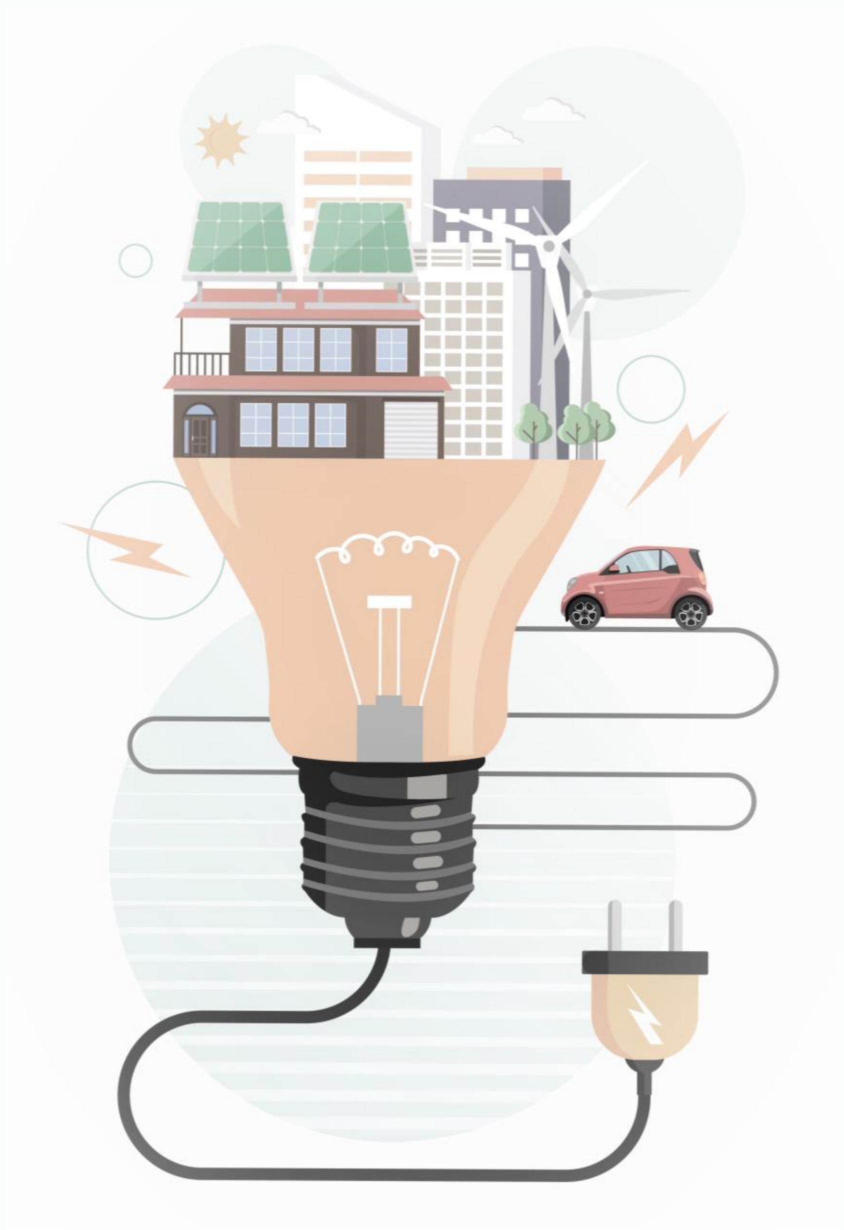
European Commission

ASSET Study on

Islands and Energy Islands in the EU Energy System



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EUROPEAN COMMISSION

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Luxembourg: Publications Office of the European Union, 2021

PDF ISBN 978-92-76-27318-9 doi: 10.2833/702065 MJ-03-20-333-EN-N

ABOUT THE ASSET PROJECT

The ASSET Project (Advanced System Studies for Energy Transition) aims at providing studies in support to EU policy making, research and innovation in the field of energy. Studies are in general focussed on the large-scale integration of renewable energy sources in the EU electricity system and consider, in particular, aspects related to consumer choices, demand-response, energy efficiency, smart meters and grids, storage, RES technologies, etc. Furthermore, connections between the electricity grid and other networks (gas, heating and cooling) as well as synergies between these networks are assessed.

The ASSET studies not only summarize the state-of-the-art in these domains, but also comprise detailed qualitative and quantitative analyses on the basis of recognized techniques in view of offering insights from a technology, policy (regulation, market design) and business point of view.

DISCLAIMER

The study is carried out for the European Commission and expresses the opinion of the organisation having undertaken them. To this end, it does not reflect the views of the European Commission, TSOs, project promoters and other stakeholders involved. The European Commission does not guarantee the accuracy of the information given in the study, nor does it accept responsibility for any use made thereof.

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EXECUTIVE SUMMARY

Islands face unique challenges regarding their energy supply, such as e.g.

- High dependency on imported fossil fuels;
- Energy supply constraints due to the lack of electricity and gas interconnections;
- Increased difficulty to balance electricity supply and demand;
- High energy costs, exceeding the average EU levels, due to the use of more expensive fuel and lower efficiencies of power plants;
- High seasonality of demand.

Therefore, islands require specific political action and tailor-made regulatory approaches.

An increased use of local renewable energy sources constitutes an opportunity to address these challenges, e.g. by

- Assuring security of supplies;
- Limiting the need for expensive energy imports or costly interconnections;
- Facilitating system security and balancing;
- Lowering the enregy costs;
- Responding to seasonality patterns.

Islands may also serve as energy transition 'laboratories' where ad-hoc optimised local energy systems can be developed and tested to serve as blueprints for the general European energy transition.

To foster the energy transition of European islands, this study focuses on three axes:

1. Understanding of islands and their energy systems.
2. Analysis of R&I initiatives related to islands, identifying potential focus areas for R&I actions.
3. Review of policy initiatives related to islands identifying policy gaps and providing recommendations for further actions, with specific focus on power systems.

UNDERSTANDING OF ISLANDS AND THEIR ENERGY SYSTEMS

In total, 447 islands from eleven countries were identified in this study, representing a population of 16.2 million[1]. The majority of the population on EU islands is concentrated on the Mediterranean Sea. Six islands or groups of islands account for the majority of the islands population (approximately 10.78 million): Sicily, Sardinia, the Balearic Islands, the Canary Islands, Crete and Corsica.

The diversity of the islands may be summarised as follows:

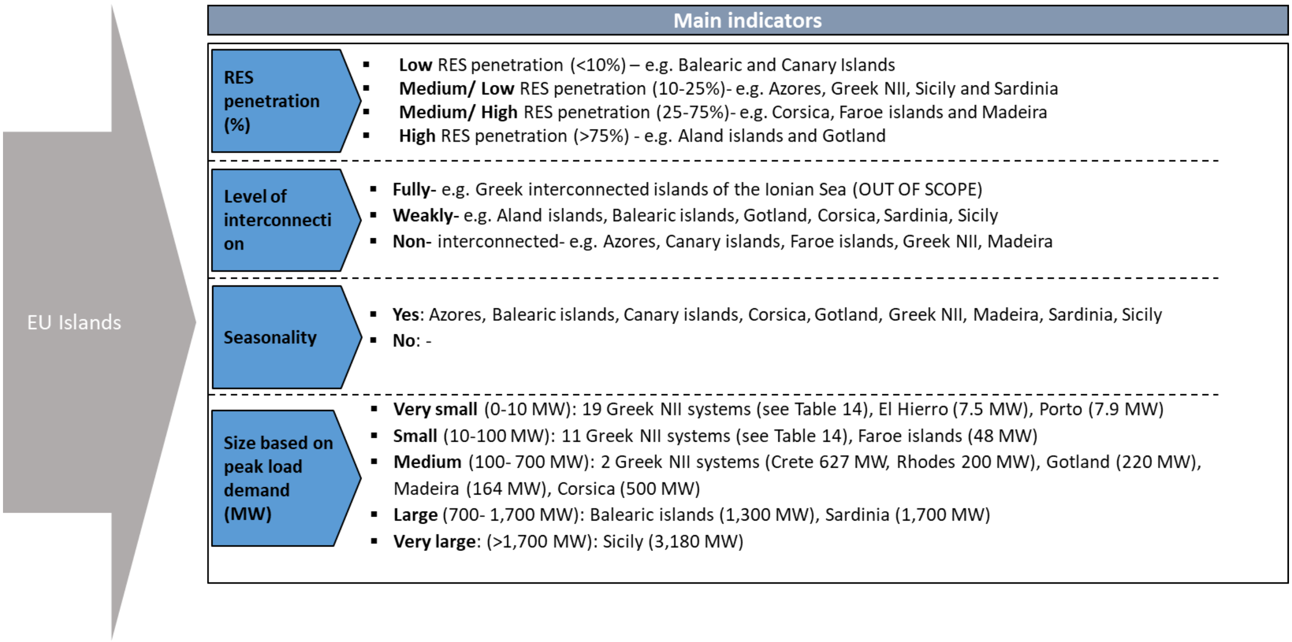
- High concentration of population on a small number of islands;
- The population may vary from < 60 (Antipaxos) to over 5 million inhabitants (Sicily);
- Large number of small islands;
- Areas may vary from 0.4 km^2 (Marathi) to over 25,000 km^2 (Sicily);
- Distance from mainland varies from 8 km (Sicily) to 1,600 km (Canary Islands).

[1] Please note that this study does not cover the total amount of European islands, but a great amount of them, for further information see Chapter 2.

To better understand the situation of the energy systems of European islands, a categorisation is proposed and applied, based on four key indicators:

- **Level of interconnection;** the majority of studied islands were found to be either weakly interconnected (i.e. not sufficient capacity) or non-interconnected at all. By weakly interconnected, we mean an island where installed capacity of interconnectors is inadequate to meet full load demand so that either a) conventional power plants are also operating and/or b) the island cannot become net exporter of electricity (as in Gotland). In some cases, there are plans to enhance the interconnection to the mainland.
- **Population and geographical size;** islands can be sorted as large/medium/small-sized, firstly based on their demographical characteristics (population) and area. However, as the majority of islands demonstrate seasonality, a more relevant indicator is the average peak load demand in MW and electricity consumption (in GWh).
- **RES penetration;** all studied island groups have operational RES plants (mostly wind, solar or geothermal) - with a varying penetration in the energy mix.
- **Seasonality;** the majority of studied islands demonstrate seasonality due to tourism while only few islands demonstrate weak seasonality (i.e. their peak load doesn't differ substantially over the year) or no seasonality at all.

Figure 1: Islands categorisation



An overview and initial categorization of islands covered by this study is shown in Figure 1. European islands greatly vary in size while they all possess a good to very good RES potential. This potential is harnessed on an increasing number of islands like Gotland, Corsica and Sicily. While only a few islands are fully interconnected with the mainland, the majority of EU islands are partially connected and only a minor number of islands (with great distances to the mainland) are not interconnected[2]. The seasonality of energy demand, which is reflected in the annual load profiles, is significant for most EU islands, especially of the ones in the Mediterranean Sea.

[2] See ENTSO-E maps, section 2.1.2 at https://www.entsoe.eu/map/Pages/default.aspx.

RESEARCH AND INNOVATION FOR ISLANDS

Due to their specific nature, islands energy systems encounter specific technical challenges hampering their energy transition. Table 1 lists the main challenges and barriers for islands' energy systems [1]. Their criticality is assessed for two extreme cases: purely fossil-fuel-based energy systems and purely RES-based energy systems.

Table 1: Main challenges impacting islands' energy systems [1]

Issue	Criticality for fossil-fuel-based energy systems	Criticality for RES-based energy systems
Lack of economies of scale	Important challenge (large power plants are more efficient than smaller ones)	Minor challenge (scale effects for wind turbines, but minor scale effects for PV and for battery storage)
Limited fuel supplies	Important challenge	Challenge irrelevant for purely RES-based energy systems, but the limited fuel supplies could impact the decarbonisation of the generation system (difficulty to provide flexibility with gas)
Adequacy	Minor challenge (for liquid fossil fuel generators, the OPEX is much more important than the CAPEX)	Important challenge (no possibility to share capacity with neighbours → storage needed to ensure adequacy)
Security	Minor challenge (limited variability, synchronous generators, flexible generators)	Important challenge (variability of RES, common-mode changes of RES output, power electronics)
Limited space	Minor challenge	Important challenge (large-scale PV plants require substantial space)
Environmental impact	Important challenge (emission of greenhouse gases and other pollutants)	Important challenge (potential impact on fauna and flora habitats, nature protection areas, landscape)

To overcome these challenges, specific Research and Innovation (R&I) actions have been taken up. Past and ongoing projects are addressing the major challenge of RES-based energy systems: their reliability. To address the two fundamental aspects of reliability, adequacy and security, the first R&I projects made use of DR and of improved control of RES generators.

Two topics seem to require further R&D attention:

- Uncertainty related to the actual generation of variable RES, such as wind and PV;
- Dynamic management of power systems dominated by inverters (e.g. PV generators, batteries).

There is also a need to have a proper overview of INTERREG studies dedicated to clean energy developments in islands.

POLICY ACTIONS FOR ISLANDS

Several European policy initiatives (ISLENET, Smart Islands Initiative, Clean Energy for EU Islands, European Small Islands Federation) deal with islands and the themes of energy and decarbonisation. Besides initiatives specifically directed at islands around the theme of sustainable energy, other European and national policy frameworks and funds such as the European Structural & Investment Funds (ESIF), as well as local initiatives address challenges revolving around the energy systems of islands. These measures require stronger coordination, to maximise value added, stronger targets and continuity to achieve fast and tangible results. In the report, actions in five key policy areas are proposed.

CONCLUSIONS AND RECOMMENDATIONS

Key conclusions and recommendations are summarised below:

1. **Understanding islands requires close cooperation with islands authorities to receive all data and analyse the full power systems and their needs.**
    - This report provides an overview of 447 islands that are either electrically non-connected to the mainland, or if an interconnection exists this is of limited capacity as these are the ones of practical significance for the purposes of an energy-focus study and future strategy. The analysis needs to be done for the remaining inhabited EU islands.
    - We recommend creation of the complete list of European islands subject to a specific policy support in the area of energy policy, based on the clear definition of islands, containing clearly defined basic parameters, such as the number of permanent inhabitants (e.g. minimum 20) and the geographical conditions (e.g. no fixed natural connection to the mainland).
    - We focused on understanding the power systems in analysed islands. It was only partly possible due to limited availability of data. Also, it is recommended to analyse the heat- and transportation patterns in the islands.
    - Overall, the collection of island data has proven to be a most challenging exercise as data in general were difficult to find or fragmented, several sources had to be used and, on many occasions, - information, if available, was only in national language. Therefore, for example, we could not estimate the overall energy share of islands in the Europe. We suggest that the issue of transparency and data availability is further pursued with local and regional agencies. The development of a standard template[3] with a regular reporting, also available in English should be initiated.

[3] For transparency templates, please refer indicatively to the “Transparency Templates” published by all gas Transmission System Operators in the context of their obligations under Regulation 715/2009. The data for the case of islands will be very different, nevertheless the publication of a standardised form could be requested upon the island system operators.

- There is a need for a more detailed understanding of RES potentials in islands with consideration for flexibility needs, infrastructure development as well as environmental – and economic effects of maximising the RES use in islands.
  Within this study we have proposed a categorisation methodology for islands. The complete categorisation can be done after the full mapping of islands and their complete energy needs takes place.
- The study revealed that the cost of electricity generation (fuel cost) on some islands analysed during the study is by factors of 2 to 10 higher than the cost on the mainland. This proves the need for a dedicated regulatory framework for islands to stimulate cost effective policy measures, aimed at use of local resources and eliminating energy poverty.

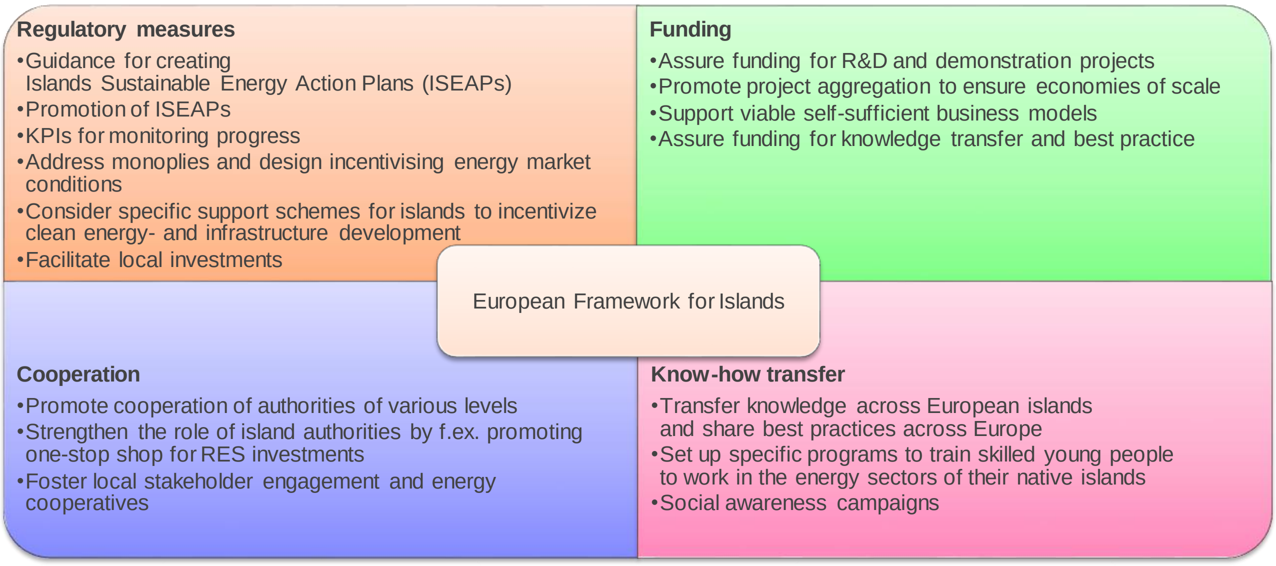
2. **There has been a series of large R&D projects dedicated for island solutions in the last decade, however, next steps are needed to evolve from R&D/demonstration projects to "business as usual" replicable and deployable approaches**

- We have identified 12 large R&D projects that have been either dedicated to islands or used islands for demonstration cases. These existing R&I projects are addressing the main challenge of reliability.
- The analysed projects prove that not only technology solutions are needed (demand response, vertical power plants, improved control of RES, storage, sector coupling) but additional markets measures are required to incentivise the population for active demand response and RES investments.
- In the area of further specific R&D support, focus should be put on
  - Enabling decarbonisation by further fostering the integration of variable renewables;
  - Optimal energy planning for assuring security and generation adequacy;
  - Dynamic management of small power systems with a high penetration of inverter-based technologies;
  - High coordinated management of distributed flexible sources.
- During the analysis, we have focused on R&D projects. We recommend analysing the work on islands realised under the INTERREG umbrella.

3. **Well-designed further coordinated policy action will facilitate creation of the fast track for islands decarbonisation**

- We have identified several islands initiatives, aimed at supporting sustainable energy supplies to islands. These initiatives are further supported EU funding via the structural and R&D funds.
- However, a further continued coordinated policy action for islands is needed to put islands on a fast track for decarbonisation. The policy action should cover five key areas: policy framework; regulatory measures; funding; cooperation and stakeholder engagement; Know-low transfer, communication and best- practise sharing.

Figure 2: Action needed for a policy framework for EU islands



- The implementation of a number of concerted, mutually supportive, measures regarding these areas should be considered, examples of measures include:
  - **Policy - European Framework for Islands**
    - ➢ Coordinated EU action with ambitious targets, aimed at achieving zero-carbon energy systems faster than on mainland (e.g. by 2030).
    - ➢ Practical action plan supporting the Malta Declaration and the Clean Energy Package, covering all key areas of possible EU intervention (regulatory, funding, know-how transfer and communication); this action plan should allow for incentivizing investments in islands and assure continuity of action.
    - ➢ Use islands as laboratories for innovative regulatory/funding approaches: island constellations allow the testing of new innovative regulatory approaches which may serve a blueprint for energy investments the whole of Europe at a later stage.
  - **Regulatory measures**
    - ➢ A blueprint/guidance for creating Islands Sustainable Energy Action Plans (ISEAP), depending on their size, seasonality, level of current and planned interconnection, RES potential and penetration.
    - ➢ Creation or review of Island Sustainable Energy Action Plans (ISEAP) for each European island that are in line with European and national energy targets and the integrated approach under the Energy Union Governance.
    - ➢ Develop KPIs for islands to monitor progress of action plans for islands.
    - ➢ Energy market regulations to fight monopolies as well as designing energy markets to incentivise investments in islands and incentivise island communities to actively participate in energy markets as prosumers, energy communities or demand side response.
  - **Funding**
    - ➢ Dedicate funding for R&D and demonstration projects for islands.
    - ➢ Ensure well-tailored support schemes for islands to incentivize clean energy- and infrastructure developments technologies.
    - ➢ Project aggregation to ensure economies of scale and cost reduction and microloans facilities for micro-scale generation regional system peer-

management, benchmarking energy costs based on island specificities, and securing ad hoc access to essential technical and regulatory expertise.
- Foresee funding for knowledge transfer and best practice exchange and capacity building and awareness raising.
- Facilitating local investments and energy communities to increase the feeling of ownership among islands inhabitants.

