality and located mostly in the Greek archipelago and in Croatia.
- Mainly Primary Sector. These are mainly flat islands where it is possible to practice agricultural activities, or in any case with lush soils that can allow activities such as livestock.
- Presence of Industries. These are large or medium-sized islands belonging to C1 and C2 mentioned above, which are therefore more industrialized than the smaller ones.

Clusters by Availability of Resources

The islands can finally be classified according to their availability of resources for their activities, or for the possible development of energy transition processes. For example, the presence of water, biomass, mineral deposits or fossil fuels, etc. can be evaluated.

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4 Technology Catalogue

4.1 Electricity Production from Renewables

Electricity production from renewables refers to all the technologies that convert a certain renewable energy to electricity.

The most common technology for conversion of renewable energy sources to electricity is solar photovoltaic (PV), considering also its economic performance in the long term.

In addition, some technological solutions regard the exploitation of wind, hydro-electric power or marine (waves).

4.1.1 Solar Photovoltaic

Solar technologies for electricity production mainly include photovoltaic systems.

In these systems, solar energy is received from solar radiation, through PVs which are arrays of cells containing an appropriate material, such as crystal silicon, that converts solar radiation into electricity through the photovoltaic effect. A broad range of applications use this technology nowadays, ranging from residential rooftop power generation arrays to medium-scale utility-level energy generation. The PV systems produce direct current electricity, which in turn is converted into alternating current and injected through the electrical grid.

4.1.2 Wind

Wind energy conversion to electricity is achievable through systems based on turbines that transform kinetic energy from wind speed into mechanical energy from blades rotation. Turbines can be either onshore or offshore.

Onshore wind turbines are land-based installations, usually in hilly or mountainous regions, in order to exploit the topographic acceleration of wind as it passes over a ridge, which results in increased energy production. Onshore wind turbines have the following major advantages: a) low cost which allows for mass farms of wind turbines, b) shorter distance between the generation location and the consumer which means less voltage drop off on the cabling, c) quicker installation (only a few months required) compared to other types of power stations. On the other hand, their disadvantages are a) aesthetic disturbance in the landscape, b) non-continuous operation due to variable wind speed, c) obstruction by physical blockages such as buildings or hills, and d) noise pollution.

Offshore wind energy is the use of wind farms constructed in bodies of water, usually in the ocean, to harvest wind energy to generate electricity. A major advantage is that offshore wind speeds tend to be higher and firmer than on land as there are not physical obstacles such as hills or buildings to block the wind flow. Offshore wind power can serve proximal coastal areas which usually have a high population concentration and high energy needs. The cost of building and maintenance can be high due to their hard to reach locations and their susceptibility to damage from very high-speed winds during storms or hurricanes as well as by salty ocean air.

In addition to the classification of wind turbines based on their location, it is worth mentioning the so-called micro wind turbines, based on capacity. Micro-wind turbines,

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with capacity of 100 kWe or less, are used in micro-wind generation and are quite smaller in size than those used in conventional wind generation making them appropriate for residential power production.

4.1.3 Biomass

Biomass can be stored and thus be used to produce power and heat on demand. In specific, biomass systems can be used in combination with the solar or wind systems, in order to balance the intermittent behavior of an electricity system.

Electricity generation technologies from biomass can be distinguished into two main categories. The first one corresponds to the direct use of raw biomass for energy production, while the second one corresponds to the production of advanced biofuels such as biogas through pre-treatment/refining technologies of raw biomass. The produced biofuels can substitute fossil fuels in the energy sector. Biomass technologies can be grouped into two major categories: a) thermochemical and b) biochemical processes. Thermochemical processes are commonly applied to dry biomass fractions, while the biochemical technologies are widespread for the case of wet biomass fractions.

4.1.4 Geothermal

Geothermal energy derives from the thermal energy contained in the Earth. The term geothermal energy production includes all the processes of exploitation of geothermal energy in domestic, rural or industrial level. Geothermal exploitation is achieved by using drillings for access to the heat source (geothermal fluids). With the use of heat exchangers, geothermal energy can then be used, directly as heat or for electricity generation or even for cooling.

Generating electricity using geothermal energy can be carried out with conventional steam turbine units or with binary cycle units. The choice of the technology is based on available enthalpy. The advantage of these systems is that as the power supply does not change and can work continuously achieving operating rates more than 70%.

4.1.5 Hydro

Hydroelectric or hydro power systems are called the systems that generate electricity by exploiting the kinetic and dynamic energy of water flows.

A common classification based on size categorizes as large systems those with installed power higher than 15 MWe, the small systems those with installed power greater than 1 MWe but lower than 15 MWe, and all the systems lower than 1 MWe are consider to be micro hydro systems. Usually small and micro hydro systems are constructed without reservoirs and they are placed in rivers runoff or in rivers with small balancing dams. Small and micro hydro systems with small reservoirs or river runoff are consider as RES.

The most important component of a hydropower system is the turbine. There are three main turbine types, namely Pelton, Francis and Kaplan.

4.1.6 Wave/Tidal

Tide or wave power plants covert wave or tide energy into electricity. Marine energy converter technologies are still in a stage of development, even if companies are thoroughly investing economic resources to introduce innovations in this field.

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When considering wave energy there are two components that can be extracted: potential energy (where the water is forced against gravity from the wave trough and crests) and the kinetic energy component (the water oscillating velocity). The structure that can efficiently capture and harvest the energy transmitted by the waves must be able to survive the marine environment (storm events). One means to convert the wave energy into mechanical energy is by using a generator that is fixed (on the sea bottom or shoreline) with parts of this system in motion. During recent decades, floating systems were introduced that are capable of being deployed offshore.

Technologies for tidal energy exploitation foresee using a barrage (a dam or other barrier) to harvest power between high and low tide, tidal-current or tidal-stream technologies, or hybrid applications.

4.2 Thermal Production from Renewables

Thermal energy production from renewables refers to all the technologies that convert a certain renewable energy to heat or cooling energy.

Solar thermal and geothermal (where it can be applied) appear to be the most adopted technological solutions for the renewable thermal energy production.

4.2.1 Solar Thermal

Solar technologies for thermal production include Concentrated Solar Power (CSP) systems.

Solar thermal systems use energy from the sun to heat water or other fluids. This technology replaces other energy sources such as fossil fuels and electricity as a mean of providing heat to buildings and processes. The major component of any solar system is the solar collector. This is a device that absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a transport fluid (usually air, water, or oil) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water/steam or space conditioning equipment or to a thermal energy storage tank from which can be drawn for future use at night and/or cloudy days.