- **Cooperation and stakeholder engagement**
  - Promote cooperation of authorities of various levels (national, regional, local) to eliminate non-cost barriers for sustainable energy systems in islands and facilitate coordinated infrastructure development programs.
  - Recognize and strengthen the role of island authorities by e.g. promoting one-stop shop for RES investments on islands.
  - Further foster local stakeholder engagement to ensure ownership as this is key for a successful insular development.
- **Know-low transfer, communication and best- practise sharing**
  - Transfer knowledge across European islands and share best practices.
  - Specific programs to train skilled young people to work in the energy sectors of their native islands and contribute to the growth of their economies. The TILOS Horizon 2020 Project presented in this report shows one approach to the transfer of technological experience through an islands' skills and information exchange platform.
  - Social awareness campaigns.
  - Promotion of the most successful demonstrators across Europe.

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1 INTRODUCTION

The relative isolation and small size of islands leads to special challenges regarding their energy supply and clearly distinguishes them from energy systems of larger regions like the EU mainland. This affects some 4% of the European Union's population living on islands. The energy supply of these 16 million Europeans is characterized by a high dependency on fossil fuels, energy supply constraints due to the lack of electricity and gas interconnections as well as energy costs that exceed average EU levels due to the use of more expensive fuel, lower efficiencies of power plants and a high seasonality of demand.

For islands, an increased use of local renewable energy sources constitutes an opportunity to address several of these challenges, e.g. reducing the need for expensive energy imports or costly interconnections. Examples of such approaches are already present in Europe, e.g. in the Canary- and Greek Islands, Bornholm, Brittany, Slovenia or within the Association of Small Islands in Europe.

Additionally, islands are interesting 'laboratories' where possible solutions for future energy systems can be developed and tested on a comparatively small scale.

1.1 Objective of the study

To foster the energy transition of European islands, this study focuses on three axes:

1. Understanding of islands and their energy systems.
2. Analysis of R&I initiatives related to islands, identifying potential focus areas for R&I actions.
3. Review of policy initiatives related to islands identifying policy gaps and providing recommendations for further actions with specific focus on the power systems.

The main focus envisaged for such actions covers:

- An increased used of local renewable energy sources;
- Decarbonisation of the transport system on the island and from the mainland to the island;
- An optimised energy system designed/retrofitted to the needs of the island and using synergies between the different networks (e.g. heating and cooling, transport), including assets for the storage of energy and potentially relation with the water network.

1.2 Structure of the report

The remainder of the report is structured as follows: Chapter 2 serves the understanding of islands and their energy systems. It assesses the energy mix, related costs and decarbonization potential of islands and provides a categorization of European islands. Chapter 3 provides a gap analysis on R&I initiatives related to islands, identifying potential focus areas for further R&I actions. In Chapter 4, a similar gap analysis on policy actions is performed by reviewing policy initiatives related to islands and the cooperation of communities, identifying policy gaps and providing recommendations. Chapter 5 presents a strategic vision for European islands. It is based on three possible approaches for the further energy transition of islands. Chapter 6 draws conclusions and lists recommendations.

2 UNDERSTANDING OF ISLANDS AND THEIR ENERGY SYSTEMS

The first part of this Section sets a base towards the understanding of European islands and their energy systems. Section 2.2 includes a detailed presentation of European islands, including information on size, population, GDP, and key energy-related indicators (capacity installed, energy mix, seasonality of demand, interconnection future RES outlook and energy dependency). A proposed categorisation of islands is discussed in Section 2.3 while Section 2.4 contains a synopsis of key findings.

2.1 Background

Firstly, background information related to RES potential (wind and solar energy), interconnections of energy islands systems on EU-level from ENTSO-E and other relevant data were sought. For reasons of consistency, islands are defined at least according to the criteria used in the Eurostat publication 'Portrait of the islands' and the DG REGIO study on island regions 2003-04 [2], see section 2.1.1. below. For the purposes of this study we have extended the definition to include islands that are electrically non-interconnected or only partially connected to mainland so that electricity demand is in total or in part met by conventional or RES power plants operating on the islands.

2.1.1 Islands definition

Islands were defined by a Eurostat publication study Portrait of the Island' [2] in 1994, which excluded islands with a national capital. This was subsequently used in a DG REGIO study to define island regions[4]. Within the EU-15 the only impact was to exclude Ireland and the UK (prior to the construction of the Channel Tunnel) as an 'island'. To ensure access to annual data, a regional approximation of islands was made focusing on regions whose entire populations lived on an island [3].

This is the definition used in the Green Paper on Territorial Cohesion [4]. Subsequently, this definition was modified to include Malta and Cyprus as island regions despite the presence of a national capital. The modification in this paper was intended to include islands with a national capital if the country was eligible for the Cohesion Fund [3].

Ultimately, the methodology was modified for the 5th Cohesion Report to simplify and harmonise the definition [5]. The criteria relating to the presence of a national capital and Cohesion Fund eligibility were both discarded. This classification is now stable.

Island regions are NUTS 3 regions entirely covered by islands. In this context, islands are defined as territories having:

- A minimum surface of 1 km²;
- A minimum distance between the island and the mainland of 1 km;
- A resident population of more than 50 inhabitants;
- No fixed link (bridge, tunnel, dyke) between the island and the mainland.

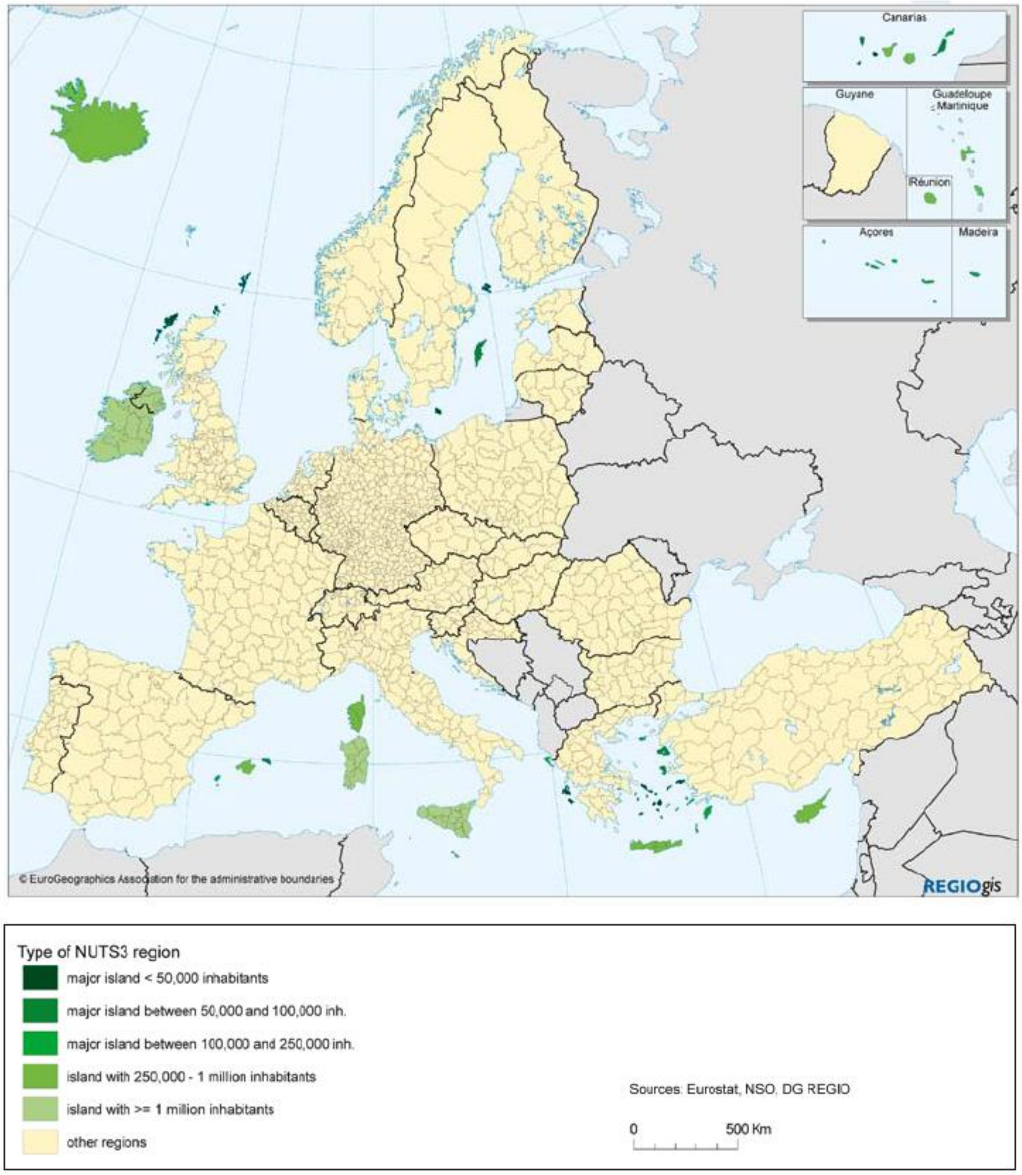
NUTS 3 island regions can correspond to a single island, or can be composed of several islands, or can be part of a bigger island containing several NUTS 3 regions.

[4] In all other NUTS 3 regions the share of population living on an island is well below 50%.

The typology of NUTS 3 island regions distinguishes five categories, depending on the size of the major island related to the NUTS 3 region:

1. Regions where the major island has less than 50 000 inhabitants.
2. Regions where the major island has between 50 000 and 100 000 inhabitants.
3. Regions where the major island has between 100 000 and 250 000 inhabitants.
4. Regions corresponding to an island with 250 000 to 1 million inhabitants, or being part of such an island.
5. Regions being part of an island with at least 1 million inhabitants.

Figure 3: Map with typology of island regions



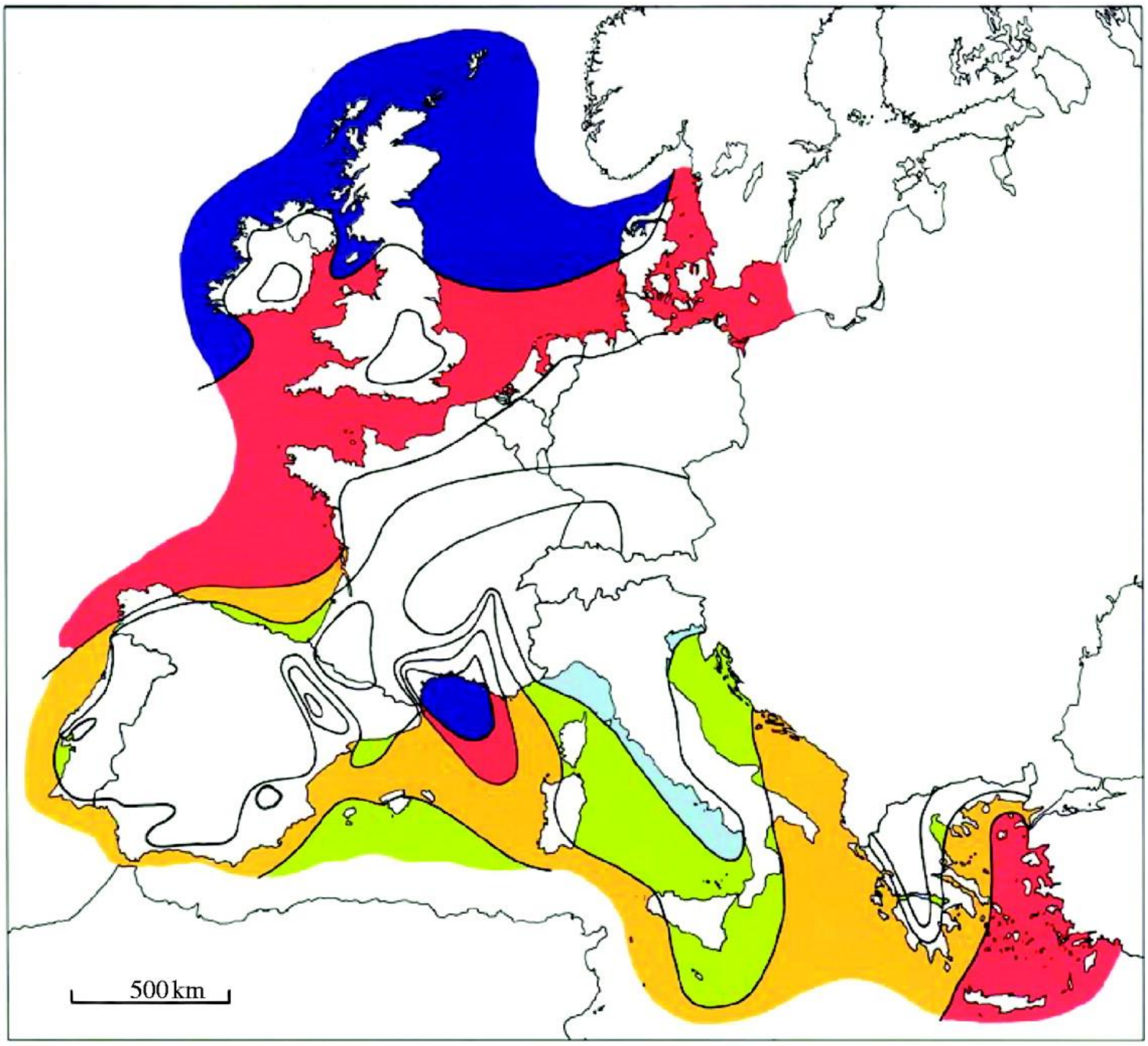
As already stated above, for the purpose of this study, we have only considered as islands territories that are electrically non-interconnected or only partially connected to EU mainland.

Island energy systems share common characteristics such as a tendency to fossil fuel dependency (mainly oil) and energy supply constraints due to the lack of electricity and gas interconnections. The cost of electricity generation on islands usually exceeds that of mainland EU due to the use of more expensive fuel (e.g. gasoil as opposed to coal and/or natural gas), lower efficiencies of power plants (due to technology, size and age) and due to the high seasonality of demand. The lack of interconnection with the mainland also restricts the penetration of variable energy sources such as wind and solar PV.

Further, the dependence of power generation on oil and oil products gives also rise to substantial air pollutants (SO_x, NO_2, particulates) per MWh of electricity generated and CO_2 emissions that exceed the corresponding levels at mainland EU Member States. Despite those challenges, most islands have the potential to become frontrunners in the energy transition and adopt innovative solutions to address climate change, security of supply and research and innovation. Many islands enjoy a significant wind and/or solar potential so that renewable energy can provide a good opportunity for their economic development. Figure 4 shows that both the Mediterranean and the North and Baltic seas, where several islands are located, enjoy a substantial wind potential. Furthermore, the islands of the Mediterranean Sea are characterized by the highest levels of solar irradiation, as seen in Figure 5. Coupling RES production with other innovative solutions such as combined RES-desalination plants, hybrid plants (e.g. RES and H_2 production for transport applications etc.) or interconnecting the islands with mainland where technically possible and economically justifiable is expected to provide a multitude of economic and environmental benefits.

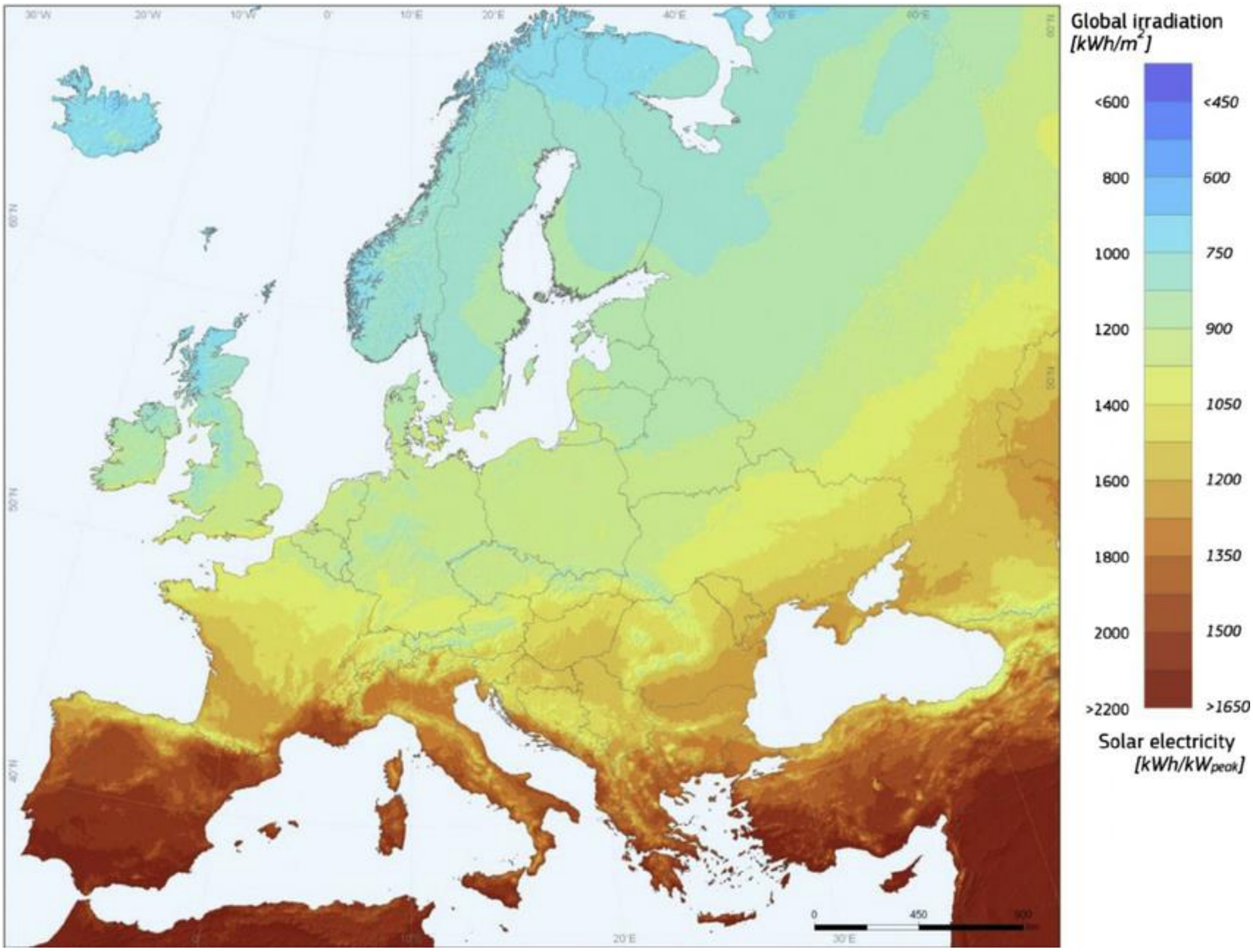
Aside of ‘green tourism’, the creation of local jobs and other benefits, e.g. improved air quality, to citizens and local communities are important economic benefits of developing sustainable energy systems in islands. During the last decade, a number of EU-funded projects aimed at testing and demonstrating innovative solutions involved islands, e.g. El Hierro in Spain, Bornholm in Denmark and Tilos in Greece. More information on EU-funded projects is discussed in section 3.

Figure 4: European offshore wind map. Source: Risø National Laboratory, Roskilde, Denmark



wind resources over open sea (more than 10km offshore) for five standard heights										
	10m		25m		50m		100m		200m	
	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$	$m s^{-1}$	$W m^{-2}$
	>8.0	>600	>8.5	>700	>9.0	>800	>10.0	>1100	>11.0	>1500
	7.0–8.0	350–600	7.5–8.5	450–700	8.0–9.0	600–800	8.5–10.0	650–1100	9.5–11.0	900–1500
	6.0–7.0	250–300	6.5–7.5	300–450	7.0–8.0	400–600	7.5 – 8.5	450 – 650	8.0 – 9.5	600 – 900
	4.5–6.0	100–250	5.0–6.5	150–300	5.5–7.0	200–400	6.0 – 7.5	250 – 450	6.5 – 8.0	300 – 600
	<4.5	<100	<5.0	<150	<5.5	<200	<6.0	<250	<6.5	<300

Figure 5: Photovoltaic solar electricity potential in European countries as shown by irradiation [kWh/m2/year] and solar electricity [kWh/kWp]. Source: PVGIS © European Union, 2012



2.1.2 Interconnection of islands systems

Islands are often non-connected or weakly connected to the mainland. Amongst the non-interconnected islands are: Crete, the Aegean islands (GR) and Faroe Islands (DK). Amongst the largest connected islands (with connections of limited capacity) are: Bornholm (Denmark), Gotland (Sweden), Aland Islands (Finland), Sicily (Italy), Corsica (France), and the Balearic Islands (Spain). The Transmission maps below show existing interconnections of large islands in the Southern and Northern Europe (source: ENTSO-E[5]). As also shown in the maps a substantial number of islands remain non-interconnected to mainland.

[5] The ENTSO-e map shows all transmission lines designed for 220 kV voltage and higher.

Legend

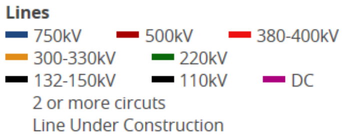


Figure 6: Transmission system map, Southern Europe

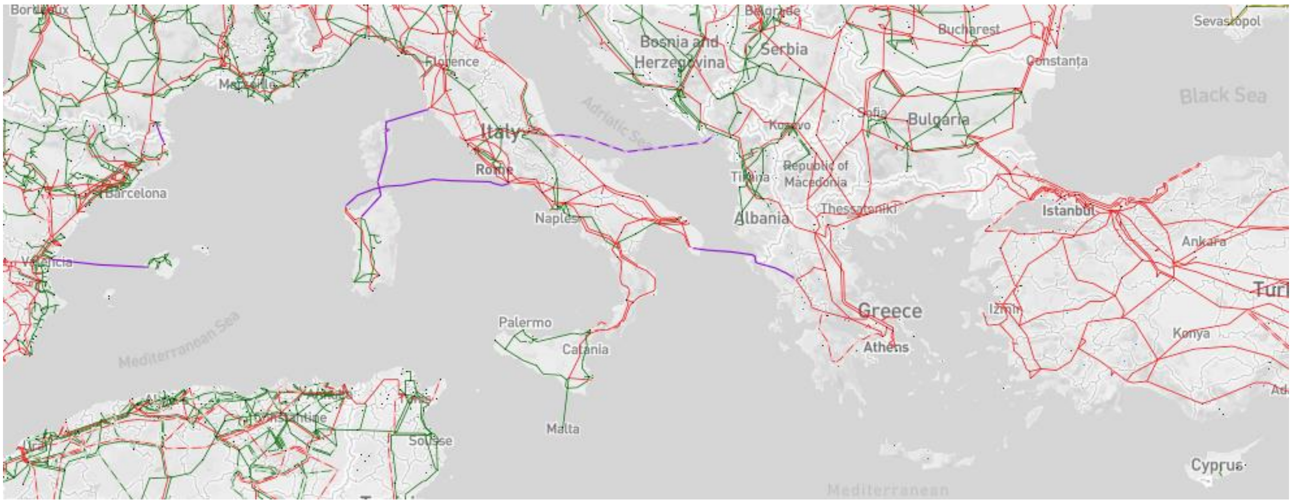
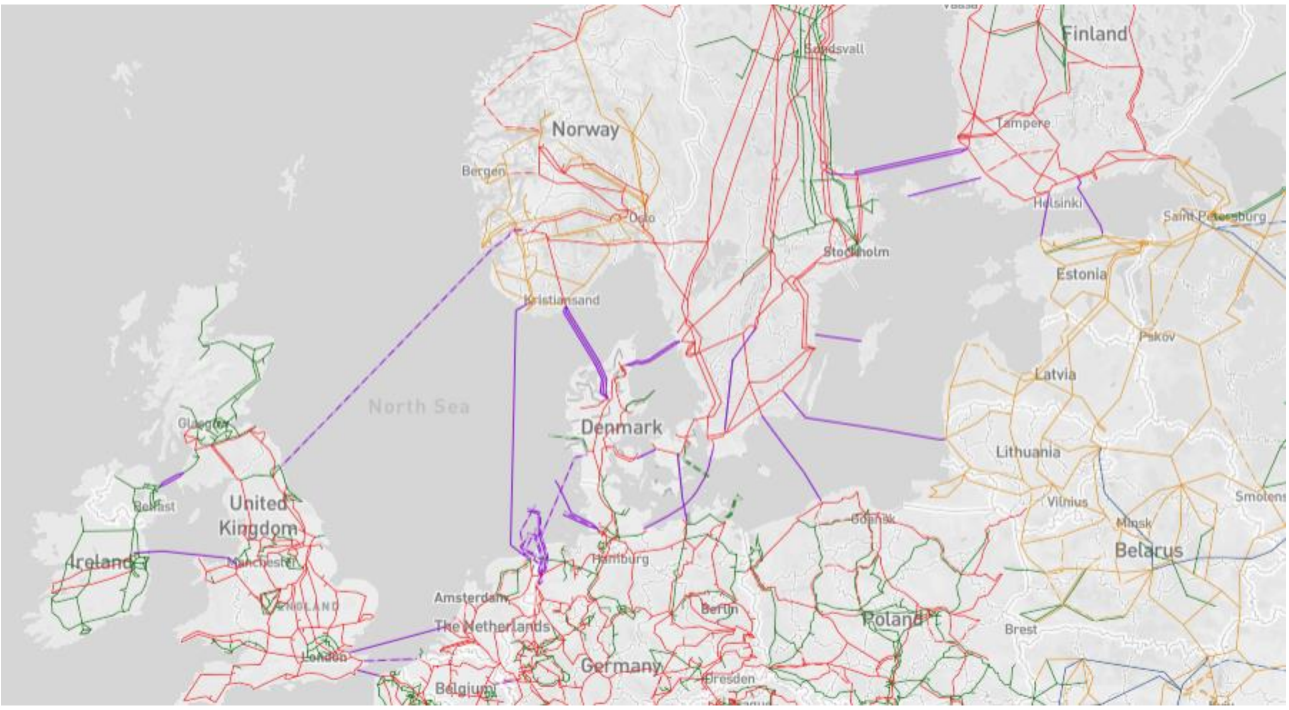


Figure 7: Transmission system, Northern Europe



2.2 Mapping of European islands

On May 18, 2017, fourteen EU countries signed a ''Political declaration on clean energy for EU islands'' [6]. This declaration aims to accelerate the clean energy transition on more than 2,700 islands in Europe[6], enable them to reduce their dependency on energy imports, maximize utilization of their local energy resources and adopt innovative energy solutions. The signatory countries were: Croatia, Cyprus, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Malta, Portugal, Spain, and Sweden.

The analysis and mapping of EU islands presented herein is an attempt to cover as many non-interconnected or partially connected islands as possible from the signatory countries. It should be stressed that obtaining information on EU islands is a non-straightforward task as there is no separate section in EUROSTAT or other databases at EU level focusing on islands. Existing information is fragmented and has mostly been sourced at national and regional levels from the sites of transmission and distribution system operators.

2.2.1 Identification through the NUTS classification

As already stated in the beginning of this section, focus was placed on non-interconnected or partially connected islands.

- Islands which are themselves an EU country (such as Cyprus, Malta, Ireland and UK) where excluded from the mapping. It is considered that these islands, due to their size and due to the fact that they are –as a whole- EU Member States, have access to different funding instruments compared to smaller regions/islands that form only part of a country.
- Islands of the EU Outermost regions (ORs), e.g. Martinique, Mayotte, Guadeloupe, French Guiana and Réunion, Saint-Martin (since 2009), located more than 5,000 km from the European mainland were also excluded from the mapping at this stage.
- The EU outermost regions e.g. Martinique, Guadeloupe, Saint Martin, French Guiana, Reunion, Mayotte were excluded at this stage but will be covered in the next stage of the mapping and the analyses of specific policy and R&I actions. This is a commitment of the Commission in its strategy toward the outermost regions (COM(2017)623 final)[7].

A first approach to identify islands and source information was made through the so-called NUTS [7] classification (Nomenclature of territorial units for statistics). We chose the NUTS classification as a starting point to also align with the EU Fifth Cohesion Report (CEC, 2010) where islands have been defined as NUTS3 regions where the majority of the population live on one or more islands without fixed connections to the mainland, such as a bridge or a tunnel". NUTS is a hierarchical system for dividing up the economic territory of the EU for the purpose of collection, development and harmonisation of EU regional statistics. It aids in the socio-economic analysis of the regions and in the framing of EU regional policies. NUTS 1 level classification is at Member States level with NUTS 2 and 3 focusing down to smaller regions which however on many cases are not small enough to include single islands of smaller size. For example, region HR035- Splitsko-dalmatinska županija (NUTS3 level) includes both mainland Croatia and several islands.

To identify separately information strictly related to islands would require going down to a more detailed classification level that of Local Administrative Units (LAU1 and 2). Analysis at LAU level

[6] This number includes islands from the fourteen signatory countries plus the UK and the Netherlands.

[7] See http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2017:623:FIN.

however would require the devotion of a substantial level of resources not available given the amount of time allocated for this study.

NUTS3 island regions, where available, comprise a single -comparatively large in terms of area - islands (e.g. EL412 - Samos (GR), EL413 - Chios (GR)), or several smaller islands (e.g. the Dodecanese islands). On the other hand, a larger in terms of area island bigger island may include several NUTS-3 regions (e.g. Sicily 9 NUTS3 regions, Crete, 4 NUTS3 regions).

Approximately 112 islands have been identified through the NUTS II or III levels classification and are summarised in the Table below. Note that as this study focuses on non-interconnected or partially connected islands only these are shown in the table below.

Table 2: Summary of NUTS levels II-III which include sole islands or island groups

NUTS II region	No of islands	NUTS III region	No of islands
		DK014- Bornholm	1
FR83- Corsica	1		1
ES53- Balearic Islands	4	ES531 - Eivissa, Formentera ES532 - Mallorca ES533 - Menorca	4
ES70- Canary Islands	7	ES703 - El Hierro ES704 - Fuerteventura ES705 - Gran Canaria ES706 - La Gomera ES707 - La Palma ES708 - Lanzarote ES709 - Tenerife	7
FI2- Aland	11	FI200 - Åland	11
ITG2- Sardinia	5		
ITG1- Sicily	15		
EL41- Voreio Aigaio	10	EL411 - Lesvos EL412 - Samos EL413 – Chios	3
EL42- Notio Aigaio	42	EL421 - Dodekanisos EL422 - Kyklades	
EL43- Crete	2		
		MT002- Gozo and Comino	2
		PT200- Azores	9
		PT300- Madeira	2
		SE214- Gotland	1
TOTAL	**97**		**41**

* Ceuta and Melilla were not included in the mapping

Where the NUTS classification proved insufficient for this work, other sources were sought (e.g. national energy authorities, DSOs, TSOs, regulators and other sources, for example ESIN).

2.2.2 Identification of islands through the European Small Islands Federation and other sources

ESIN (2014) in its *'Atlas of the ESIN Islands'* estimated the number of inhabited European islands identified as '[..] *big or small, bridged or un-bridged, NUTS or non- NUTS, in seas, rivers, lakes, states, regions and municipalities [..]'* be 2,418 with a population of 13.9 million people. This estimate includes Greenland, Iceland, Montenegro, Ukraine and the UK which have not been included in our categorization.

The European Small Islands Federation (ESIN) represents members from Croatia, Denmark, Estonia, Finland, France, Greece, Italy, Ireland, Scotland and Sweden. Typically, the ESIN network covers small (less than 5,000 inhabitants) and very small islands (5 to 50 inhabitants).

As the ESIN definition of islands has not been found to be in line with the EUROSTAT definition of islands, data have been treated with caution and cross-checked with other references.

2.2.3 Final mapping of EU islands

Following the first categorisation and a compilation of data from various sources, a detailed mapping of European islands was prepared (see Annex). Sources included EUROSTAT, national agencies, scientific publications, trade associations etc. Data for German and Croatian islands [8] were limited and are not presented here.

In total, 447 islands were identified from eleven countries, representing a population of 16.2 million [8].

[8] For the purposes of this first mapping, Greek interconnected islands have been identified, representing 43 islands with a population of 520,000.

Table 3: Mapping of EU islands

Country	Number of islands	Population
Denmark	**126**	**3,590,891**
✓ Faroe Islands	18	50,250
✓ DK small islands	108	3,540,641
Estonia	**20**	**45,287**
✓ EE small islands	20	45,287
France	**22**	**343,848**
✓ Corsica	1	327,374
✓ FR small islands	21	16,474
Finland	**72**	**34,639**
✓ FI islands	30	5,656
✓ Aland islands	42	28,983
Greece	**91**	**1,376,270**
✓ Interconnected islands	33	261,467
✓ non-interconnected islands	58	1,114,803
Italy	**34**	**6,801,656**
✓ Sicily	1	5,082,000
✓ Sardinia	1	1,661,819
✓ IT small islands	32	57,837
Ireland	**29**	**2,939**
✓ IE small islands	29	2,939
Malta	**2**	**31,592**
✓ Gozo and Comino	2	31,592
Portugal	**11**	**505,039**
✓ Azores	9	246,353
✓ Madeira	2	258,686
Spain	**11**	**3,095,094**
✓ Balearic Islands	4	968,950
✓ Canary Islands	7	2,126,144
Sweden	**29**	**370,228**
✓ Gotland	1	56,656
✓ SE small islands	28	313,572
TOTAL	**447**	**16,197,483**

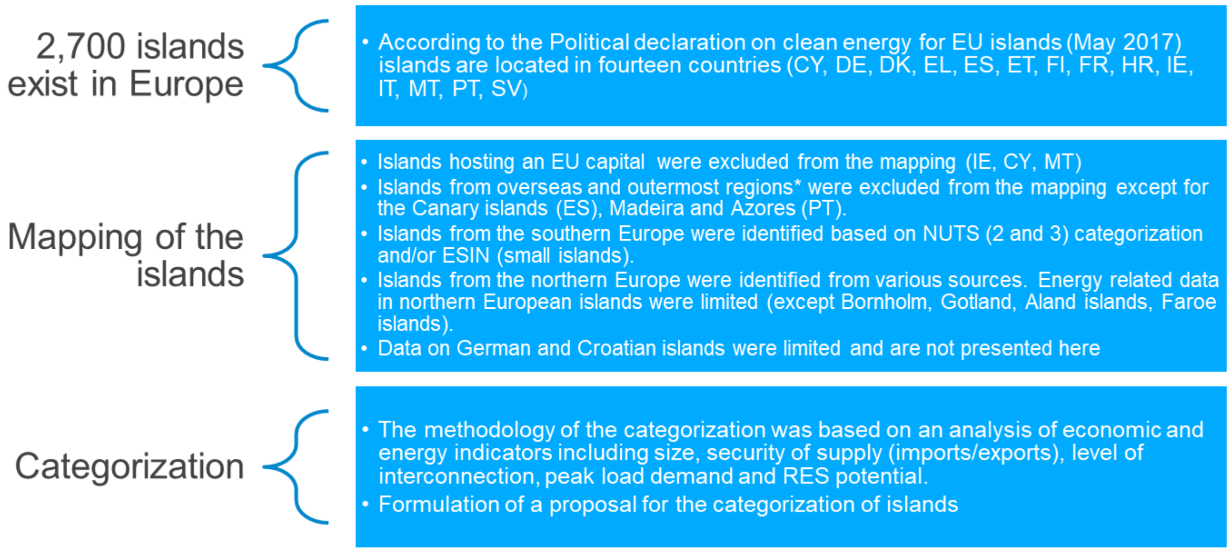
2.2.4 Preliminary findings

Most of the population on EU islands is concentrated on the Mediterranean Sea. Six islands or groups of islands account for most of the islands' population (approximately 10.78 million): Sicily, Sardinia, the Balearic Islands, the Canary Islands, Crete and Corsica.

The diversity of the islands may be summarised as follows:

- High concentration of population on a small number of islands;
- The population may vary from 60 (Antipaxos) to over 5 million inhabitants (Sicily);
- Large number of small islands;
- Areas may vary from 0.4 km^2 (Marathi) to over 25,000 km^2 (Sicily);
- Distance from mainland varies from 8 km (Sicily) to 1,600 km (Canary Islands).

Figure 8: Overview of EU islands mapping



2.2.5 Basic information

This section presents an overview of basic information on the European islands identified such as size, population and distance to mainland. A vast collection of further energy related indicators can be found in Annex 1. This includes the capacity installed per type of technology and fuel, levels of generated electricity (distinguished between thermal and RES), current and future planned interconnections with mainland or other islands, related costs if available and RES potentials.

Data was sourced from IRENA, the World Bank, EUROSTAT, national energy agencies and other sources. In total, 160 islands have been analysed representing a population of 12 million, three quarters of which reside in the Mediterranean.

Table 4: Basic information on EU islands archipelagos and their energy systems

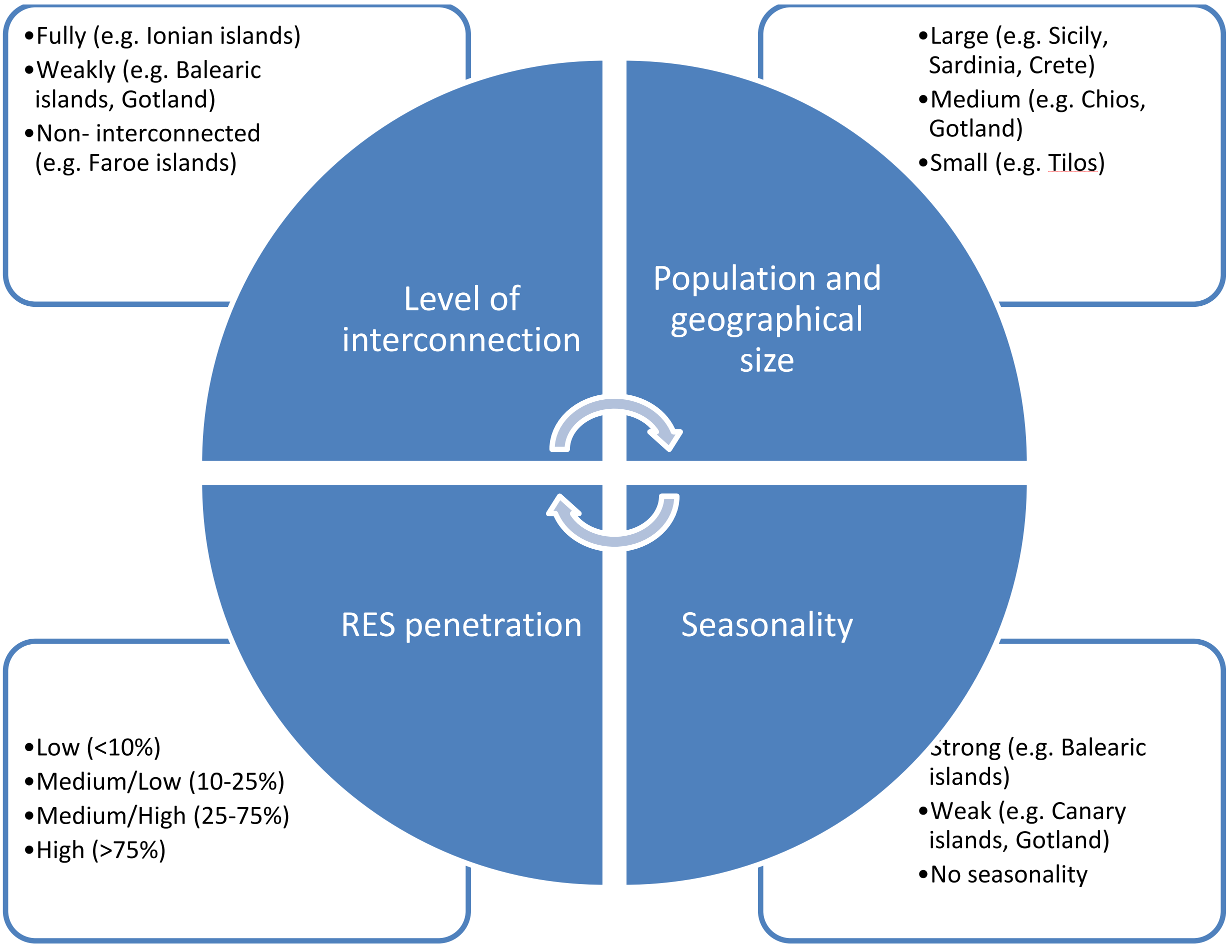
Islands	Population (2015)	Area (km²)	Distance to mainland (km)	Interconnection	Location
Aland Islands (FI)	28,916	1,580	70 to mainland Sweden	Interconnection with mainland and other islands	Baltic Sea
Azores (PT)	246,353	2,322	1,570 to mainland Portugal	No interconnection	Atlantic Ocean
Balearic Islands (ES)	968,950	4,992	280 to mainland Spain	Interconnection with mainland and other islands	Mediterranean Sea
Canary Islands (ES)	2,126,144	7,447	1,600 to mainland Spain	No interconnection with mainland, partial interconnection with other islands	Atlantic Ocean
Corsica (FR)	327,374	8,680	111 to mainland Italy	Partial interconnection with mainland, interconnection with other islands	Mediterranean Sea
Faroe Islands (DK)	50,250	1,399	1,120 to mainland Denmark	No interconnection with mainland, interconnection with other island	Norwegian Sea/ North Atlantic
Gotland (SE)	57,391	2,968	90 to mainland Sweden	Partial interconnection with mainland, no interconnection with other islands	Baltic Sea
Greek islands (non-interconnected) (GR)	1,114,803	[9]	-	No interconnection with mainland, partial interconnection with other island	Mediterranean Sea
Madeira (PT)	258,686	801	900 to mainland Portugal	No interconnection	Atlantic Ocean
Sardinia (IT)	1,658,138	24,090	240 to mainland Italy	Partial interconnection with mainland, interconnection with another island	Mediterranean Sea
Sicily (IT)	5,074,261	25,711	8 to mainland Italy	Partial interconnection with mainland, no interconnection with other island	Mediterranean Sea
TOTAL	**11,911,266**				

[9] Please see detailed list in Annex 1.