4.2.2 Geothermal

The production of heat is the most direct form of exploitation of geothermal fluids. It usually includes low enthalpy fluids that do not allow electricity production. These fluids are either extracted directly from geological reservoirs, or they come from geothermal electric power plants (thermal effluents).

A common system for exploitation of geothermal energy for heat production is constituted by heat pumps. Geothermal heat pumps have the same operating principle as the simple heat pumps with only difference that they use the ground as heat intake/discharge tank. Their heat exchanger is installed at shallow depths, usually a layer between 0 and 100 m, whose temperature is usually between 10 and 15 °C depending on the geographical location. At the same time, depending on the climate and geographical location of our country, solar thermal energy may be stored in the subsoil, potentially allowing the exploitation of much larger amounts of energy.

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A heat pump makes it possible to extract energy from a low temperature heat source (called a cold source) and to reinsert it at a higher temperature in a heat sink (called a hot source).

4.3 Cogeneration of Heat and Power

As reported by the European Commission, cogeneration is the simultaneous production of electricity and useful heat. In a regular power plant, the heat produced in the generation of electricity is lost, often through the chimneys. But in a cogeneration plant it is recovered for use in homes, businesses, and industry.

Cogeneration plants can achieve energy efficiency levels of around 90%. Increased cogeneration could lower greenhouse gas emissions and can also be an effective way to supply energy to remote areas without the need for expensive grid infrastructure.

Energy sources that can feed such type of plants are various and they can be either fossil-based or renewable. Fossil sources mainly include natural gas, while renewable sources are biomass, solar energy and geothermal energy.

4.4 Electric Mobility

The term electric mobility refers to all the technologies and the systems that – properly combined – enable to ensure road / rail / marine / air transportation using electricity as energy source.

Electric mobility represents a priority for sustainable development, as transportation systems are largely dependent on fossil fuel sources and are also responsible for significant shares of energy demand in most Countries.

4.4.1 Electric Vehicles

An electric vehicle (EV) is a vehicle which is equipped with one or more electric motors or traction motors for propulsion. An electric vehicle is powered through a system which collects electricity from off-vehicle sources, or may be self-contained with a battery, solar panels, fuel cells or an electric generator to convert fuel to electricity. EVs include, but are not limited to, road and rail vehicles, surface and underwater vessels, and electric aircrafts.

4.4.2 Charging Infrastructures

Types of charging technologies can be categorized into conductive and inductive charging.

Conductive charging utilizes a direct, cable-based contact between the EV connector and charge inlet which can be from a standard socket-outlet, a wallbox or a fixed installed or even movable charging station. Among them, AC charging is the most common technology.

Inductive charging (also referred to as wireless charging) uses magnetic induction technology of coils that allows EV, independent from the type or size, to charge by flexible positioning over a charging pad (primary coil), through any materials like concrete or asphalt. The wireless charging pad can be installed above the ground or mounted into the floor of a garage or road. Wireless power delivers similar charge speeds and efficiency levels as traditional plug-in charging methods when placed correctly.

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4.4.3 Information and communications technology (ICT)

Information and communications technologies (ICT) constitute the link between vehicles, charging infrastructure and the energy ecosystem. They control the charging at private and public charging points and enable the communication of electric vehicles with EMS, Smart Grids and other smart technologies by offering smart charging solutions. ICT also ensures that users have comfortable and comprehensive access to publicly accessible charging infrastructure via roaming platforms.

4.5 Energy Storage

Energy storage is essential to overcome limitations related to the discontinuity and to a certain degree of unpredictability of energy generation from renewable sources. A proper storage system is thus able to secure energy supply and to meet energy demand also when instantaneous energy generation from renewable sources is not sufficient to meet the correspondent demand.

Additionally, when speaking of electric mini-grids connected to the main network, energy storage provides services to the grid like peak shaving, reduction of network loads at predicted times, substitution of network enhancement works, reduction of future network infrastructure costs. Electric storage also allows fast response to balance network loads, and resilience against winter resource limitations / blackouts.

4.5.1 Battery Storage

Batteries are one of the most cost-effective energy storage technologies available, with energy to be stored electrochemically. Battery energy storage systems (BESS) are modular, quiet, and non-polluting. They can be positioned almost anywhere and can be installed relatively quickly. Charging a battery causes reactions in the compounds, which then store the energy in chemical substances. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and given back to the grid.

Fast response is one of the strong points of battery technology. The efficiency of battery modules is in the range of 60–80 %. Batteries, however, present some very unique challenges, such as the need to keep temperature changes during charging and discharging cycles to improve life's expectancy and well as the number of life cycles that the battery can guarantee.

There are several types of batteries depending on the desired use. The main uses of batteries combined with renewable energy sources are to cover loads, to provide grid flexibility, for use in starting machines and for the use in emergency systems. Lead-sulfuric acid (Pb/H_2SO_4) batteries were commonly used in renewable energy applications due to their low specific cost (€/kWh) and high reliability. In recent years however, most of the market growth has been attributed to lithium ion (Li-Ion) batteries.

4.5.2 Hydro Storage

Pumped hydroelectric energy storage (PHES) has been in use worldwide for more than 70 years. Pumped hydro units operate on the principle of a hydro-electric powerplant. However, their generator units usually serve also as motors or pumps used as turbines. During off-peak hours surplus power is used to pump water from a lower reservoir to a higher-level reservoir whilst pump/turbine operates as a pump and a motor/generator as

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a motor. At peak demand hours, water is released from the higher reservoir to turn the turbine and to produce electricity, and the motor operates in the generating mode and the pump as a turbine.

PHES can produce a great amount of energy for continuous periods of time. In addition, these plants have round trip efficiencies in the range of 70 to 80 %. Their storage capacity depends on the size and the height of the reservoir. Thus, instead of having only a few hours of energy storage it could be days. The major drawback of this design is the significant area required to create the reservoirs and the elevation needed between them. Environmental considerations such as impacts on fisheries, recreation, water quality, aesthetics, and land use have sharply limited the further development of this technology. There is, however, an alternative to avoid the environmental impacts of the large reservoirs by placing them underground, for example, flooded mine shafts or other cavities can be used as lower reservoirs.

4.5.3 Thermal Energy Storage

There are several solutions for Thermal Energy Storage (TES) which can be applied in either industrial or residential scale. Thermal energy can be stored as a change in internal energy of a material mainly as sensible heat or latent heat, but there are also other options in which thermochemical energy or combination of these is stored.