2.3 Proposed categorisation of EU islands

As outlined in the graph below, we suggest the categorisation of European islands to focus on four key indicators: level of interconnection, size, RES penetration and seasonality.

Figure 9: Proposed categorisation and examples



The proposed categorisation of islands:

- **Level of interconnection;** the majority of studied islands were found to be either weakly interconnected (i.e. not sufficient capacity) or non-interconnected at all. By weakly interconnected, we mean an island where installed capacity of interconnectors is inadequate to meet full load demand so that either a) conventional power plants are also operating and/or b) the island cannot become net exporter of electricity (as in Gotland). In some cases, there are plans to enhance the interconnection to the mainland.
- **Population and geographical size;** islands can be sorted as large/medium/small-sized, firstly based on their demographical characteristics (population) and area. However, as the majority of islands demonstrate seasonality, a more relevant indicator is the average peak load demand in MW and electricity consumption (in GWh).
- **RES penetration;** all studied island groups have operational RES plants (mostly wind, solar or geothermal) - with a varying penetration in the energy mix.

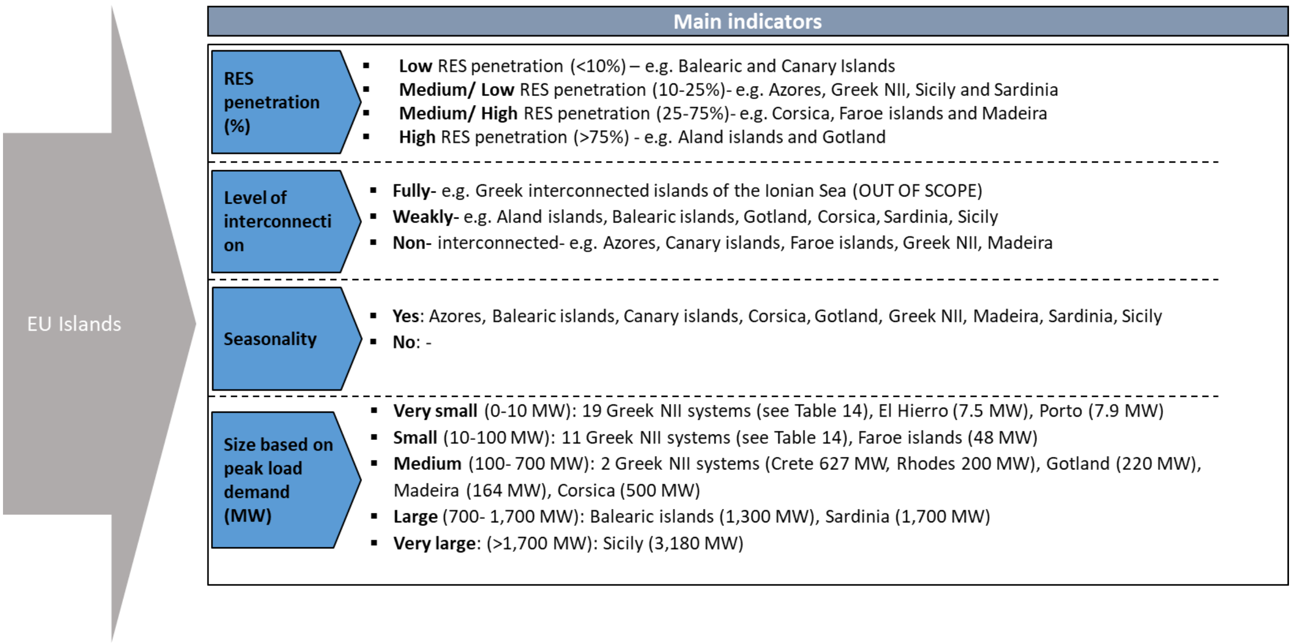
- **Seasonality;** the majority of studied islands demonstrate seasonality due to tourism while only few islands demonstrate weak seasonality (i.e. their peak load doesn't differ substantially over the year) or no seasonality at all.

Depending on data availability, some additional indicators can be used such as:

- **GDP per capita**: this indicator can be useful especially for comparing relative economic 'performance' of islands and island groups.
- **Average cost of energy production per MWh**: this indicator is used to assess local price of a unit of electricity (MWh) generated on an island (conventional thermal plants).
- **Average cost of energy production per MWh over the price of the Day-Ahead market (**Other benchmarking values may be used (such as the peak price, the price of long term contracts etc.).

Consequently, the islands studied in Section 2.2 can be grouped as such:

Figure 10: Islands categorisation



2.4 Conclusions from the statistical overview

The aim of the overview was to understand the energy landscape of islands. To be able to present the most accurate picture of islands, two distinct analyses were completed. The first considered macroeconomic indicators, including size, population and GDP of islands. Data were collected for a total of 447 islands. The other looked into energy-related indicators, more specifically level of interconnections, peak load demand, yearly energy consumption, energy mix, cost of electricity generation and RES potential, where available. Information (based on data availability) was retrieved for a total of 160 islands (4 islands and 7 island groups) in the South and North of Europe. Additional data such as future interconnection plans were also recorded.

However, the consortium did not manage to provide full understanding of the energy landscape in islands, due to difficulties with access to specific data. In terms of availability, data for German and Croatian islands could not be compiled due to lack of readily available information and therefore are not presented in this study. Energy-related data for Northern European islands were also scarce. Overall, the collection of island data has proven to be a most challenging exercise as data in general were difficult to find or fragmented, several sources had to be used and on many occasions information, if available, was only in the national language.

We recommend that, in the context of the EU islands initiative, a **regular and standardized reporting process at island level is initiated**. The development of **a transparency template[10] for reporting, also available in English**, would certainly help towards this direction. Local communities should be educated on the advantages of transparency and timely and accurate reporting.

The mapping exercises concluded with **an indicative categorisation of islands** by use of four basic indicators:

- RES penetration;
- Level of interconnection;
- Seasonality and
- Size- quantified by the peak load demand (MW).

Three additional indicators (GDP per capita, average cost of energy production and average cost of energy production over a benchmarking price of the mainland electricity market) can lead to a further categorisation.

The study confirmed – where data was available - the islands unique energy characteristics and challenges: fossil fuel dependency, weak or non-existent interconnection to the mainland, stand-alone power infrastructure.

The study further revealed that the **cost of electricity generation (fuel cost) on several islands is by factors of 2 to 10 higher than the cost in the mainland**. Although the study has not considered conventional plants operating on EU islands in detail, preliminary findings confirm that on several occasions, plants are aged, oil fired power and responsible for the release of larger quantities of air pollutants and CO^2 emissions per MWh of energy produced than conventional plants operating on the mainland. Renewable energy sources present a substantial opportunity for sustainable development and growth.

3 RESEARCH AND INNOVATION FOR ISLANDS

Due to their specific nature, islands energy systems encounter specific technical challenges hampering their energy transition. To overcome these challenges, specific Research and Innovation (R&I) actions are needed. The purpose of this chapter is to propose a clear view of challenges and barriers already addressed, as well as the remaining ones.

For that purpose, Section 3.1 summarizes the main challenges and barriers affecting islands' energy systems and their transition, Section 3.2 reviews past and ongoing R&I projects at the European level that specifically addressed islands energy systems and Section 0 concludes on remaining gaps. Note that some challenges are also relevant for other energy systems. Therefore, challenges hampering the energy transition of islands are also addressed by R&I

[10] For transparency templates, please refer indicatively to the "Transparency Templates" published by all gas Transmission System Operators in the context of their obligations under Regulation 715/2009. Of course, the data for the case of islands will be very different, nevertheless the publication of a standardised form could be requested upon the island system operators.

actions not focusing on islands energy systems. The analysis of these R&I actions is out of scope of this report[11].

3.1 Challenges and barriers for (the transition of) islands' energy systems

Table 5 lists the main challenges and barriers for islands' energy systems [1]. Their criticality is assessed for two extreme cases: purely fossil-fuel-based energy systems and purely RES-based energy systems. For that table, the general concept of reliability of energy systems is split into its two fundamental aspects, adequacy and security. The adequacy of an energy system can be defined as its ability to satisfy the consumer demand and system's operational constraints at any time, in the presence of scheduled and unscheduled outages of components or facilities. The security of an energy system can be defined as its ability to withstand disturbances arising from faults and unscheduled removal of equipment without further loss of facilities or cascading failures. The table below presents the key challenges ahead of islands.

Table 5: Main challenges impacting islands' energy systems [1]

Issue	Criticality for fossil-fuel-based energy systems	Criticality for RES-based energy systems
Lack of economies of scale	Important challenge (large power plants are more efficient than smaller ones)	Minor challenge (scale effects for wind turbines, but minor scale effects for PV and for battery storage)
Limited fuel supplies	Important challenge	Challenge irrelevant for purely RES-based energy systems, but the limited fuel supplies could impact the decarbonisation of the generation system (difficulty to provide flexibility with gas)
Adequacy	Minor challenge (for liquid fossil fuel generators, the OPEX is much more important than the CAPEX)	Important challenge (no possibility to share capacity with neighbours → storage needed to ensure adequacy)
Security	Minor challenge (limited variability, synchronous generators, flexible generators)	Important challenge (variability of RES, common-mode changes of RES output, power electronics)
Limited space	Minor challenge	Important challenge (large-scale PV plants require substantial space, if not integrated in buildings)
Environmental impact	Important challenge (emission of greenhouse gases and other pollutants)	Important challenge (potential impact on fauna and flora habitats, nature protection areas, landscape)

[11] A review of smart grid projects in Europe is available in the JRC "Smart Grid Projects Outlook 2017", https://ses.jrc.ec.europa.eu/smart-grids-observatory.

Lack of economies of scale

Due to the small size of power systems on islands, a first challenge is the lack of economies of scale. The criticality of this issue is more stringent for fossil-fuel-based energy systems than for RES-based energy systems. Indeed, the efficiency of thermal generators increases significantly with their size up to several hundreds of MW, while economies of scale for PV installations saturate at several tens of MW. It also leads to impossibility to develop local industry for the supply of equipment, and it thus makes the islands dependent on imports of equipment (higher costs).

Limited (fossil) fuel resources

Due to geographical isolation and limited onshore fossil energy sources, a second challenge is the limited fuel supplies: if liquid fossil fuels are usually easy to import, gas is much more complicated. The criticality of that is obviously strong for fossil-fuel-based energy systems and not relevant for RES-based energy systems. However, note that it could impact the decarbonisation of the generation system because the difficulty to import gas leads to a difficulty to provide flexibility with flexible gas units (e.g. aero-derivative gas turbines).

Adequacy and security

The next two challenges are linked to reliability (i.e. both adequacy and security aspects) [9]. These reliability issues are less critical for fossil-fuel-based energy system. Indeed, redundancy in the generating facilities can be afforded because the initial investment usually represents a small share of the LCOE for liquid fossil fuel generators, these generating facilities are flexible. Furthermore, synchronous generators, if properly designed and controlled, can contribute to enhancing voltage and frequency stability. They are much more critical for RES-based islands' energy systems for three reasons: (i) because, for non-interconnected (or weakly connected) islands, there is no (or limited) possibility to share capacity with neighbours to balance the system[12]; (ii) because RES are inherently variable and the system has to manage that variability; (iii) because inverter-based generation has typically a weaker contribution to voltage [10] [11] and frequency stability. Note however that inverters can be oversized to improve their contribution to voltage stability, and that synthetic inertia could improve their contribution to frequency stability.

[12] This factor is obviously not-relevant for fully connected islands, and interconnectors could be developed between energy islands to make profit of the complementarity of RES generation patterns between different geographical regions.

Limited space

The next identified issue is (lack of) space, especially on small islands. The criticality of this issue is limited for fossil-fuel-based energy systems and wind offshore but could be stringent for onshore RES-based energy systems because PV plants require substantial space.

Environmental aspects

Finally, environmental aspects are critical for both fossil-fuel-based energy systems and RES-based energy systems. On one hand, conventional energy technologies are a source of emissions to air and waste, and emission standards of small units are usually bigger than those of large units. On the other hand, building a truly RES-based energy system also requires special attention to habitats of fauna and flora, nature protection areas as well as landscape protection. It is particularly valid for larger scale applications (e.g. hydro, pump-storage for flexibility, utility scale RES power plants, grids development). The potential environmental impact coupled to the visual impact of large-scale RES (e.g. offshore wind) can lead to social acceptance issues.

3.2 Review of past and ongoing European R&I projects

A number of past and ongoing European R&I projects address the challenges listed in the previous section, as described in the following subsections. Note that the reviewed projects mainly focus on the integration of solar and wind energy, but other RES can be relevant to islands as well (e.g. geothermal, ocean/wave energy).

3.2.1 Past EC-funded R&I projects under FP7 program

Under the 7th Framework Programme for Research and Technological Development (FP7) funded by the European Commission, two main projects dealt with islands: Twenties (2010-2013) and EcoGrid (2011-2015). Furthermore, even if the FP7 Grid4EU project (2011-2016) did not deal directly with physical islands, experience gained in that project is also relevant for energy islands. A detailed analysis of these projects is presented in Annex 5.

In a nutshell, islands demonstrators of Twenties and EcoGrid projects focused on ensuring the load/generation balance through DR and active control of DERs, while Grid4EU considered also the use of storage for that purpose. Table 6 summarizes the main takeaways of each project. In all of them, it was concluded that proper incentives must be deployed to ensure the participation of customers in DR programs. Furthermore, the Twenties and the EcoGrid projects revealed that adequate regulatory and market frameworks are needed for a large-scale implementation of DR. Grid4EU emphasized, as well, the importance of dealing with stochasticity of RES, demand and flexibility sources (e.g. RES are not perfectly forecastable and crucial apparatus such as storage units can fail).

Table 6: Summary table of past EC-funded R&D projects

Project	Islands concerned	Main takeaways
Twenties	Faroe Islands (Denmark)	• A VPP controlling in an integrated way DERs and DR can significantly improve the security of systems with a large share of RES • Challenging to obtain the commitment of industrial stakeholders • Regulatory and market barriers exist for the implementation of such VPPs
EcoGrid	Bornholm (Denmark)	• Large-scale deployment of DR relies on technology standardization, plug-and-play functionalities and user friendliness • Financial incentives and an emphasis on environmental benefits are needed to gain the commitment of the population • Adequate market models are needed to allow DR
Grid4EU	Examination of general principles	• Economic incentives and an emphasis on environmental benefits are needed to gain the adhesion of the population • Forecasts are imperfect • Energy storage systems are not perfectly reliable

3.2.2 Ongoing EC-funded R&I projects under H2020 program

Under the Horizon 2020 (H2020) programme funded by the European Commission, eleven main projects are dealing with islands: NETfficient (2015-2018), TILOS (2015-2019), GRIDSOL (2016-2019), Storage4Grid (2016-2019), WiseGRID (2016-2020), InterFlex (2017-2019), INVADE (2017-2019), inteGRIDy (2017-2020), and SMILE (2017-2021). A detailed analysis of these projects is presented in Appendix 5.

In a nutshell, ongoing projects are not anymore limited to the use of DR, storage and control of DERs to balance the power system but are also studying the coupling of different energy systems for that purpose. Furthermore, a larger emphasis is put on environmental impacts and population engagement. Table 7 summarizes the key points studied by each project.

Table 7: Summary table of key past and ongoing EC-funded R&D projects

Project	Islands concerned	Key points under study
Twenties	Faroe Islands (Denmark)	• A virtual power plant (VPP) controlling in an integrated way Distributed Energy Resources (DERs) and demand Response (DR) can significantly improve the security of systems with a large share of Renewable Energy Sources (RES) • Challenging to obtain the commitment of industrial stakeholders • Regulatory and market barriers exist for the implementation of such VPPs
EcoGrid	Bornholm (Denmark)	• Large-scale deployment of DR relies on technology standardization, plug-and-play functionalities and user friendliness • Financial incentives and an emphasis on environmental benefits are needed to gain the commitment of the population • Adequate market models are needed to allow DR
Grid4EU	Examination of general principles	• Economic incentives and an emphasis on environmental benefits are needed to gain the adhesion of the population in DR • Renewable generation forecasts are of paramount importance to plan flexibility activation and storage use, but real-time adjustments are necessary to correct and update the planned schedule because forecast errors do exist; • Energy storage systems are not perfectly reliable (availability of approximately 90% in that case), which means that the system operation needs a backup solution in case of unavailability of a storage system.
NETfficient	Borkum (Germany)	• Use of battery storage, distributed energy sources and DR (thermal storage) to ensure the load/generation balance and the provision of frequency support • Conclusions not yet available due to early phase of the project
TILOS	Tilos (Greece)	• Use of storage and active network management to maximize the use of RES in covering the electricity needs
GRIDSOL	Examination of general principles	• Combination of CSP, biogas combined cycle generators and PV to provide self-regulating flexible generation and ancillary services
Storage4Grid	Island of Fur (Denmark)	• Integration and operation of distributed energy storage systems
WiseGRID	Kythnos (Greece)	• Coupling of the power system with the mobility sector (e.g. e-mobility, electric transport systems, V2G) to provide services to the grid, such as storage capacity • Coupling of the power system with heating systems to benefit from the flexibility of thermal storage
InterFlex	Examination of general principles	• Study of the interactions between energy storage systems, smart charging of EVs, DR, islanding, grid automation and the integration of different energy carriers
INVADE	Examination of general principles	• Stronger coupling of the power system with the mobility sector (EV, e-bikes) and with the heating sector (electrically heated water boiler) • Integration of battery storage systems
inteGRIDy	Isle of Wight (UK)	• Balancing the network through the interaction with EVs and DR
SMILE	Orkney (UK), Samsø (Denmark), Madeira (Portugal)	• Implementation of solutions for DR, intelligent control and automation of distribution networks • Conclusions not yet available due to early phase of the project

3.2.3 Other National R&I projects of interest

Other recent and ongoing projects on energy islands with strong R&I components, outside FP7 and H2020 programs, are also of interest. Without being exhaustive, it is particularly the case of the STORE project (2013-2016), of the LA GRACIOSA project (2015-2018) and of Green+ (2018-2020).

The STORE project aimed at demonstrating the technical feasibility of large-scale energy storage systems based on different technologies in the Canary Islands to provide ancillary services: electrochemical storage by Li-ion batteries in La Aldea de San Nicolas (Gran Canaria), flywheel in Playa Santiago (La Gomera) and ultra-capacitors in CD Los Guinchos (La Palma) [12]. The overall budget was €11,5 million and it was supported by Spain's Ministry of the Economy and Competitiveness and the European Union. It was carried out by a consortium led by Endesa. The Gran Canaria project involved the integration of 1 MW/3 MWh Li-ion batteries. It demonstrated the capability of the Li-ion batteries to perform peak shaving, to support the voltage in case of disturbances and to participate in primary and secondary regulation. It also showed that the average efficiency was around 75% (including standby periods) and that the consumption of auxiliary equipment is a significant cause of power losses. The La Gomera project involved the integration of a 0.5 MW/18 MWs flywheel. It demonstrated the capability of the flywheel system to improve the frequency quality and to help in the regulation of the frequency very quickly after a sudden power imbalance. It also showed that control integration was a critical issue to avoid resonance effects. The La Palma project involved the integration of 4 MW/20 MWs ultra-capacitors. It demonstrated the capability of ultra-capacitors to contribute to the system reserve (i.e. to provide active power after generation losses), with a rapid response (approximately 100 ms). It also showed that the aggressive environmental conditions usually present in islands must be considered in the design to avoid corrosion.

The LA GRACIOSA project aims at developing in the La Graciosa Island a micro-grid that will integrate PV distributed generation with batteries and ultra-capacitors that will help to manage that fluctuating energy. La Graciosa is a small island of the Canary Islands of 27 km² and about 700 inhabitants. Its energy supply depends on that cable that links it to Lanzarote. The project is currently ongoing and there are not yet published conclusions.

The Green+ project aims at upgrading the distribution networks of the mountainous areas of Nicosia and Limassol districts in Cyprus with smart technologies to integrate in a better way distributed RES generation [13] [14]. In particular, energy storage systems based on different technologies (flywheel, battery, fuel cell) will be installed, smart meters will be massively deployed and active demand load management will be adopted to shave peak demand. In that case, the final investment decision is not taken yet and is dues on June 30, 2018. The overall investment cost is estimated at €41 million. The expected operation period is 2020-2025.

3.3 Analysis and remaining challenges

Past and ongoing projects are addressing the major challenge of RES-based energy systems: their reliability. To address the two fundamental aspects of reliability, adequacy and security, the first R&I projects made use of DR and of improved control of RES generators. Quickly after 2010, energy storage systems have also been considered as an unavoidable part of the solution, especially because an impressive drop in the costs of batteries was observed. While keeping DR, the control of RES generators and energy storage, ongoing R&I projects are also strongly focusing on possible synergies between different energy systems, in particular between power systems, mobility systems, and heating systems. Batteries within EVs could provide ancillary services to the grid. Thermal storage could also provide flexibility at a lower cost. Note that interactions between the energy systems and the water system could also provide flexibility (e.g. RES-based desalination, energy storage using water reservoirs located at different altitudes), even if they were not explicitly analysed in the reviewed projects.

However, one specific aspect inherent to the energy transition seems to have been largely left out of R&I projects: the uncertainty related to the actual generation of variable RES sources such as wind and PV. Indeed, although forecasting techniques are improving, forecast errors do exist. Flexibility sources (e.g. storage) shift energy in time and forecast errors must thus be considered in their management. Consequently, cost-efficient management techniques of flexibility sources might have to rely on dedicated stochastic optimization techniques. Because a part of flexibility sources is distributed, a central optimization might not be relevant: distributed but coordinated management of these sources might be required. Even if past and ongoing projects are studying the coordination of different flexibility sources, they focus more on the demonstration of the technical possibilities and the added value of their joint integration. The optimal system planning and operation to minimize the global cost of energy to the society while maximizing the penetration of RES have not been part of the major points under study, up to now. Research works on these questions do exist, but they remain mainly academic, without real demonstrators.

Another challenge addressed only in a limited way by previous R&I projects is the dynamic management of power systems dominated by inverters (e.g. PV generators, batteries). Indeed, inverter-based generation could entail dynamic stability issues, selectivity problems for protection systems and could degrade the power quality if the system is not properly planned [11]. Furthermore, the technical capabilities of inverters allow fast reactions to disturbances, but the controls need to be coordinated to keep the system stable. The H2020 MIGRATE project is addressing these challenges but is more focused on transmission systems. Achieving 100%-RES based energy systems in energy islands will require dedicated solutions building on the current technical capabilities of inverters for these specific systems as well.

4 POLICY ACTIONS FOR ISLANDS

The relative isolation and small size of islands leads to special challenges regarding their energy supply. This is reflected e.g. in a high (import) dependency on fossil fuels and high energy costs. Besides technical challenges that result out of this, which are discussed in the previous chapter, the situation of islands requires specific political action and tailor-made regulatory approaches, too. These challenges are (partially) addressed locally. However, not all political challenges related to the energy supply of islands can be solved on a local level. From the 1990's onward, policy initiatives formed throughout Europe to address and improve the situation of insular energy systems and related economic and environmental issues.

Below, existing policy initiatives regarding islands and their energy systems are reviewed and topics for further policy action are investigated. For that purpose, section 4.1 reviews existing policy initiatives related to islands. Section 4.2 complements with a review of relevant local initiatives. An analysis of these policy initiatives and recommendations for further actions conclude the chapter in section 4.3.

4.1 Review of policy initiatives related to European islands

Several European initiatives deal with islands and the themes of energy and decarbonisation. Besides initiatives specifically directed at islands energy systems that are presented in section 4.1.1, there are additional programmes and initiatives relevant to islands. These are dealt with in sections 4.1.2 and 4.1.3.

4.1.1 Initiatives solely directed at islands

European island initiatives regarding the topics of energy and decarbonisation emerged in the 1990's.

As a first network of island authorities promoting sustainable energy and environmental management, ***ISLENET – the European Islands Energy and Environment Network*** was founded by the Islands Commission of the CPMR (Conference of Peripheral and Maritime Regions)[13] in 1993 and comprises the Western Isles, Shetland, Orkney, Madeira, Azores and the Canary Islands. The initiative actively promotes the adoption of local energy saving strategies and renewable energy projects. It aims to facilitate the transfer of information on energy issues, generation techniques and initiatives, with a view to islands becoming less dependent on imported fuels. In the process, the following six long-term goals for a proposed Energy and Environment Charter for European Islands have been identified:

- A greater local control of energy and the environment in islands;
- A greater role for islands in a more rational management of energy;
- The development of indigenous resources in islands;
- The development of an island strategy for energy and the environment;
- Progress towards a European energy and environment policy for the islands;
- Provision of safeguards for island economies. [15]

[13] The Islands Commission is one of the 6 Geographical Commissions of the Conference of Peripheral Maritime Regions of Europe and covers twenty-three European regional island authorities from 11 countries located in the Mediterranean, North Sea, Baltic Sea and the Atlantic, Indian and Pacific Oceans.

Following the Islenet initiative, the **Pact of Islands**, started as a consortium of 12 European islands[14] in 2009. The initiative adopted by the European Parliament embraces European island authorities committed to take concerted action in line with the EU 2020 energy targets through the support and promotion of renewable energy, energy efficiency and sustainable transport projects at local level. It runs parallel to the Covenant of Mayors[15] and encourages island authorities to make a number of significant commitments regarding energy and climate objectives outlined in a so-called Island Sustainable Energy Action Plan (ISEAP). Up to today, 64 insular communities have signed the pact and 56 Islands Sustainable Energy Action Plans have been submitted. The submitted plans lead to a decrease of CO_2 emissions by 25% and result in annual reductions of 18 Mio t CO_2. In addition, multiple other benefits such as new (local) jobs and the improvement of environmental and economic conditions are achieved. [16]

Building upon the momentum of the Pact of islands, the Smilegov - Multilevel Governance project was initiated in 2013. It aims at enhancing effective implementation of sustainable energy action plans in European islands through reinforcement of smart multilevel governance, thereby adding a new dimension to existing policy actions: the different levels of governance and their interaction.

The project was built on the idea that cooperation between different levels of governance of islands (i.e. National, regional, local) can have a key role to play towards reaching the 20-20-20 EU goals in the area of energy and climate change. At its core, Smilegov aimed at

- Examining the challenges and the barriers (institutional, legal and regulatory) of multilevel governance facing European island communities in their efforts to promote and implement sustainable energy actions and bankable projects;
- Providing training and online support to island authorities with the view to developing expertise in planning and implementing ISEAPs and Bankable Projects;
- Maturing 50 bankable sustainable projects in the island regions, by taking significant steps towards their implementation;
- Widening the family of Pact of Islands by inviting more signatories and supporting them in the ISEAP development process;
- Facilitating the market penetration of innovative sustainable technologies through the strengthening of co-operation among European islands.

As a result of the Smilegov project, 40 new islands joined the Pact of Islands, 15 new ISEAPs have been developed and 12 sustainable energy projects emerged. [17] In addition, the following lessons learnt were derived from good practice examples:

- **Strong political stimulation and follow-up is needed for large scale innovative energy infrastructure projects**: Regular meetings at different regional administrative levels (Cabildo, Regional Government of the Canaries, National Government) favoured administrative procedures. This kind of project is not included in any regulation, as it is an innovative initiative integrating different technologies.
- **Important stakeholders should get involved the maximum degree.**
- **Feeling of ownership**: Involving the local community and all stakeholders is important in general and this specific project can only be realised by people themselves supported

[14] The consortium was led by Comhairle nan Eilean Siar (CnES – the regional authority of the Outer Hebrides of Scotland) and included partners from Gotland – Sweden, Samsø – Denmark, Azores and Madeira – Portugal, Canary Islands and Balearics – Spain, Sardinia – Italy, Malta, the Greek Islands of the Aegean, Crete and Cyprus.

[15] This has been recognized by the European Parliament in its Declaration 37/2011.

by the municipality. Furthermore, the participation of external partners has improved the process.
- Aiming to early social awareness can assist the realisation of the project.
- Approach large scale infrastructure projects through integrated master plans.
- Master plans should reach down to local level to be successful.
- Economy of scale in meetings: By grouping municipalities and coordinating them by the regional structures a total funding was easier to be reassured and used in a more effective way in terms of economy of scale.
- Local specialists have more interest about projects affecting their lives.

Another initiative related to islands is the European Economic and Social Committee's (EESC) "**Smart Islands**" project based on the EESC TEN section's own-initiative opinion TEN/558. It aims to engage and exchange with local stakeholders on innovative projects developed by island communities to identify best practices, which could suggest similar or adapted solutions for other island communities in the EU. The final project report presents best practices and recommendations in the areas of ICT, tourism, transport, energy and environment as well as smart solutions in governance and social innovation, referring among other things to the Smilegov project. [18]

In contrast to R&I projects related to islands, which tend to address individual and specific technology topics, see Chapter 3, European policy initiatives for the energy transition of islands seem to build upon the topics of earlier initiatives to develop them further. In that sense, policy action for energy systems of islands can be seen as a continuous evolution, addressing political challenges for islands and their energy transitions from different angles and with an evolving focus.

In that sense, the **Smart Islands Initiative**, initiated in 2016, is building upon past initiatives and years of collaboration between EU islands. It is a bottom-up effort of island authorities and communities that seeks to convey the significant potential of islands to further function as laboratories for technological, social, environmental, economic and political innovation. The Smart Islands Initiative calls for an **integrated approach to the management of natural resources and infrastructures**. Drawing inspiration from the Smart Cities concept, the Initiative goes one step further by extending the synergies beyond energy, transport and ICT to also include water and waste, directly addressing circularity in the economy. [19]

The cornerstone document of the Smart Islands Initiative is its Declaration, summarising the above-mentioned topics in 10 steps through which the signatories plan to become smart, inclusive and thriving societies. The declaration was signed 36 island representatives in March 2017 in a ceremony launched by EU Director-General for Energy Dominique Ristori.

As most recent development, in May 2017 the European Commission together with 14 EU countries [20] has signed a political declaration to launch the **'Clean Energy for EU Islands' initiative**. Aimed at accelerating the clean energy transition on Europe's islands, this initiative will help islands reduce their dependency on energy imports by making better use of their own renewable energy sources and embracing more modern and innovative energy systems. The initiative is aimed at comparing notes on common problems that different islands face, building on best practices and experience from pilot projects. Part of the scheme is also aimed at making it easier to access new energy technologies and sources of funding. The initiative will create a forum for all those with an interest in the clean energy transition on EU islands to share best practice and support the creation of a long-term framework to promote funding and technical assistance. [21]

4.1.2 EU funding for the decarbonisation of islands

In addition to Horizon 2020, see Chapter 3, other EU funding that can contribute to decarbonisation of islands includes the five **European structural and investment funds (ESIF)**, presented in the following:

The **European Regional Development Fund (ERDF)** aims to strengthen economic, social and territorial cohesion in the European Union by correcting imbalances between its regions. The ERDF focuses its investments on several key priority areas. This is known as 'thematic concentration': Innovation and research, the digital agenda and support for Small and Medium-sized Enterprises (SMEs); The low-carbon economy [22]. Its Operational Programmes address specific regions and topics and establish the main guidelines by the ERDF. All European islands are covered by at least one national or regional programme [23]. An example is the support for Crete, in which sustainable development with environmental upgrade and climate change adaptations is one of the key priorities.

Under the European Territorial Cooperation programmes, which provide a framework for the implementation of joint actions and policy exchanges between national, regional and local actors from different Member States, including islands, at least 80% of funds are concentrated on the four priority areas mentioned above, including the low-carbon economy [24].

European social fund (ESF) supports employment-related projects throughout Europe and invests in Europe's human capital – its workers, its young people and all those seeking a job [25].

The **Cohesion Fund (CF)** aims to reduce economic and social disparities and to promote sustainable development. It is aimed at Member States whose Gross National Income (GNI) per inhabitant is less than 90% of the EU average. The Cohesion Fund supports projects related to energy or transport, as long as they clearly benefit the environment in terms of energy efficiency, use of renewable energy, developing rail transport, supporting intermodality, strengthening public transport, etc. [26].

European agricultural fund for rural development (EAFRD) – focuses on resolving particular challenges of EU's rural areas [27].

European maritime and fisheries fund (EMFF) helps fishermen to adopt sustainable fishing practices and coastal communities to diversify their economies, improving quality of life along European coasts [28].

4.1.3 Other coordinating initiatives of relevance

The **Covenant of Mayors** is an initiative launched by the European Commission in 2008 with the objective of engaging and supporting mayors to commit to reaching the EU climate and energy targets. It brings together local and regional authorities voluntarily committing to implementing the EU's climate and energy objectives on their territory. This unique bottom-up movement, which started in 2008 with the support of the European Commission, now counts over 6,500 signatories*. In 2015, the initiative took on new objectives: the Covenant of Mayors for Climate and Energy steps up the initial CO_2-reduction commitment and includes adaptation to climate change. Signatory local authorities share a vision for making cities decarbonised and resilient, where citizens have access to secure, sustainable and affordable energy. By now a global initiative, it gathers 7,000+ local and regional authorities across 57 countries drawing on the strengths of a worldwide multi-stakeholder movement and the technical and methodological support offered by dedicated offices. [29]

Other initiatives of relevance are the partnership for **Smart Cities and Communities**, which aims to come up with innovative solutions to the major environmental, societal and health challenges facing European cities today [30], as well as the **EU Strategy for the Adriatic and Ionian Region** and the **EU Strategy for the Baltic Sea Region**.

These initiatives can be used as a good practice example for federating European islands.

4.2 Review of local initiatives for islands

Another important and highly relevant way of cooperation are local initiatives.

Regarding islands, the most prominent local initiative is the **European Small Islands Federation (ESIN)**. Founded in 2001 as a non-political federation of associations for small islands and archipelagos in Europe. ESIN represents its members on issues of mutual importance before the European Union parliament and institutions and is also a forum for comparison of experience between the members. ESIN has at present (2016) 11 members representing small islands of Croatia, Denmark, Estonia, Finland, France, Greece, Ireland, Italy, Ireland, Scotland, Sweden and Åland. The initiative is the voice of 359,357 islanders on 1,640 small islands.

ESIN acts at two levels:

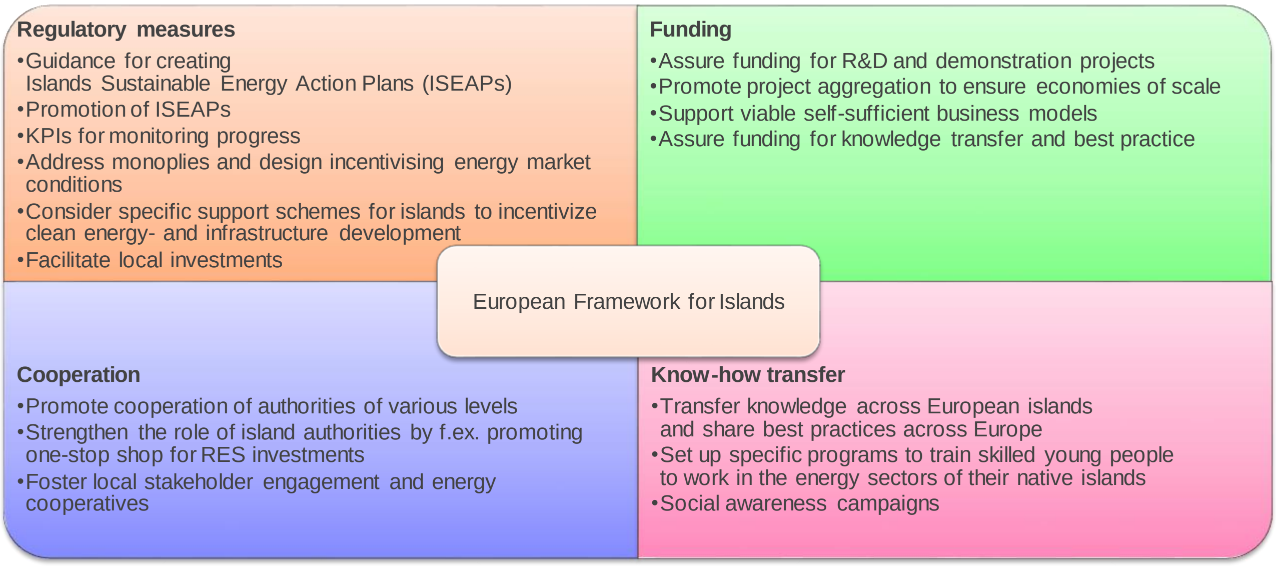
- Local level: strengthening islands cultural identity, facilitating the circulation of information between its members, allowing comparison on how different countries cope with issues, sharing knowledge.
- European level: informing relevant EU institutions, influencing EU policies and rules by increasing their awareness and understanding of small islands.

4.3 Analysis and remaining policy challenges

This section analyses established policy initiatives presented in Chapters 4.1 and 4.2 to draw conclusions and identify specific points that should be addressed when designing further policy initiatives aimed at federating islands around the theme of energy and decarbonisation.

To successfully foster the **cooperation** of islands regarding energy and decarbonisation, there needs to be an overlap of shared challenges and opportunities among islands, as cooperation is especially successful when it has positive outcomes for all. The five key policy areas in which islands share common challenges regarding their energy system and decarbonisation efforts are 1) policy, 2) regulation, 3) funding), 4) cooperation and stakeholder engagement 5) knowledge/best practise exchange. All five areas have been addressed by existing initiatives. However, there is a need for further structured political action for European islands to foster the successful energy transition of European islands. Concrete recommendations for further actions derived from the review of existing initiatives and the analysis of potential needs presented below.

Figure 11: Action needed for a policy framework for EU islands



The following measures may support realisation of the fast-track energy transition in islands:

- **Policy: European Framework for Islands**
  - **Continued further coordinated EU action** is needed for islands to facilitate their energy transition; this action may be a practical strategy and action plan, supporting the Malta Declaration: ***Create a European framework for islands*** with **ambitious targets**, aimed at achieving zero-carbon energy systems faster than on mainland (e.g. by 2030); the policy should facilitate innovative energy investments in islands and assure continuity.
  - The EU policy should be followed by **practical action plan** supporting the Malta Declaration and the Clean Energy Package, covering all key areas of possible EU intervention; this action plan should allow for incentivizing investments in islands and assure continuity of action.
  - The EU strategy and action plan should be supported by **policy measures** at the EU, national, regional and local level to assure cost-effective decarbonization of energy islands. This strategy should include supporting measures such as target setting, guidance, increased cooperation between various authorities, dedicated targeted funding.
  - ***Use islands*** not only for technological pilot programs, but also ***as laboratories for innovative regulatory approaches***: Due to their small size and isolation, it is more challenging and expensive for islands to balance their electricity supply and demand. Island constellations allow the testing of new innovative regulatory approaches which may serve a blueprint for the whole of Europe at a later stage.
- **Regulatory measures**
  - **Islands Sustainable Energy Action Plans** (ISEAP) should be developed, depending on their size, seasonality, level of current and planned interconnection, RES potential and penetration, in cooperation with local and national authorities.
  - These **ISEAPS** should be built on, on an integrated approach, including:
    - ➢ Maximalization of local RES resource use;
    - ➢ Level and cost of potential interconnection;
    - ➢ Energy efficiency measures;

- Consideration for environmental aspects such as nature protection areas, NATURA 2000, national parks and others;
- Impact on jobs and local economy;
- Coordinated approach to infrastructure development;
- Adaptation to climate change.

- ISEAPs should be in line with European and national energy targets and the integrated approach under the Energy Union Governance.
  Existing plans need to be reviewed and adapted. Not only regarding the time horizon (2020 to 2030), but also regarding underlying assumptions: costs for clean energy technologies, such as wind and solar power or battery storage have decreased significantly and beyond expectations in recent years. This might change the outcome of certain assessments and investment decisions. While the building of a new interconnection to an island in combination with increased electrification of heating and transport might not have been economic some years ago, this may well have changed by now. Sustainable Energy Action Plans for Islands should also include spatial planning and social acceptance considerations.
- Develop **KPIs for islands** to monitor progress of action plans for islands.
- **Energy market regulations** to fight monopolies as well as designing energy markets to incentivise investments in islands and incentivise island communities to actively participate in energy markets as prosumers, energy communities or demand side response.