TES technologies can be classified according to the technology and method of storage into three categories:

- Sensible heat: they are the most common TES systems. In these systems, thermal storage materials store heat energy by changing temperature. The storage medium can be liquid (water) or solid (rock, earth). They are flexible decentralized solutions where large-scale heat transfer systems such as district heating and cooling are not practical or are too expensive to apply. However, most present systems are water-based, and their capacity is limited by the fact that water capacity depends on the operating temperature difference of the heating system used;
- Latent heat: in latent heat storage, the materials used, also known as phase change materials, store latent heat during a phase change from solid to liquid. It is suitable for applications where temperature must be maintained stable in a narrow range;
- Thermochemical: thermal Chemical Energy Storage is based on the utilization of heat of reaction released by reversible chemical reactions. These systems have certain advantages, such as higher density for energy storage (due to higher reaction enthalpy), possibility for long-term storage, and long-range transport at ambient temperature. On the other hand, there is still a necessity for reduction of volume and improvement of materials used in this technology. More demonstrations are needed to assess their commercial use.

4.6 Upgrade of Local Public Assets

This section illustrates common interventions to upgrade the energy performance of public assets that are significant in the context of islands. These assets can be a power distribution grid, including transformers, public lighting, port infrastructures, water and waste treatment plants.

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4.6.1 Power Distribution Grids

Successful case studies have proved that upgrades to grid infrastructure can be implemented effectively, providing that the systems and controls are designed carefully to achieve balance between island power supply and demand. Such improvements are mainly conceived to improve the performance of grids/mini-grids with inputs from renewable energy sources, as relevant for this analysis.

Options to achieve improvements of power distribution grids are:

- replacement of standard type transformers by Voltage Regulation Distribution Transformer (VRDT). The use of VRDT noticeably increases the absorption capacity of the distribution grids for renewable energies and enables economical, stable operation even with massive feed-in, thus reducing the need for grid expansion;
- balanced grid. A balanced grid allows control of the grid frequency, voltage, total harmonics distortion, thermal constraints, transient stability and loss of main power;
- frequency management. In island mode, frequency must be controlled by the microgrid and controlling frequency requires matching the demand and generation. Given that frequency is the same at all points in the microgrid, it can be controlled by any adjustable generation of demand;
- voltage management. Unlike frequency, voltage is a local variable requiring careful local control. Careful up-front design of the microgrid is a key aspect in ensuring voltage is suitably controlled in operation, particularly in island mode.

4.6.2 Power Transformers

A power transformer is defined as a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power. The TRL and maturity level for all transformers is generally very high.

In a typical supply grid, electric transformer power loss typically contributes to about 40-50% of the total transmission and distribution losses. Replacement of aged, low-efficient transformers by energy efficient transformers are therefore an important means to reduce transmission and distribution losses.

4.6.3 Public Lighting

Renovation of municipal street lighting with LED lamps is a common low carbon action among cities that account for electricity savings of minimum 50%. The payback period of such renovation, including also savings in maintenance, may be of 4 years or less. Main barriers towards this upgrading of public assets are limited institutional training and equipment. Municipal governments may require capacity building for the design of efficient street lighting.

Such renovation intervention has been subject of various initiatives in Spain (Spanish assistance programme for the renovation of municipal street lighting 2014-2015), and in European islands.

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4.6.4 Shore-Side Electricity in Ports

Several technologies are currently being adapted by ports to achieve energy efficiency and reduce GHG emissions. These solutions include:

- onshore power supply: also known as cold-ironing, it consists on supplying electric energy to the vessel directly from the port, avoiding the use of ship's auxiliary engines for hotelling activities (i.e. power system maintenance, lighting, refrigerating). The electricity can be supplied by the grid, renewable sources or other sources, replacing the use of diesel oil, heavy fuel oil or LNG.
- electrification and automation for equipment: operation in all functional areas of a port, namely quayside, yardside and landside, to be ensured by electric equipment rather than fossil-fueled equipment, to reduce energy consumption and operational cost;
- reefer containers: trade of refrigerated containers is a port operation that has been steadily growing in recent years and it can be responsible of large shares of energy consumption. Solutions may stem from specific planning and scheduling of such operations. For instance, determining the number of plugs for reefers, minimizing travel distances with optimal location of reefer area, designing better electrical distribution systems, etc.
- lighting: switching to LED lamps, instead of high-pressure sodium ones, in port facilities and buildings (administrative, terminals, etc.) and outdoor lighting. Lighting represents around 3-5% of total energy in ports.

Similarly, the adoption of energy management systems, integration of RES and clean fuels, such as biofuels and LNG, and the implementation of microgrids and smart grids are alternatives being tested by ports to improve their energy performance.

4.6.5 Special Projects Related to Energy Topics

Additional projects relevant to improve the energy performance of islands refer to:

- improved waste management, including maximization of prevention, reuse and recycle according to the waste hierarchy and separation of organic waste from other wastes, to possibly allow biogas production for energy generation;
- energy generation from waste water treatment plants: this result can be achieved through anaerobic sludge treatment, electric and thermal energy from digestor gas (biogas) combustion, thermal energy generation from wastewater heat (and cold) recovery, thermal energy generation from solar or other renewables installations on the premises of the plants.

4.7 Energy Efficiency in Buildings

This section illustrates common interventions to upgrade the energy performance of buildings, considering their main typical energy users.

4.7.1 Lighting

Main interventions to reduce lighting consumptions are:

- replacement of conventional luminaires for LED technology, which owing to their higher performance guarantees energy savings up to 50-80%;

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- installation of a lighting control systems, allowing the lighting of any space to be switched on or off according to the presence of people in it.

4.7.2 HVAC

Heating, ventilation and air conditioning (HVAC) systems constitute approximately 35% of the energy consumed in commercial and residential buildings.

Main interventions to reduce HVAC consumptions include the application of innovative technologies that help to achieve a remarkably higher heat transfer efficiency in heat exchangers and an energy saving of up to 50% in the total energy consumption of an HVAC system.

Specific interventions are, for example:

- use of aerothermal heat pumps;
- high-performance gas condensing boilers, low operating temperatures or floor heating installation;
- underfloor heating;
- Biomass boiler installation:
  - Wood chip boilers,
  - Wood log boilers,
  - Wood Pellet Boilers;
- Variable refrigerant flow (VRF) for HVAC systems;
- Inverter technology.

4.7.3 Domotics and Building Energy Management System (BEMS)

Domotics and BEMS are computer-based systems that consist of automation, control and monitoring applied to residential and commercial buildings. These devices allow to control lighting, climate, entertainment systems and appliances, using better the natural resources and minimizing energy tariffs.