- **Funding**: to enable progressive energy transitions of islands, adequate funding of the envisaged actions needs to be available. In addition, a joint European approach can bring down costs significantly, e.g. through a WAAC equalizer.
  - Assure funding for R&D and demonstration projects for islands, especially in:
    - Optimal energy planning for adequacy and security of supplies;
    - Dynamic management of small power systems with a high penetration of inverter- based technologies;
    - High coordinated management of distributed flexible sources.
  - **Project aggregation** to ensure economies of scale and cost reduction and **microloans facilities** for micro-scale generation regional system peer-management, benchmarking energy costs based on island specificities, and securing ad hoc access to essential technical and regulatory expertise.
  - ***Ensure well-tailored support schemes for islands to incentivize*** clean energy- and infrastructure developments technologies. Exemplary concrete action:
    - An island- bonus/premium within existing and planned support schemes where appropriate;
    - Soft loans for infrastructure development in islands.
  - **Facilitating local investments** and energy communities to increase the feeling of ownership among islands inhabitants.
    Assure **funding for knowledge transfer and best practice exchange** and capacity building awareness raising.
  - **Cooperation and stakeholder engagement**
    - Promote **cooperation between authorities** of various levels (national, regional, local) to eliminate non-cost barriers for sustainable energy systems in islands and facilitate coordinated infrastructure development programs.
      - Recognize and **strengthen the role of island authorities** by f.ex. promoting a one-stop shop for RES investments in islands;

    - Further **foster local stakeholder engagement to ensure (the feeling of) ownership** as this is key for a successful insular development.
- **Know-how transfer, communication and best- practises:**
    - **Transfer knowledge** across European islands and share best practices.
  - Specific programs to **train skilled young people** to work in the energy sectors of their native islands and contribute to the growth of their economies. The TILOS Horizon 2020 Project presented in this report shows one approach to the transfer of technological experience through an islands skills and information exchange platform.
  - **Social awareness campaigns**
  - **Promotion of the most successful demonstrators** across Europe.

5 CONCLUSIONS AND RECOMMENDATIONS

This study focused on European islands with the aim to understand the island energy landscape, define basic principles of an energy-environment-economy strategy and to assess the added value of carrying out specific policies as well as research and innovation (R&I) actions – both dedicated specifically to islands.

Key conclusions and recommendations are summarised below:

1. **Understanding islands requires close cooperation with islands authorities to receive all data and analyse the full power systems and their needs.**

- This report provides an overview of 447 islands that are either electrically non-connected to the mainland, or if an interconnection exists this is of limited capacity as these are the ones of practical significance for the purposes of an energy-focus study and future strategy. The analysis needs to be done for the remaining inhabited EU islands.
- We recommend creation of the complete list of European islands subject to a specific policy support in the area of energy policy, based on the clear definition of islands, containing clearly defined basic parameters, such as the number of permanent inhabitants (e.g. minimum 20) and the geographical conditions (e.g. no fixed natural connection to the mainland).
- We focused on understanding the power systems in analysed islands. It was only partly possible due to limited availability of data. Also, it is recommended to analyse the heat- and transportation patterns in the islands.
- Overall, the collection of island data has proven to be a most challenging exercise as data in general were difficult to find or fragmented, several sources had to be used and on many occasions information, if available, was only in national language. Therefore, for example, we could not estimate the overall energy share of islands in the Europe. We suggest that the issue of transparency and data availability is further pursued with local and regional agencies. The development of a standard template[16] with a regular reporting, also available in English should be initiated.
- There is a need for a more detailed understanding of RES potentials in islands with consideration for flexibility needs, infrastructure development as well as environmental – and economic effects of maximising the RES use in islands.

  Within this study we have proposed a categorisation methodology for islands. The complete categorisation can be done after the full mapping of islands and their complete energy needs takes place.
- The study revealed that the cost of electricity generation (fuel cost) on some islands analysed during the study is by factors of 2 to 10 higher than the cost on the mainland. This proves the need for a dedicated regulatory framework for islands to stimulate cost effective policy measures, aimed at use of local resources and eliminating energy poverty.

2. **There has been a series of large R&D projects dedicated for island solutions in the last decade, however, next steps are needed to evolve from R&D/demonstration projects to "business as usual" replicable and deployable approaches**

[16] For transparency templates, please refer indicatively to the "Transparency Templates" published by all gas Transmission System Operators in the context of their obligations under Regulation 715/2009. Of course, the data for the case of islands will be very different, nevertheless the publication of a standardised form could be requested upon the island system operators.

- We have identified 12 large R&D projects that have been either dedicated to islands or used islands for demonstration cases. These existing R&I projects are addressing the main challenge of reliability.
- The analysed projects prove that not only technology solutions are needed (demand response, vertical power plants, improved control of RES, storage, sector coupling) but additional markets measures are required to incentivise the population for active demand response and RES investments.
- In the area of further specific R&D support, focus should be put on:
    - Enabling decarbonisation by further fostering the integration of variable renewables;
    - Optimal energy planning for assuring security and generation adequacy;
    - Dynamic management of small power systems with a high penetration of inverter-based technologies;
    - High coordinated management of distributed flexible sources.
- During the analysis, we have focused on R&D projects. We recommend analysing the work on islands realised under the INTERREG umbrella.

3. Well-designed further coordinated policy action will facilitate creation of the fast track for islands decarbonisation

- We have identified several islands initiatives, aimed at supporting sustainable energy supplies to islands. These initiatives are further supported EU funding via the structural and R&D funds.
- However, a further continued coordinated policy action for islands is needed to put islands on a fast track for decarbonisation. The policy action should cover five key areas: policy framework; regulatory measures; funding; cooperation and stakeholder engagement; Know-low transfer, communication and best- practise sharing. The implementation of a number of concerted, mutually supportive, measures regarding these areas should be considered, examples of measures include:
    - **Policy - European Framework for Islands**
        - Coordinated EU action with ambitious targets, aimed at achieving zero-carbon energy systems faster than on mainland (e.g. by 2030).
        - Practical action plan supporting the Malta Declaration and the Clean Energy Package, covering all key areas of possible EU intervention (regulatory, funding, know-how transfer and communication); this action plan should allow for incentivizing investments in islands and assure continuity of action.
        - Use islands as laboratories for innovative regulatory/funding approaches: island constellations allow the testing of new innovative regulatory approaches which may serve a blueprint for energy investments the whole of Europe at a later stage.
    - **Regulatory measures**
        - A blueprint/guidance for creating Islands Sustainable Energy Action Plans (ISEAP), depending on their size, seasonality, level of current and planned interconnection, RES potential and penetration.
        - Creation or review of Island Sustainable Energy Action Plans (ISEAP) for each European island that are in line with European and national energy targets and the integrated approach under the Energy Union Governance.
        - Develop KPIs for islands to monitor progress of action plans for islands.
        - Energy market regulations to fight monopolies as well as designing energy markets to incentivise investments in islands and incentivise island communities to actively participate in energy markets as prosumers, energy communities or demand side response.

- **Funding**
  - Dedicate funding for R&D and demonstration projects for islands.
  - Ensure well-tailored support schemes for islands to incentivize clean energy- and infrastructure developments technologies.
  - Project aggregation to ensure economies of scale and cost reduction and microloans facilities for micro-scale generation regional system peer-management, benchmarking energy costs based on island specificities, and securing ad hoc access to essential technical and regulatory expertise.
  - Foresee funding for knowledge transfer and best practice exchange and capacity building and awareness raising.
  - Facilitating local investments and energy communities to increase the feeling of ownership among islands inhabitants.
- **Cooperation and stakeholder engagement**
  - Promote cooperation of authorities of various levels (national, regional, local) to eliminate non-cost barriers for sustainable energy systems in islands and facilitate coordinated infrastructure development programs.
  - Recognize and strengthen the role of island authorities by e.g. promoting one-stop shop for RES investments on islands.
  - Further foster local stakeholder engagement to ensure ownership as this is key for a successful insular development.
- **Know-low transfer, communication and best- practise sharing**
  - Transfer knowledge across European islands and share best practices.
  - Specific programs to train skilled young people to work in the energy sectors of their native islands and contribute to the growth of their economies. The TILOS Horizon 2020 Project presented in this report shows one approach to the transfer of technological experience through an islands skills and information exchange platform.
  - Social awareness campaigns.
  - Promotion of the most successful demonstrators across Europe.

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7 APPENDIX

7.1 Annex 1: Basic information on islands

This annex presents further energy related indicators such as the capacity installed per type of technology and fuel, levels of generated electricity (distinguished between thermal and RES), current and future planned interconnections with mainland or other islands, related costs if available and RES potentials of the islands mapped in section 2.2.5.

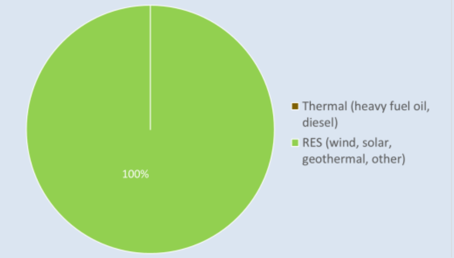
Data was sourced from IRENA, the World Bank, EUROSTAT, national energy agencies and other sources. In total, 160 islands have been analysed representing a population of 12 million, three quarters of which reside in the Mediterranean.

7.1.1 Åland Islands (Finland)

The Åland Islands are an autonomous Finnish province, an archipelago consisting of 6,700 separate islands. Only about 60 are inhabited.

Figure 12: The Åland Islands

Table 8: Info sheet- Åland Islands

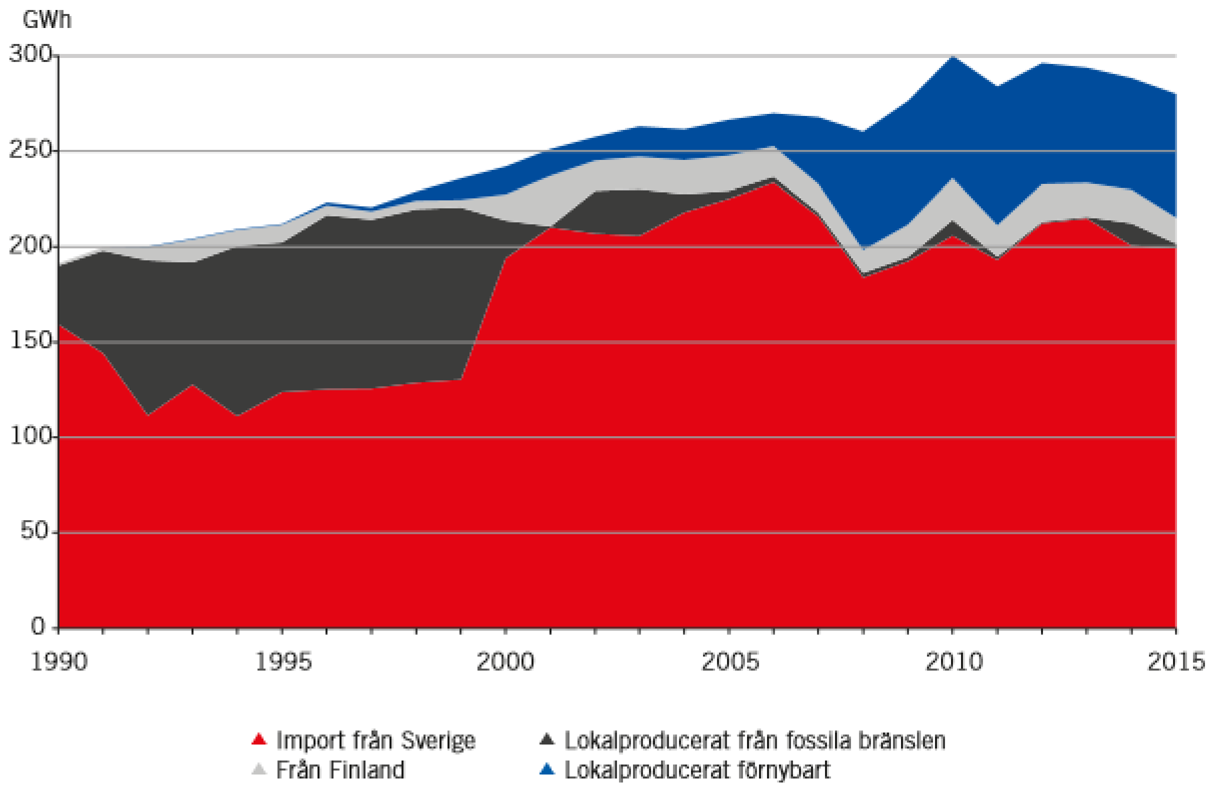
Population (2016)	28,983
Area (km²)	1,580
GDP (m. €) (2015)	1,346
Distance from mainland (km)	70 [from mainland Sweden]
Seasonality in electricity demand	NA
Interconnection (with mainland) **Interconnection (with other islands)**	Yes Yes
Operator	Kraftnät Åland (TSO)
Local electricity production (GWh, 2016)	76 (25%)
Local energy mix (%)	
Imported electricity from mainland (GWh, 2016)	230.2 (75%)

Local Electricity Production and Imports

The local Transmission System Operator Kraftnät Åland Ab, owned by the Åland Government, is responsible for the transmission of electric energy in the Åland Islands. Kraftnät Åland, owns and operates some 300 km of transmission line and 18 substations.

Electricity demand in Åland in 2016 reached 306.2 GWh in 2016 (an increase of by 6.5% compared to 2015 levels). Demand was met by 230.2 GWh imported from neighbouring countries (75.2% from Sweden, i.e. about 225 GWh) and 25% local production (almost entirely wind energy).

Figure 13: Energy production including imports (GWh), 1990- 2015, Source: Kraftnat



Import från Sverige= Imports from Sweden, från Finland= from Finland.

Lokalproducerat från fossila bränslen= fossil fuels local production, Lokalproducerat förnybart= RES local production.

The Åland Islands are connected to Finland via a 100 MW cable (110 kV) set in operation in 2016. The islands were already interconnected to Sweden via a 60 MW cable (110 kV).

The 2016 connection with Finland will help secure the electricity supply in Åland, and will be also used as a new route between Finland and Sweden to help stabilise the Nordic electricity market. It will further support wind energy deployment on the islands.

Figure 14: Interconnection to Sweden and Finland

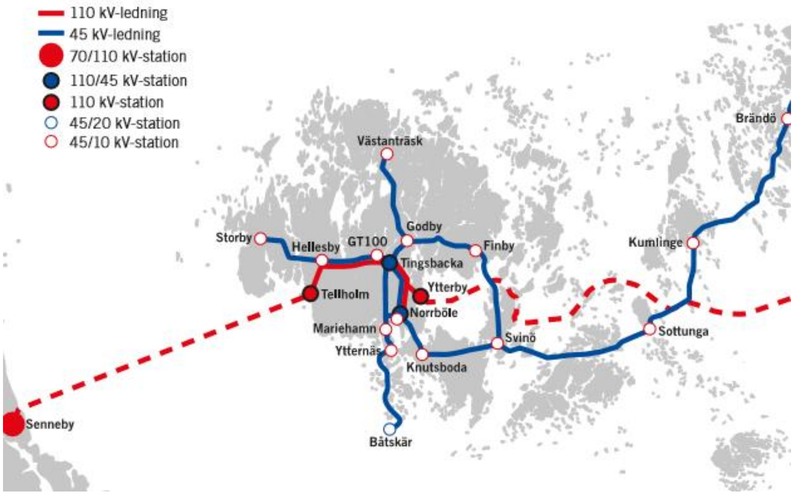
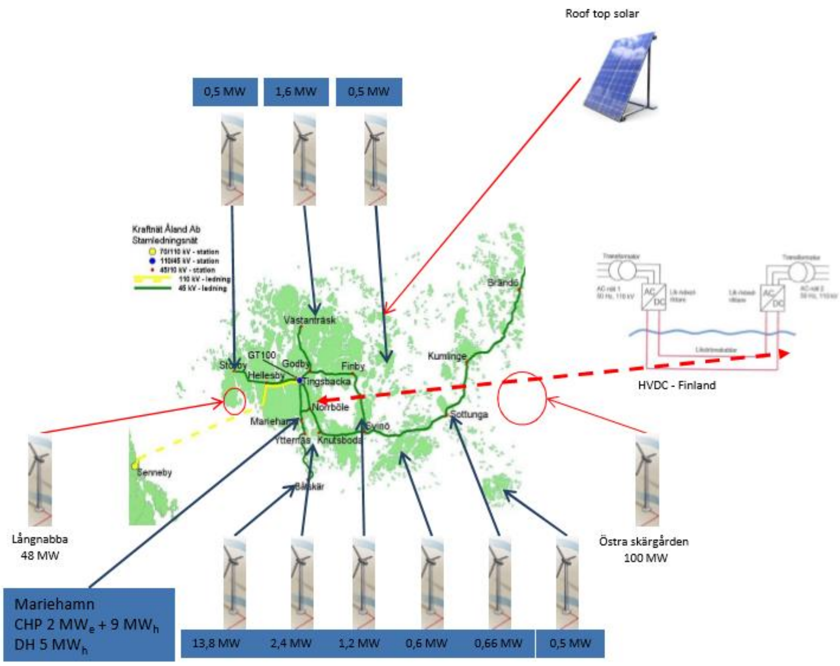


Figure 15: The Aland energy system



7.1.2 Azores (Portugal)

The area of the Azores archipelago spans 2,322 km^2. The largest island, Sao Miguel has an area of 744.6 km^2 and the smallest, Corvo has an area of 17.1 km^2.
In 2011 data, the number of tourists who visited the Azores was 344,595 (nearly 1.5 times the local population).

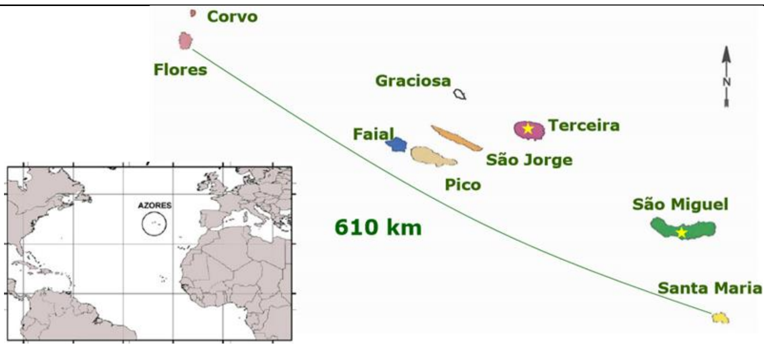


Figure 16: The Azores archipelago

Table 9: Azores Info sheet

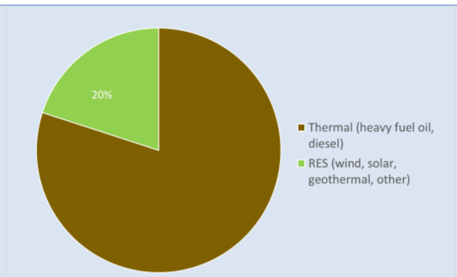
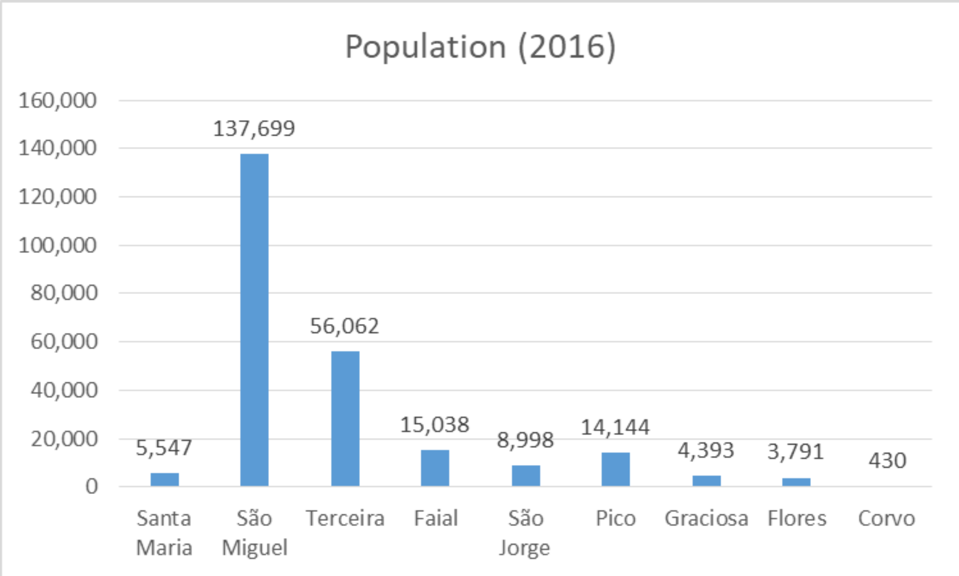
Population (2015)	246,353
Area (km^2)	2,321.96
GDP (m. €) (2014)	3,706
Distance from mainland (km)	1,570 from mainland Portugal
Seasonality in electricity demand	Yes
Interconnection (with mainland)	No
Interconnection (with other islands)	No
Operator	Electricidade dos Azores (production and distribution of energy)
Local electricity production (GWh)	800
Local electricity production mix (%)	
Imported electricity from mainland (GWh, 2016)	0 (0%)

Figure 17: Population breakdown per island in the Azores



Local Electricity Production and Imports

The Autonomous Region of the Azores consists of nine independent electricity- producing systems (one per island), non- interconnected. Power generation mix varies per island. Out of the nine islands, only two (Sao Miguel and Flores) have a diverse production mix. The rest mainly rely on thermal generation, particularly diesel- and fuel oil (above 80%).

Total electricity consumption reached 673.8 GWh in 2016 (see table below for breakdown).

Figure 18: Electricity demand in the Azores (GWh, 2016)

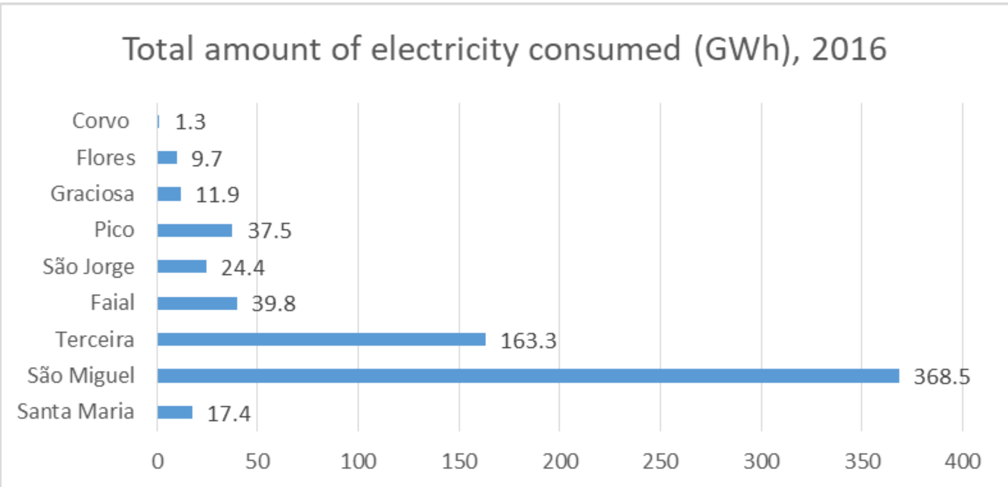
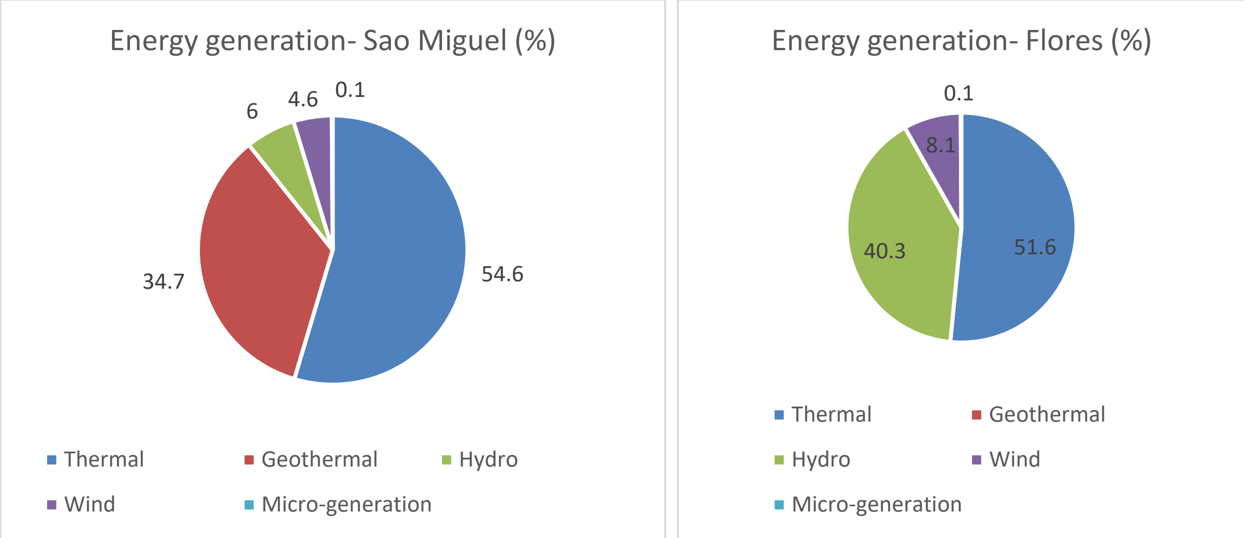


Figure 19: Generation mix for Sao Miguel and Flores islands (%)



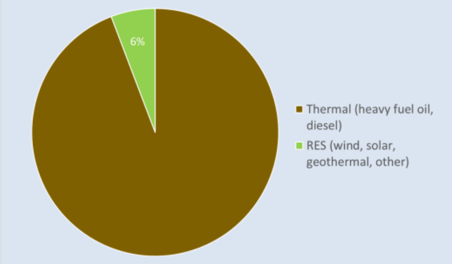
7.1.3 Balearic Islands (Spain)

The Balearic Islands are an archipelago located in the West Mediterranean Sea, consisting of four big islands and other minor islands and islets.

In 2016, the four Balearic Islands (Mallorca, Menorca, Formentera and Ibiza) received over 13 million tourists (13 times the resident population).

Figure 20: The Balearic Islands

Table 10: Info sheet- Balearic Islands

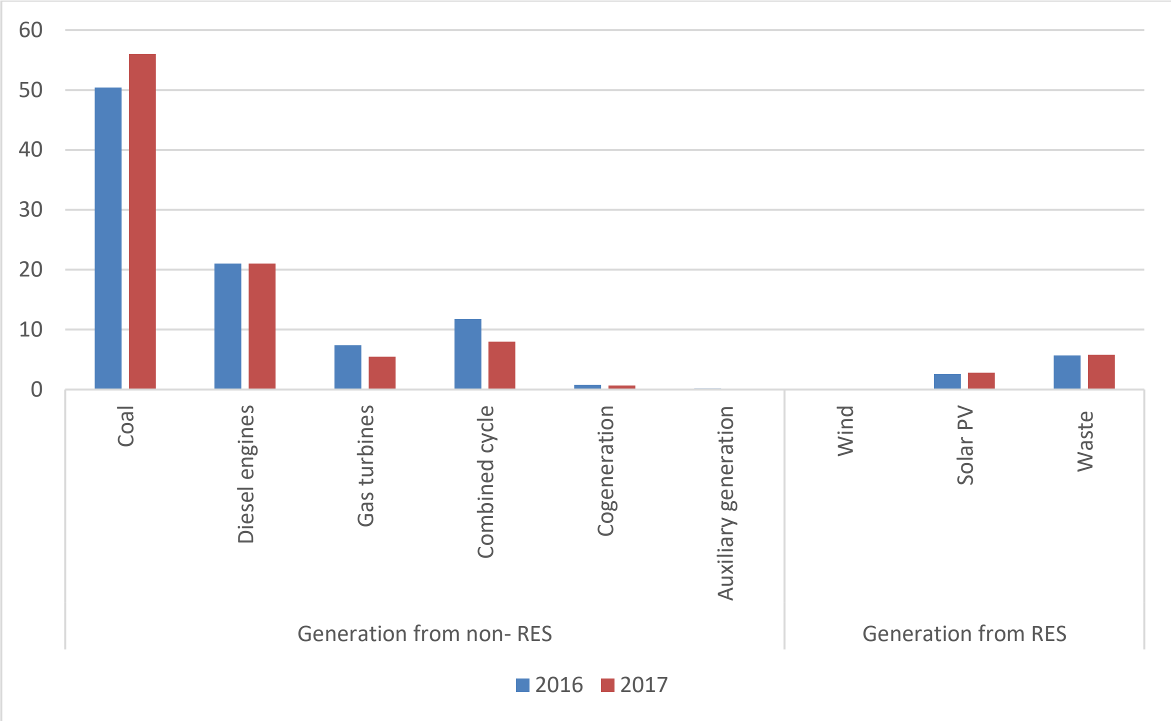
Population (2014)	968,950
Area (km²)	4,992
GDP (m. €) (2014)	22,982
Distance from mainland (km)	280 from mainland Spain
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	Yes Yes
Operator	RED Electrica de Espana (TSO)
Local electricity production (GWh)	NA
Local electricity production mix (%)	
Imported electricity from mainland (GWh, 2016)	-

Local Electricity Production and Imports

The Balearic Islands are interconnected with the Spanish peninsula (Romulo project), through a high voltage submarine interconnection of ±250 kV, comprising of three cables (one return cable) of 237 km in length and of transmission capacity of 400 MW (2 x 200 MW). The islands have been originally interconnected as two small-sized isolated systems: Mallorca- Menorca and Ibiza- Formentera. In 2016 the two electricity subsystems of the Balearic Islands were finally connected by the Mallorca-Ibiza double electricity link. At the time of its commissioning, this interconnection link was the longest and deepest submarine link in alternating current of its kind in the world, as the submarine cable rests on the seafloor at a depth of 800 metres. It still remains to be seen how the new interconnection will shape the islands' energy mix.

The current electricity mix is dominated by coal and diesel (see Table below). The contribution of renewable energy sources to generation was 5.8% in 2017.

Figure 21: Annual generation breakdown, Balearic Islands (%)



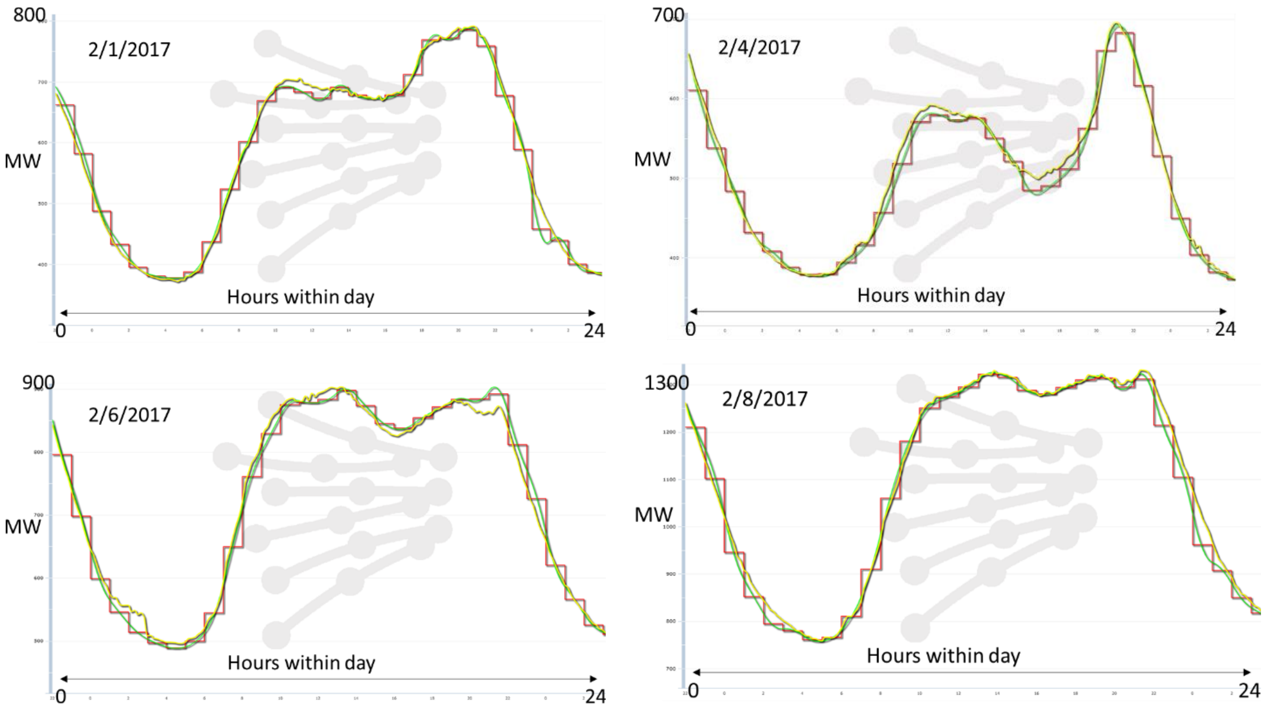
Source: RED Electrica de Espana

According to RED Electrica (2017), out of the 2,296 MW total capacity installed in the Balearic Islands, wind farms accounted for 4 MW and solar PV for 78 MW.

In the figures below, the electricity demand in the Balearic Islands is shown on four 2017 dates: 2nd of January, 2nd of April, 2nd of June and 2nd of August. It is confirmed that:

- Summer load curve has a steady peak for almost 10 hours (from around 11 am to 10 pm). This is probably due to A/C use. Winter load peak lasts for 3 to 4 hours and is registered in the evening (use of lights, cooking etc).
- There is a distinct seasonality in electricity demand as peak load strongly varies in the summer (from 1,320 MW to nearly 800 MW in the winter).
- Different types of plants are required to meet the fluctuating electricity demand so that an extensive utilisation of open cycle gas turbines is noted in the summer and during peak hours throughout the year.

Figure 22: Electricity demand 2017 in Balearic Islands (MWh) (Source: RED Electrica de Espana)

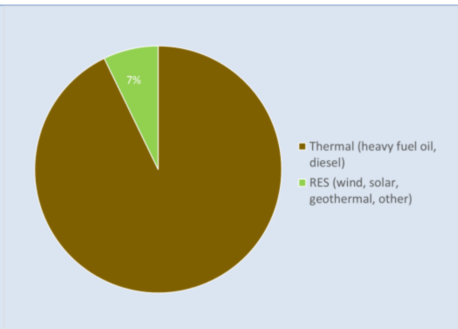


7.1.4 Canary Islands (Spain)

The Canary Islands is a group of seven main islands, located on the Atlantic Ocean, just 100 km off the Morocco coast. The largest and most populated island is Tenerife, followed by Gran Canaria. The smallest island is El Hierro. The Canary Islands welcome about 12 million tourists per year (six times the resident population), but there is no big impact on the peak load as flows are occurring throughout the year.

Figure 23: The Canary Islands

Table 11: Info sheet- Canary Islands

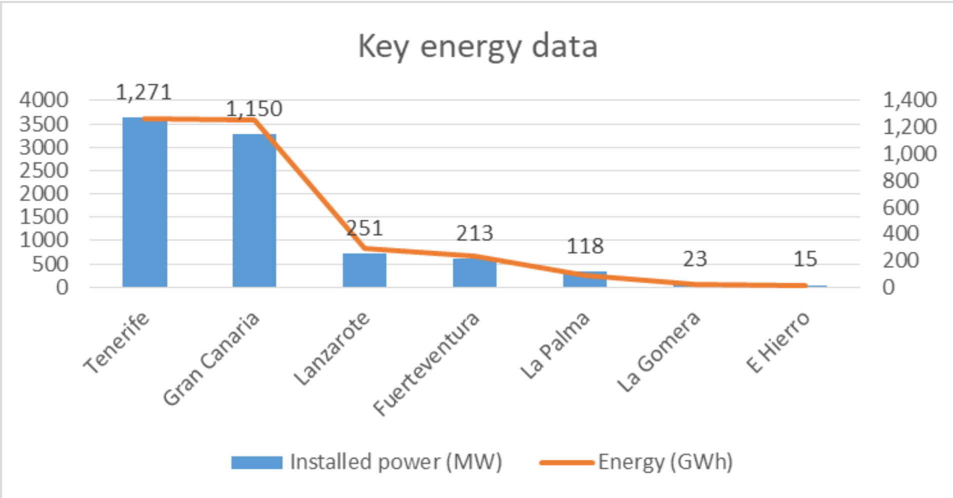
Population (2014)	2,126,144
Area (km²)	7,446.95
GDP (m. €) (2014)	39,739
Distance from mainland (km)	1,600 from mainland Spain
Seasonality in electricity demand	Weak
Interconnection (with mainland) **Interconnection (with other islands)**	No Partly
Operator	RED Electrica de Espana (TSO)
Local electricity production (GWh)	NA
Local electricity generation mix (%)	
Imported electricity from mainland (GWh, 2016)	0 (0%)

Local Electricity Production and Imports

The electricity system of the Canary Islands consists of five small sized isolated electrical systems and one weakly interconnected system between Fuerteventura- Lanzarote.

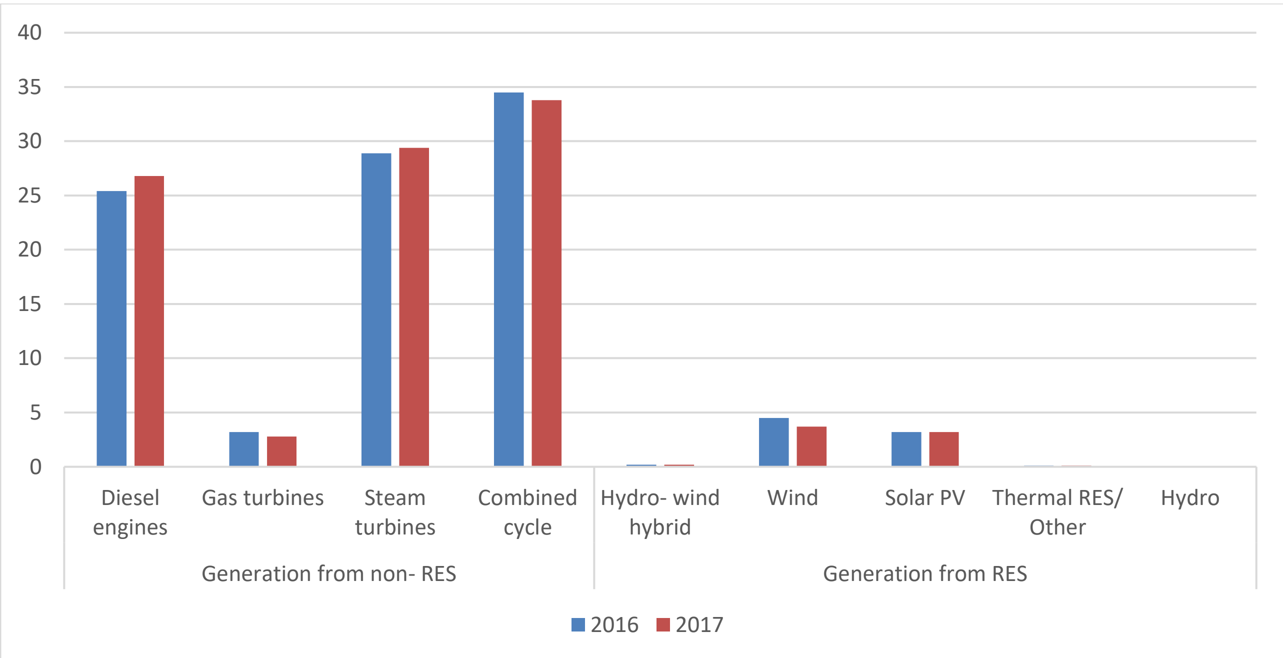
Due to their isolated energy systems, the islands are heavily dependent on external sources. However, there is a strategic need to maximize the use of local resources (such as RES and water).

Figure 24: Key energy data for the Canary Islands (2013)



Source: BEAST project [32]

Figure 25: Annual generation breakdown, Canary Islands (%)



Source: RED Electrica de Espana

According to RED Electrica (2017), out of the 2,751 MW total capacity installed in the Canary Islands, wind farms accounted for 135 MW and solar PV for 166 MW.