This technology is still at an early stage. However, thanks to its development, nowadays it offers solutions for almost all kind of buildings, increasing the quality of life of their occupants.

Adopting these systems can achieve between 5% to 20% of energy savings overall.

4.7.4 Smart Metering

Smart meters are electronic devices that record information of energy consumption, voltage levels, current and power factor. Smart meters give the possibility of sharing bidirectional data between consumers and energy suppliers, giving the users information about their hourly and daily energy use, their consumption profile and energy prices and allowing distributors to monitor the consumption and manage the electricity demand, adapting the service to the user necessities.

Thanks to remote management using smart meters, energy savings up to 10% can be achieved.

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4.7.5 Building Envelope Thermal Insulation

High performance thermal insulation plays a very important role in regulating the environmental conditions of the interior of a building and in determining the energy demand for heating and cooling.

A well-designed envelope – including walls, roof, windows and doors - ensures the comfort and efficiency of the entire building.

4.7.6 District Heating and Cooling

District energy involves multi-building heating and cooling, in which heating and/or cooling is distributed by circulating either hot water or low-pressure steam through underground piping. District networks incorporate an underground system of piping from one or more central sources to industrial, commercial and/or residential users. The heat delivered to buildings can also be used for air conditioning by adding a heat pump or absorption chiller. District energy can provide efficiency, environmental and economic benefits to communities and energy consumers.

District heating networks can be coupled with several renewable energy sources, such as biomass, solar and geothermal.

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5 Technology Pairing

This chapter focuses on technology pairing according to three main approaches, i.e. the pairing of two (or more) technologies to enhance islands decarbonization, the pairing between the islands' needs and the available technologies and the pairing between the selected technologies and the most suitable stakeholders.

The following sections focus on these three approaches.

5.1 Pairing among Technologies to Enhance Islands Decarbonization

All the technologies presented in the previous paragraphs can be implemented as stand-alone solutions to contribute to the island decarbonization through the two main pathways of energy efficiency and renewable energy production.

Nevertheless, many of the listed interventions allow higher benefits if adopted jointly with other technological solutions out of the proposed ones. The aim of this section is to describe the potential synergies among different technological solutions in the framework of decarbonization of islands' energy systems.

The following paragraphs present the potential technology pairings separately for solutions achieving impacts at island level and at building level; then, a technology pairing matrix is presented to summarize the results of the analysis.

5.1.1 Island-Level Pairing

As concerns projects that can achieve impacts at island level, the analysis on the selected technologies allows several potential pairings, in particular related to the use of energy produced from renewables or sustainable sources to supply high-efficiency systems for energy conversion according to the needs of different types of final users.

The following bullets briefly present the potential pairings:

- installation of utility-scale systems/plants exploiting a non-programmable renewable energy source (wind, wave/tidal but also solar) for power generation, coupled with a suitable electricity storage system (battery- or hydro-based, or exploiting hydrogen as energy carrier) in order to match the demand and the supply trends thus minimizing the use of fossil fuels for power generation purposes;
- considering that solar photovoltaic energy cannot produce electricity at times of absence of light during the night period, one way of solving this problem is to combine it with wind energy in this hourly range of absence of sunshine;
- the use of cogeneration with biomass allows 30-35% of its energy content to be transformed into electrical energy and into usable heat. In order to use the different types of biomass as fuels, it is necessary to transform it i.e. from raw biomass (as collected in the field), pre-treated by compacting, chipping or grinding, or from biomass transformed by thermochemical (syngas) or biological (biogas) processes. Cogeneration allows for excellent energy recovery from biogas produced in: wastewater treatment plants, both public and industrial; agricultural and

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livestock farms and landfills. By means of cogeneration, biogas can be used locally to generate electricity and useful heat;

- retrofitting of existing public lighting infrastructure with LED-based lighting systems equipped with photovoltaic modules and batteries to self-produce the needed electricity; this solution is particularly interesting since it is consolidated, easy to implement and reduces - potentially decreasing to zero - the impact of street lighting systems on the local electricity distribution grid;
- installation of an electric vehicles charging infrastructure on the island, based on local production of electricity from a medium-small sized photovoltaic or other renewable power generation system with local energy storage; this supports the diffusion of electric vehicles (cars/trucks but also bikes and scooters) on the island and the abatement of GHG and pollutant emissions related to the use of fossil fuels for local mobility;
- similarly to the previous bullet but with different scales, the coupling between photovoltaic or other renewable power generation systems and electric mobility systems can be implemented also for shore-side electricity supply for boats, yachts and ferries;
- the installation of a system for electricity production from renewables can also be done with the aim of supplying power to important island-level public assets like water desalination and more in general water treatment plants; in this case, the need for an energy storage system depends - on one hand – on the size of the renewable power plant and on the possibility to exchange power with the local distribution grid, and – on the other – on the typical power absorption trend of the water treatment system that varies with the hydraulic load and the management practices adopted, with power-to-water solutions for energy storage that can be implemented, too;
- as concerns wastewater treatment plants, another opportunity for technology coupling is constituted by the exploitation of the produced sludges for biogas production through anaerobic digestion and subsequent cogeneration of heat and power for uses within and around the plant;
- concerning thermal energy production, the use of cogeneration is suitable for integration with existing or new district heating networks; this solution, coupled where needed also with systems for thermal energy storage, allows providing heat and power to the final energy users in the island with a lower primary energy consumption and GHG/pollutant emissions compared to the separate production of electricity and heat;
- linked to the previous bullet, the use of biofuels (if locally available) for cogeneration or heat-only production purposes can be easily integrated into existing or new district heating networks;
- in addition to biomass and residues from wastewater treatment, also organic wastes (from residential or agricultural/industrial activities) produced on the island are suitable for biogas production through anaerobic digestion and subsequently for cogeneration or (less efficiently) separate heat/power production;
- smart-grid projects may include many of the previously mentioned technologies, including renewable-based power generation plants, energy storage systems, electric vehicles, heat pumps, with the latter technologies playing also a demand management role at grid level in addition to the energy efficiency one.

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5.1.2 Site-Level Pairing

In addition to the opportunities for technology pairing that are presented in the previous paragraph at island level, further opportunities are related to technology pairing at site level, i.e. building or industry level. These opportunities are not much different from those that could be implemented in buildings and industries located on the mainland, but their benefits in terms of reduction of primary energy consumption and GHG/pollutant emissions are even more important in the context of an island.

The identified opportunities are mainly related to heating and cooling and include:

- the improvement of the energy performance of the building envelope (walls, windows, doors, etc.) - aimed at reducing the energy demand of the building - coupled with an improvement of HVAC – aimed at reducing the final energy consumption of the building - that according to the local heating and cooling needs and availability of resources may be constituted by the use of a high-efficiency heat pump (geothermal/hydrothermal/aerothermal), the cogeneration of heat and power based on fossil or renewable fuels (biomass), the use of biomass for heat production, the recovery of waste heat from a nearby industrial process;
- the installation of a small-sized system for power generation from a renewable source (in most cases, a rooftop photovoltaic plant) to supply electricity to a heat pump covering the heating and/or cooling needs of the building; this solution is especially of interest for cooling purposes since the periods of the day and of the year with maximum availability of solar radiation are those with the maximum cooling needs;
- the installation of a solar thermal system to supply heat to absorption chillers used for cooling purposes; similarly to the previous solution, this is also especially of interest for cooling purposes since the periods of the day and of the year with maximum availability of solar radiation are those with the maximum cooling needs;
- linked to the previous opportunity for technology coupling, the cogeneration of power and heat can be coupled to the production of cold through absorption chillers through the integrated solution typically known as trigeneration;
- the adoption of a Building Energy Management System to optimize the management of the HVAC systems, to be carried out jointly with the implementation of energy efficiency improvement actions on the HVAC systems and the building envelope, as mentioned in the previous bullets;
- the exploitation of locally produced residues and wastes (e.g. in plants processing food and/or agricultural products) for biogas production through anaerobic digestion and subsequent cogeneration or (less efficiently) separate heat/power production;
- the exploitation of residues and wastes from wood processing and woods cleaning for biomass production and subsequent cogeneration or (less efficiently) separate production of heat and/or power;
- as an opportunity under development, the realization of integrated offshore renewable farms including different types of power generation systems, e.g. wave/tidal, wind and solar.

In addition, other opportunities for technology pairing related to electricity consumption and supply may include the installation of local systems for power generation from renewable (mainly: photovoltaic plants or micro-wind turbines) or sustainable (mainly:

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heat recovery-based Organic Rankine Cycles) sources with other power-related energy efficiency actions, such as:

- retrofitting of indoor and outdoor lighting of the complex (applicable to industrial sites, office buildings, hotels, supermarket, residential complexes, etc.);
- replacement of electric motors, improvement of motors' control through Variable Frequency Drives, etc. (mainly applicable to industrial sites);
- retrofitting of food refrigeration systems (for supermarkets and food processing/distribution centers);
- the replacement of company/municipality existing vehicles with electric vehicles, with installation of dedicated charging points.

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5.1.3 Technology-Technology Pairing Matrix

	Electricity Production from Renewables	Thermal Production from Renewables	Cogeneration of Heat and Power	Electric Mobility	Energy Storage	Upgrade of Local Public Assets	Energy Efficiency in Buildings
Electricity Production from Renewables	Yes, e.g. in integrated offshore renewable farms	Yes, e.g. in hybrid thermal-electric photovoltaic plants	Yes, e.g. in the frame of smart grid projects	Yes, e.g. for renewable-based vehicles charging infrastructure	Yes, e.g. in the case of renewable power plant with integrated energy storage	Yes, e.g. for shore-side power supply in ports, solar-lighting poles, biogas from waste/water treatment	Yes, e.g. for power supply to heat pumps
Thermal Production from Renewables	-	Yes, e.g. in hybrid solar-biomass or solar-geothermal systems	Yes, e.g. in hybrid high-efficiency heating systems	No	Yes, e.g. for flexible supply of heat to buildings and DH networks	No	Yes, e.g. for heat supply to absorption chillers for space cooling
Cogeneration of Heat and Power	-	-	-	Yes, e.g. in the frame of smart grid projects	Yes, e.g. for flexible supply of heat to buildings and DH networks	Yes, e.g. in the frame of smart grid projects	Yes, as source for high-efficiency heating and DH networks and for trigeneration
Electric Mobility	-	-	-	Yes, e.g. in case of integrated projects covering different types of vehicles	Yes, e.g. for RES-based vehicle charging stations	Yes, e.g. in the frame of smart grid projects	Yes, e.g. within integrated projects for building refurbishment

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	Electricity Production from Renewables	Thermal Production from Renewables	Cogeneration of Heat and Power	Electric Mobility	Energy Storage	Upgrade of Local Public Assets	Energy Efficiency in Buildings
Energy Storage	-	-	-	-	-	Yes, e.g. in the frame of smart grid projects for peak shaving and load management purposes	Yes, e.g. in high-efficiency HVAC systems for peak shaving purposes
Upgrade of Local Public Assets	-	-	-	-	-	Yes, e.g. in the frame of smart grid projects	Yes, for refurbishment of public buildings
Energy Efficiency in Buildings	-	-	-	-	-	-	Yes, many actions for buildings' energy efficiency can be done in a refurbishment joint project

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5.2 Pairing between Islands' Needs and Technologies

The following paragraphs focus on the groups of technologies as presented in Chapter 4 (Electricity Production from Renewables, Thermal Production from Renewables, Cogeneration of Heat and Power, Electric Mobility, Energy Storage, Upgrade of Local Public Assets, Energy Efficiency in Buildings) and, for each, discuss the relevance and suitability for the different clusters of islands defined in Chapter 3 (by size/interconnection, latitude, geographical features, economic activities).

5.2.1 Electricity Production from Renewables

This group of technologies includes electricity production from solar, wind, biomass, geothermal, hydro and wave/tidal.

The pairing of the above-mentioned technology with the needs of the different clusters of islands is described in the following bullets:

- size/interconnection: these solutions are in principle applicable to islands of every size; the installation of utility-scale plants is more feasible in large islands due to their higher electricity demand and/or in interconnected islands due to the possibility of feeding the electricity produced in excess to the island needs to the national grid, especially if the island is characterized by a high seasonality; on the other hand, the relative decarbonization impact may be much higher in non-interconnected islands that cannot import electricity from the mainland, although this implies the need to implement at least energy storage systems or smart solutions for load management;
- latitude: due to the higher availability of solar radiation, solar power production systems are more applicable in Southern Europe than in Northern Europe; as concerns other technologies, the suitability of an area depends more on the local availability of the specific resource (wind, biomass, geothermal heat, etc.) rather than the latitude; wave/tidal solutions are generally more applicable for islands located in the Ocean rather than in closed seas;
- geographical features: renewable power generation systems are applicable to islands independently from the orographic configuration and urban/rural pattern; a slightly higher potential for wind power could be in principle identified for mountainous islands and a higher biomass potential for rural islands, but significant variations may exist from case to case;
- economic activities: in islands where tourism is the main economic activity, the energy consumption patterns present a high seasonal variation, with the high-season that generally corresponds with summer period; this leads to a high suitability of solar power generation systems for that kind of islands, since the period with maximum energy production corresponds to the period with the maximum consumption; on the other hand, other renewable power production technologies producing energy more constantly during the year need to be properly sized in order to fully exploit their potential even in low-season periods; islands with prevailing primary sector activities (agriculture, animal growing, fishery) may present a higher potential for biomass-related technologies; to conclude, for islands characterized by variegated economic activities, the applicability of renewable power production systems is good and closer to that of the mainland.

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5.2.2 Thermal Production from Renewables

This group of technologies includes solar thermal, biomass and geothermal.

As concerns solar thermal, as mentioned for solar power production system, the potential for application is higher in Southern Europe compared to Northern Europe, and for islands with high seasonality and developed tourism sector compared to islands with no seasonality. The presence of industries on the island may lead to a not negligible potential for integration of solar heat in industrial processes, especially those related to production of food and beverage and processing of agricultural products. On the other hand, no significant correlation between the size of the island and the applicability of solar thermal is identified, since solar thermal are mainly standalone installations used for the production of heat for use in the building where they are installed.

Regarding biomass, the potential for their use in boilers for heat production purposes depends more on the availability of suitable materials on the islands rather than other features of the island. Nevertheless, the presence of a significant heating demand is needed to allow the installation of such a system, therefore a slightly higher potential can be identified for islands in Northern Europe.

Similarly, as concerns geothermal heat pumps, the potential for their application mainly depends on the geological characteristics of the soil rather than on other features related to size, geographical features and economic activities, but the presence of a significant heating demand is needed, therefore a slightly higher potential is identified for Northern European islands.

5.2.3 Cogeneration of Heat and Power

At site level, the combined production of heat and power is particularly applicable to buildings/industries with considerable energy demand in both thermal and electrical form. As concerns the installation in buildings, this solution is particularly of interest for residential and office complexes in islands of Northern-Central Europe; in case the cogeneration plant is coupled with an absorption chiller to realize a trigeneration system, the solution may become of interest also for residential and office complexes in Southern Europe, since it may allow also covering summer cooling needs.

As for the application in industries, the potential for cogeneration is clearly higher in large islands with variegated economic activities, due to the higher presence of industrial activities that may have process heat needs.

At island level and utility-scale, this technology may be of interest only in case a district heating system is present, which means that the highest potential for this solution is found in islands located in Northern-Central Europe and in islands with population concentrated in urban area, where district heating systems are typically located.

5.2.4 Electric Mobility

This category refers to the realization on the island of an infrastructure for charging electric vehicles of different types (electric cars, scooters, buses, boats/ferries) and to the replacement of existing conventional vehicles with electric models.

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These actions may be particularly of interest if coupled with renewable power generation systems, as already discussed in the technology pairing section, or in view of the realization of a comprehensive smart grid project.

As concerns their applicability to the different clusters of islands, no significant correlation is identified with the latitude (except for those related to the potential for renewable power generation, already discussed) and with the geographical characteristics (since public and private internal mobility on the island is needed both in urban and rural, mountainous and flat contexts); a higher potential for electric public transport and rental of e-bikes or e-scooters may exist on islands with high seasonality due to significant development of tourism and in smaller islands compared to larger ones.

5.2.5 Energy Storage

This paragraph focuses on both electricity storage systems (battery storage, pumped-hydro storage) and thermal energy storage.

As concerns the latter, thermal energy storage systems are particularly of interest in the context of a district heating system (higher potential for islands in Northern Europe with most population in urban areas) or in case of industrial applications related to heat recovery and solar thermal energy production (higher potential for large islands with developed industrial activities).

As concerns electricity storage, these solutions provide maximum benefits when coupled with non-programmable renewable power production systems, or in the context of the refurbishment of the local electrical grid for peak shaving purposes in view of the realization of a comprehensive smart grid project. This means that these solutions show the highest potential for application in small-sized non-interconnected islands; as regards specifically pumped-hydro storage systems, they are particularly applicable to mountainous islands with good water availability.

5.2.6 Upgrade of Local Public Assets

This category includes a variegated range of technological solutions related to the upgrade of different public assets:

- power distribution grid: the improvement of the local grid always allows benefits, but these are particularly relevant for small non-interconnected islands and less on large islands whose electricity grid is more similar to the one on the mainland; for islands with high industrial development, specific actions to manage the impact on the grid of large industrial energy consumers are highly applicable;
- public lighting: the switch to LED lamps and the improved control of public lighting systems is applicable in all contexts with no correlation with island characteristics; as far as solar-powered lighting poles are concerned, pairing criteria mentioned for solar power production systems apply (refer to paragraph 5.2.1);
- shore-side electricity in ports: this solution may be particularly of interest if coupled with renewable power generation systems (refer to pairing criteria in paragraph 5.2.1) or in general with a relatively clean energy mix; no significant correlation is identified with other characteristics of the island, except for a slightly higher potential for islands with high seasonality due to significant development of tourism;

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- special projects related to energy topics: projects related to the improvement of water desalination are more applicable to islands of any size in Southern Europe, characterized by low availability of local water resources; wastewater and waste-related projects on the other hand could be more suitable for medium-large islands with low seasonality, being characterized by significant and constant waste generation during the year, suitable for the realization of medium-large scale plants.

5.2.7 Energy Efficiency in Buildings

The interventions related to the improvement of energy efficiency in buildings include actions on lighting, HVAC systems, thermal insulation of building envelope, domotics and building energy management systems, smart metering, district heating and cooling.

Being most of these actions related to single buildings, there are few correlations with the characteristics of the island, hereby summarized:

- lighting: the switch to LED lamps and the improved control of lighting systems is applicable in all contexts with no correlation with island characteristics;
- HVAC systems: the retrofitting of heating, ventilation, air conditioning systems is of interest in all contexts; depending on the technological solution adopted for retrofitting, specific requirements may apply, e.g. in case of use of solar, biomass or geothermal energy sources (refer to paragraph 5.2.2) or cogeneration (refer to 5.2.3); it is clear that, depending on the climate of the island, HVAC needs will vary, e.g. in an island in the North of Europe, needs for heating will be very important, whereas in an island in the Mediterranean sea, in general, needs for cooling in summer will be much important;
- thermal insulation of building envelope: generally applicable in all contexts, but with higher benefits if implemented in areas with high heating (or cooling) demand, i.e. Northern Europe for heating and Southern Europe for cooling;
- domotics and building energy management systems: applicable to all contexts; no correlation with island characteristics;
- smart metering: applicable to all contexts; no correlation with island features;
- district heating and cooling: the highest potential is found in islands located in Northern-Central Europe due to their higher heating demand and in islands with population concentrated in urban areas, where the feasibility of these systems is higher due to the lower distance between energy users.

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5.2.8 Technology-Island Pairing Matrix

	Size/ Interconnection	Latitude	Geographical Features	Economic Activities	Other
Electricity Production from Renewables	No specific restriction to islands' size. Utility-scale plants could be more applicable to large interconnected islands compared to small non-interconnected ones, although benefits are higher in small non-interconnected islands.	For solar technologies, higher applicability in Southern Europe than in Northern Europe. For other technologies, no strong correlation with island location and latitude.	No strong correlation with islands' geographical features such as orography and rural/urban context. For wave/tidal solutions, suitability is higher in Ocean areas.	For solar technologies, higher applicability to tourism-based islands. In large islands with variegated economic activities, the suitability of the technology is the same as in the mainland.	For wind, geothermal biomass, hydro, the suitability depends on the availability of the specific resource and on the availability of spaces and absence of environmental constraints
Thermal Production from Renewables	No specific restriction to islands' size. Solar thermal plants for domestic hot water production are more applicable to islands with high-seasonality.	For solar thermal, higher applicability in Southern Europe than in Northern Europe. For geothermal and biomass, applicability is higher in Northern Europe due to the higher heating demand.	No strong correlation with island orography; if used to supply heat to a DH system, higher applicability to urban contexts	No specific correlation with the main economic activities. Solar thermal on residential/tertiary facilities can be implemented with success both in tourism-based islands and in islands with industrial activities	For geothermal and biomass, suitability depends on the availability of the specific resource
Cogeneration of Heat and Power	No specific correlation with islands' size. In principle higher potential in larger islands with more industrial activities.	For heating purposes, higher applicability in Northern Europe due to the higher heating demand; for industrial purposes, no specific correlation with islands' latitude.	No strong correlation with island orography; if used to supply heat to a DH system, higher applicability to urban contexts	Higher applicability to islands with industrial activities; suitable also for tourism-based islands if coupled with absorption chillers for trigeneration purposes.	Fuel availability may be an issue: cogeneration makes sense if based on renewable fuels or natural gas, not on diesel or other fuels.

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	Size/ Interconnection	Latitude	Geographical Features	Economic Activities	Other
Electric Mobility	No specific correlation with islands’ size and interconnection	No specific correlation with latitude (except if coupled with solar power production systems)	No specific correlation with orography and urban/rural context	Higher potential for sharing and rental of e-vehicles in tourism-based islands. For privately-owned vehicles, no correlation with economic activities on the island.	-
Energy Storage	For electricity: mainly applicable in small non-interconnected islands for peak shaving purposes. For heat: no specific correlation with islands’ size and interconnection	No specific correlation with latitude, except for thermal storage in DH systems that is mostly applicable in Northern Europe due to higher heating demand	No specific correlation with orography and urban/rural context, except for thermal storage in DH systems that is mostly applicable in urban contexts where DH networks are present	In general, no specific correlation with islands’ economic activities.	-
Upgrade of Local Public Assets	Always applicable without reference to islands’ size and interconnection. For electricity grid upgrade, higher applicability in non-interconnected islands; for water- and waste-related projects, higher suitability to large islands.	No specific correlation with latitude	No specific correlation with geographical features like orography and urban/rural context	No specific correlation with economic activities on the island	-

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	Size/ Interconnection	Latitude	Geographical Features	Economic Activities	Other
Energy Efficiency in Buildings	No correlation with islands' size and interconnection	No specific correlation with latitude, except for DH-related measures that are mostly applicable in Northern Europe due to higher heating demand	No specific correlation with orography and urban/rural context, except for DH-related measures that are by nature mainly applicable to urban contexts	No specific correlation with economic activities on the island	-

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5.3 Pairing between Projects and Suitable Stakeholders

The following paragraphs focus on the groups of technologies as presented in Chapter 4 (Electricity Production from Renewables, Thermal Production from Renewables, Cogeneration of Heat and Power, Electric Mobility, Energy Storage, Upgrade of Local Public Assets, Energy Efficiency in Buildings) and, for each, discuss the suitability for different types of stakeholders as described in D3.1 (Municipality or other public authority, Public asset operator – i.e. DSO, local utility, DH network operator, transport company, Private companies – i.e. industries, hotels, supermarkets, Energy communities).

5.3.1 Electricity Production from Renewables

This group of technologies includes electricity production from solar, wind, biomass, geothermal, hydro and wave/tidal.

Projects related to the installation of systems and plants for self-production of electricity from solar radiation (and to a lesser extent from wind) may be implemented by any type of stakeholder, ranging from individuals, energy communities or small companies as owners of single buildings, to large private complexes (hotels, supermarkets, industries), to private buildings (schools, hospitals, offices, etc.).

On the other hand, large utility-scale plants such as solar or wind farms, biomass power generation plants, geothermal power or hydroelectric plants are usually implemented by the local utility or by a private company in agreement with the local utility and/or the local grid operator and authorities.

Being most of the technologies characterized by a high maturity and market availability, for private installations support from institutional players should not be needed and projects can be realized with investors' own funding or conventional loans with banks, since they are typically able to generate sufficient cash flows to repay the loan. For large-scale installation, support from institutional investors and/or funds may be gathered.

5.3.2 Thermal Production from Renewables

This group of technologies includes solar thermal, biomass and geothermal technologies for heat production.

Small scale for self-production of heat may be implemented by any type of stakeholder, ranging from individuals, energy communities or small companies as owners of single buildings, to large private complexes (hotels, supermarkets, industries), to private buildings (schools, hospitals, offices, etc.).

On the other hand, large-scale exploitation of these technologies can be foreseen only in case of integration into a district heating system, therefore the investment needs to be promoted or at least involve the local DH operator and the local authorities.

Similarly to the previous technology group, this type of projects are characterized by a significant high maturity and market availability for the main components, thus for private use they can be realized with own funds or conventional loans with banks. Only infrastructural projects related for instance to district heating in cities can be supported by the local municipality and/or by institutional national or EU funds.

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5.3.3 Cogeneration of Heat and Power

Similarly to the previous group of technologies, two main possible cases are identified for this solution:

- cogeneration plants to self-produce heat and power can be installed by any type of stakeholder with variable size depending on the energy needs;
- larger project foreseeing the installation of a larger cogeneration plant are typically promoted by or agreed with the local DSO and DH operator and the local authorities.

Also in this case, technologies are consolidated and widely available on the market; in the former case of the above-presented list, the investment shall be done with own funds or supported by banks through conventional loans; in the latter case, as for renewable-based heating systems, projects related to district heating can be supported by the local municipality and/or by institutional national or EU funds.

5.3.4 Electric Mobility

Large-scale solutions for electric mobility, i.e. realization of a vehicle charging infrastructure and the increased diffusion of electric vehicles, can be promoted by private companies (including suppliers of such services on the mainland, but also operators of public assets on the island, like public transport providers) but generally with the support of the municipality or of another local authority.

On the other hand, it is mentioned that also individual citizens or energy communities, as well as private companies (especially if working in logistic activities on the island) may realize private investments in this field for their own vehicles.

If implemented as infrastructural investment at island level, this kind of project is typically strongly supported by the public sector, either directly from the municipality/region or authority balance or recurring, directly or indirectly, to national or EU structural funds.

5.3.5 Energy Storage

This kind of solutions, related to electricity storage (battery or pumped-hydro) or thermal energy storage, are almost exclusively of interest of the grid operators on the island (DSO for electricity, DH operator for heat, if present), or of utilities and private companies interested in selling this kind of service to grid operators. However, they might be of interest – at a smaller scale - also for energy communities and final users.

They generally are implemented with own funds by the Companies, but being projects related to local infrastructures they may receive support from local authorities, as well as from national or European funds.

Upgrade of Local Public Assets

Being all the technical solutions of this group of technologies applied to local public assets, such as power distribution grid, public lighting, ports, water treatment and waste treatment facilities, it is clear that this kind of projects are generally promoted by the operator of the public asset subject of the refurbishment, where needed with the support of third private companies and/or of the municipality or other local authority.

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Since these are infrastructural projects, related to the provision of services to islands' inhabitants and businesses, and can also be considered as enabling technologies for further activities in the energy transition field, they are generally strongly supported by the public sector, either directly from the municipality or local authority own balance or recurring, directly or indirectly, to national or EU structural funds.

5.3.6 Energy Efficiency in Buildings

The interventions related to the improvement of energy efficiency in buildings include actions on lighting, HVAC systems, thermal insulation of building envelope, domotics and building energy management systems, smart metering, district heating and cooling.

Being most of these actions related to single buildings, they might be realized by any kind of stakeholder owning or managing a building on the island, including:

- municipality and any other local authorities for public buildings including schools, public office buildings, hospitals, etc.;
- any type of private entities (including industries, residential/tertiary complexes, private buildings, energy communities, etc.) for their own buildings.

As concerns the only solution that is not focusing on a single building, i.e. the realization/upgrade of a district heating (or cooling) network, it shall be promoted by the municipality or other local authority or by the company managing (or willing to manage, under concession/license of the relevant authorities) the DH (or DC) network.

Projects related to energy efficiency in buildings are generally based on consolidated technologies and components widely available on the market. This means that these projects are able to generate savings connected with the reduction of energy consumptions that are sufficient to repay the investment; therefore, depending on the specific intervention carried out, these projects are implemented with own funds or supported by banks through conventional loans, or even realized as turnkey solutions by Energy Service Companies.

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5.3.7 Technology-Stakeholders Pairing Matrix

	Municipality Other Local Authority	Public Asset Operator	Private Company	Energy Community
Electricity Production from Renewables	Yes, both at small scale for self-production on public buildings or at utility-scale supporting the promoter for power supply to the local grid	Yes, both at small scale for self-production on own assets or at utility-scale for power supply to the local grid	Yes, at small scale for self-production on own assets or at utility-scale for power supply to the local electricity grid	Yes, only at small scale for power supply to the own assets of community members
Thermal Production from Renewables	Yes, both at small scale for self-production on public buildings or at utility-scale supporting the promoter for heat supply to the local grid	Yes, both at small scale for self-production on own assets or at utility-scale for heat supply to the local grid	Yes, at small scale for self-production on own assets or at utility-scale for heat supply to the local DH grid	Yes, only at small scale for heat supply to the own assets of community members
Cogeneration of Heat and Power	Yes, both at small scale for self-production on public buildings or at utility-scale supporting the promoter for power/heat supply to the local grid	Yes, both at small scale for self-production on own assets or at utility-scale for energy supply to local electric/DH grid	Yes, at small scale for self-production on own assets or at utility-scale for energy supply to the local electric/DH grid	Yes, only at small scale for power and heat supply to the own assets of community members
Electric Mobility	Yes, for the development of the infrastructure	Yes, for the management of the infrastructure and of the vehicles, if shared	Yes, but only for own vehicles	Yes, for the vehicles of the energy community members only
Energy Storage	Yes, supporting the relevant public asset operator	Yes, on the asset they operate (e.g. DSO or utility for electricity grid, or DH operator)	No	No
Upgrade of Local Public Assets	Yes, supporting the relevant public asset operator	Yes, on the asset they operate	No	No
Energy Efficiency in Buildings	Yes, on public buildings	Yes, on buildings related to the operated asset	Yes, on own buildings	Yes, only for buildings owned by community members

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6 Conclusions

This document presents a comprehensive technology pairing between technologies for islands' energy transition and different clusters of islands.

As concerns technologies, starting from the analysis carried out in WP1, the main strengths/weaknesses are analyzed and potential complementarities are identified with the aim of maximizing the decarbonization impact.

The groups of technologies analyzed are:

- Electricity Production from Renewables;
- Thermal Production from Renewables,
- Cogeneration of Heat and Power;
- Electric Mobility;
- Energy Storage;
- Upgrade of Local Public Assets;
- Energy Efficiency in Buildings.

Then, clusters of islands are created depending on a number of different characteristics such as:

- islands' size, interconnection with the mainland electricity grid and seasonal variation of population, in line with WP1 activities;
- geographical features like latitude, orography, urban/rural population distribution;
- economic development, main productive sectors and presence of natural resources;
- other potential specific local characteristics.

Pairings are defined according to the analysis of technologies' characteristics and islands clusters needs, and cover the following three main aspects:

- grouping between/among technologies into potential joint projects aimed at maximizing the potential for islands' decarbonization;
- association of selected technologies with the needs/characteristics of islands belonging to different clusters;
- coupling between the type of projects/technological solutions and the main stakeholders involved in the energy transition of islands.

To conclude, it is highlighted that in this version of the Deliverable the focus is on consolidated technologies with high potential for implementation on islands; after the first round of calls, an update of the pairings will be provided to account for inputs from the received applications and the technical assistance provided, as well as to cover more innovative technologies.

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