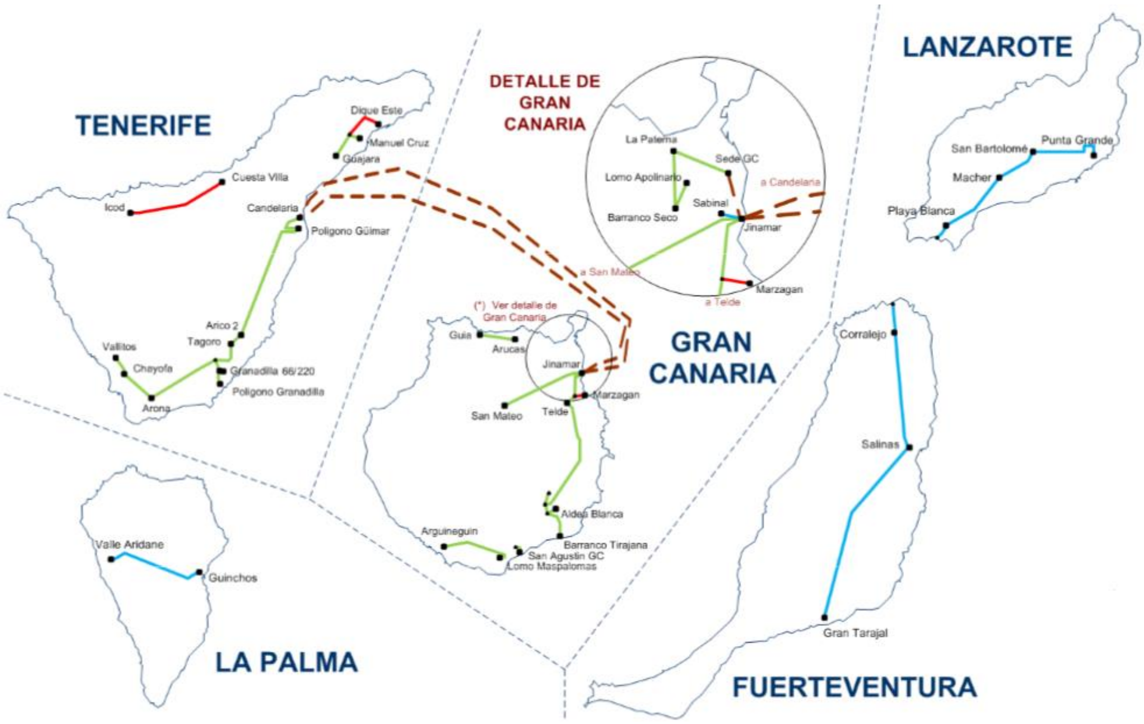
The Lanzarote and Fuerteventura islands are weakly connected via two submarine cables (66 kV from Playa Blanca- Corralejo and 132 kV from Playa Blanca- La Oliva).

Table 12: The Lanzarote- Fuerteventura electrical system

	Peak Load (MW)	Total capacity (diesel and gas power plants)
Lanzarote	170.3	Punta Grande- 244. 24 MW
Fuerteventura	123.8	Las Salinas- 187.43 MW

In order to support renewable energy integration and security of supply, two additional elements have been constructed: Los Realejos 66 kV substation and the Arico II 66 kV substation in the existing Candelaria- Tagoro circuit on Tenerife island (see Map below).

Figure 26: Map of the Canary Islands, including grid infrastructure network



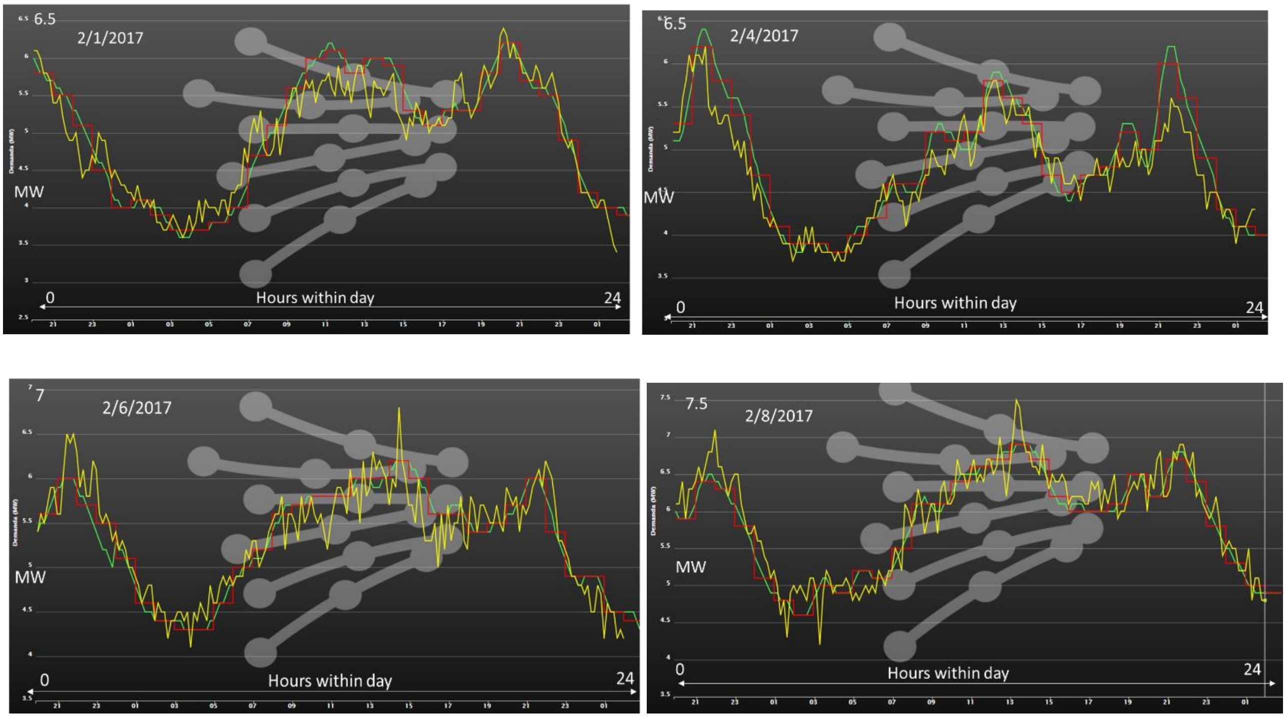
Source: Project MAR, RED Electrica [33]

El Hierro relies on Gorona del Viento, a recent hybrid (hydro/wind) power station built on the south-eastern part of the island, with a total capacity of 11.5MW. This is more than enough to meet the 7 to 7.5 MW peak load of demand (see below). Until recently, the island was relying on diesel-powered generators. It is estimated that for every hour that the hybrid power the island, 1.5 tons of diesel are saved.

In the figures below, the electricity demand in El Hierro islands is shown on four 2017 dates: 2nd of January, 2nd of April, 2nd of June and 2nd of August. It is confirmed that:

- There is no strong variation in the summer versus winter load curve. Peak load is registered in the evening (use of lights, cooking etc).
- There is weak seasonality in electricity demand as peak load only changes from around 6.5 MW in the winter to 7.5 MW in the summer.

Figure 27: Electricity demand 2017 in El Hierro (MWh)



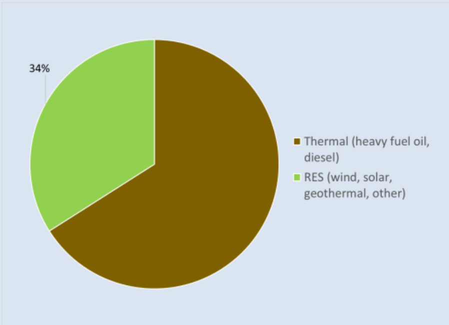
Source: RED Electrica de España

7.1.5 Corsica (France)

Corsica is an island in the Mediterranean Sea and one of the 18 regions of France. It is located southeast of the French mainland and west of the Italian Peninsula, with the nearest land mass being the Italian island of Sardinia to the immediate south.

Figure 28: Corsica

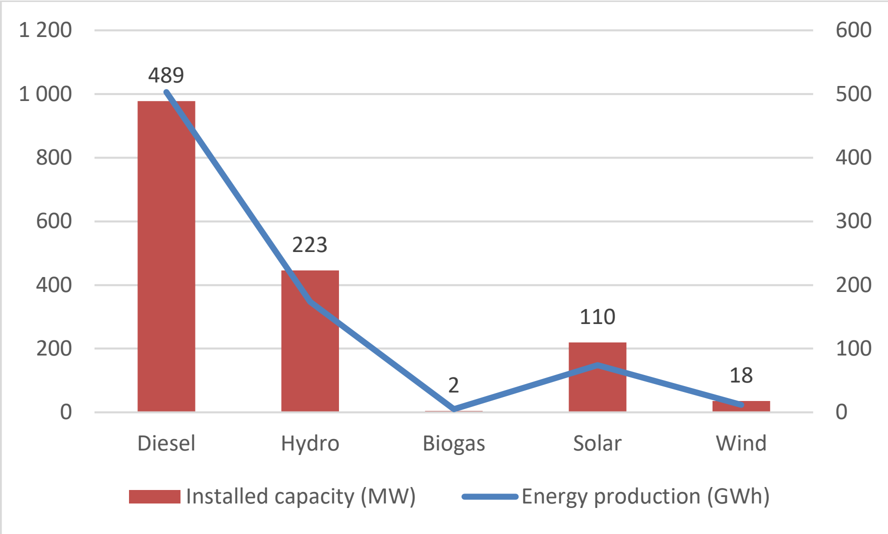
Table 13: Info sheet- Corsica

Population (2015)	327,374
Area (km²)	8,680
GDP (m. €) (2014)	8,628
Distance from mainland (km)	111 from mainland Italy
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	Weakly Yes
Operator	EDF Systèmes Énergétiques Insulaires for Corsica
Local electricity production (GWh)	1,535 (79%)
Local electricity production mix (%)	
Imported electricity from mainland (GWh, 2015)	414 (21%)

Local Electricity Production and Imports

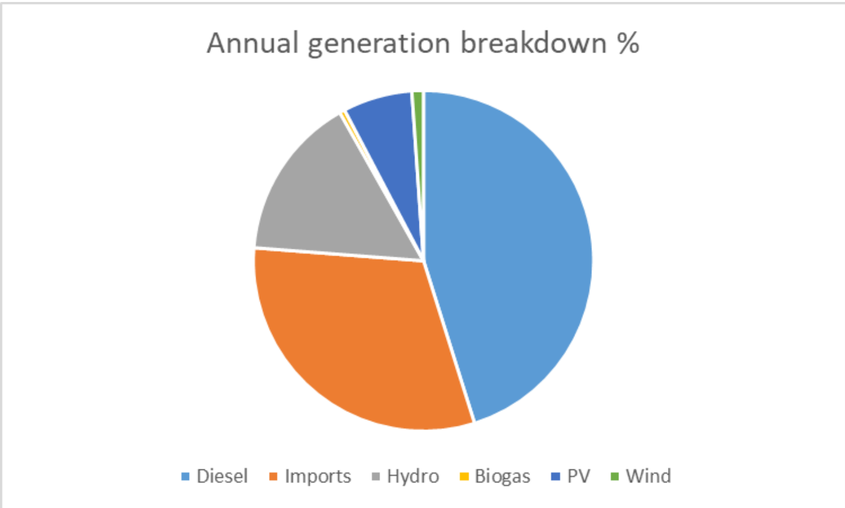
The electricity mix consists of locally based thermal and renewable electricity generation and imports from the existing link with Italy. At the end of 2015, energy production reached 1,535 GWh while total energy demand amounted for 1,949 GWh. Total installed generation capacity amounted for 842 MW in 2015.

Figure 29: Energy production and installed capacity in Corsica, 2015



Source: RTE

Figure 30: Annual generation breakdown, 2015



Source: EDF

Corsica has two interconnections namely:

- A 200 kV 300 MW HVDC connection on the Sardinia- Corsica- Italy (SA.CO.I) line which connects Tuscany to Sardinia since late 60s. It is characterised by limited transmission capacity and poor operational flexibility.
- A Sardinia- Corsica (SAR.CO.) interconnection, an AC link commissioned in 2006. Its initial capacity was at 50 MW, then increased to 80 MW and recently to 100MW (end of 2010).

7.1.6 Faroe Islands (Denmark)

The Faroe Islands are an archipelago located in the north Atlantic Sea between Scotland and Iceland, consisting of 18 small islands, 17 of which are populated. They form part of the Kingdom of Denmark.

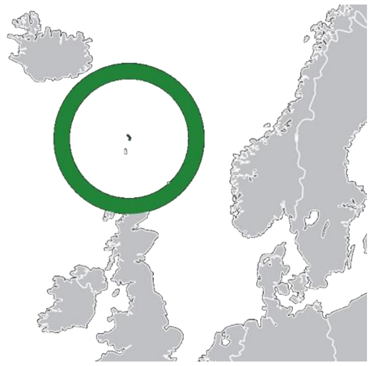
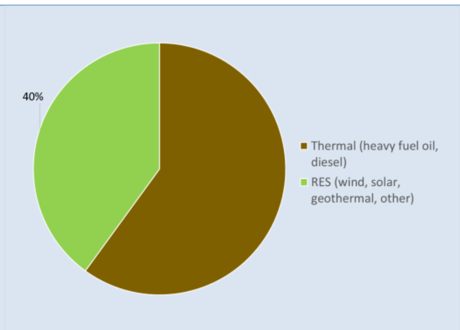


Figure 31: The Faroe Islands

Table 14: Info sheet- Faroe Islands

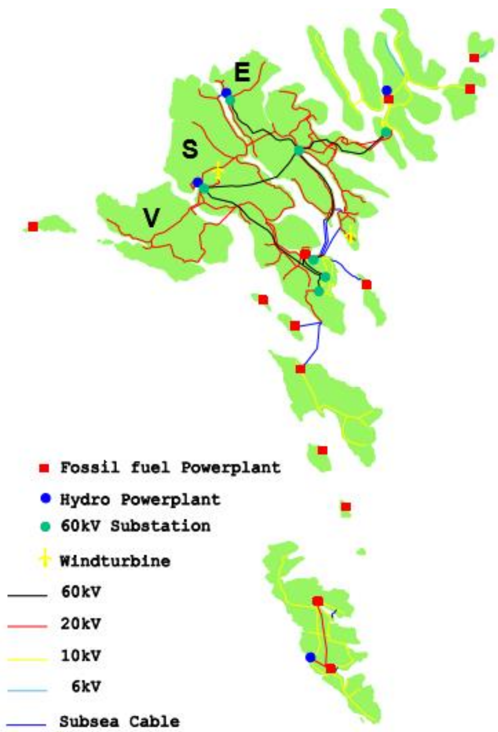
Population (2017)	50,250
Area (km²)	1,399
GDP (m. €) (2013)	2,600
Distance from mainland (km)	1,120 from mainland Denmark
Seasonality in electricity demand	NA
Interconnection (with mainland) **Interconnection (with other islands)**	No Yes
Operator	SEV (Power producer and DSO)
Local electricity production (GWh)	305
Local electricity production mix (%)	
Imported electricity from mainland (GWh, 2015)	0 (0%)

Source: World Bank, Faroe Islands statistics

Local Energy Production

The power system of the Faroe Islands is isolated with a peak load of around 48 MW (2011), with a high share of wind power. The system was particularly challenged when wind power went from 5 to 25% of the energy mix within an only 2-year period (2012-14). The annual electrical production is at 305 GWh (2014 data). The islands have six hydroelectric plants, four diesel plants and several wind farms.

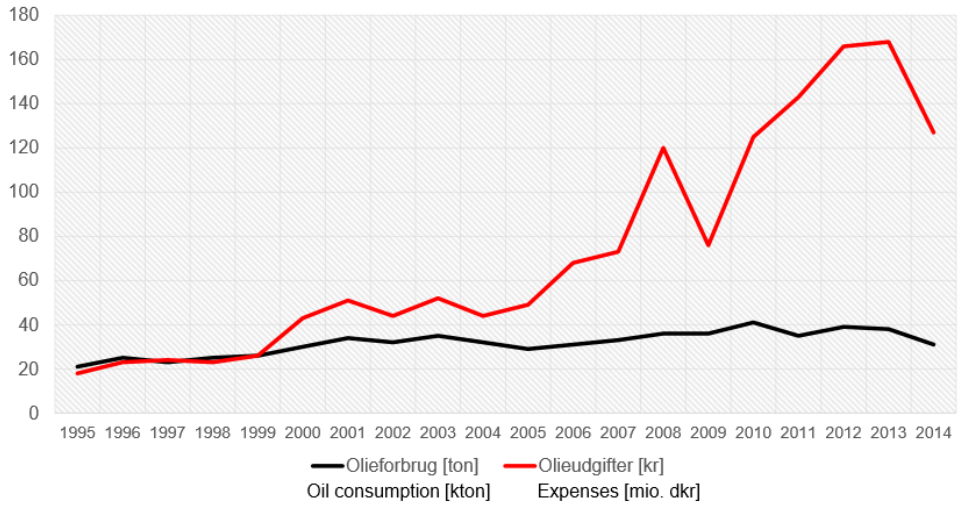
Figure 32: The Faroe Islands power system



The Faroe Islands experience often blackouts compared to continental Europe: this is due to non-existent interconnections, adverse weather conditions and frequent storms. The power system can collapse in just a few seconds.

The SEV (local power producer and DSO) is also challenged by the high cost of oil consumption (Source: Twenties project) [34].

Figure 33: Oil consumption and expenses



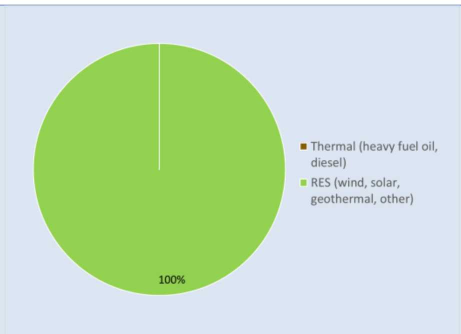
As part of EU-funded Twenties project, several innovative solutions were developed to cope with the challenges mentioned. They are discussed in detail in Section 3. In 2014, the 12MW Húsahagi wind farm became operational near Torshavn and increased wind capacity from 6.6 to 18.6MW. A 2.3MW 700kWh lithium-ion battery at €2 million near Húsahagi became operational in 2016. As shown in the graph above, the increased wind penetration has essentially capped oil-product consumption and led to a substantial reduction in the operating costs for power generation.

7.1.7 Gotland (Sweden)

Gotland is the largest island in the Baltic Sea. One third of its population lives in Visby (capital).
In 2016, Gotland welcomed 2.2 million tourists by air or ferry (almost 40 times the resident population). Peak season occurs during summer but the island has seen constant visits throughout the year.

Figure 34: Gotland

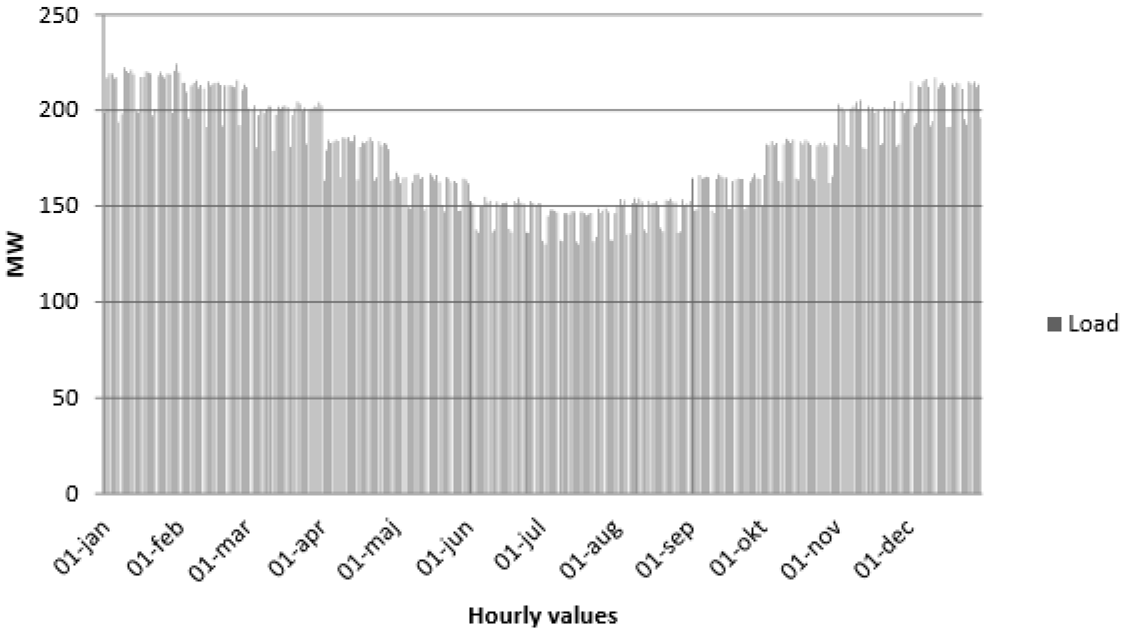
Table 15: Info sheet- Gotland

Population (2016)	57,391
Area (km²)	2,968
GDP (m. €) (2014)	1,965
Distance from mainland (km)	90 from mainland Sweden
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	Weak No
Operator	Gotlands Energi AB (DSO)
Local electricity production (GWh)	of the order of 400 GWh (40-50% of total demand)
Local electricity production mix (%)	
Imported electricity from mainland (GWh, 2015)	of the order of 400 GWh (50%)

Local electricity Production and Imports

Gotland's peak demand is during the winter months regardless of the tourism activities during the summer.

Figure 35: Hourly electric load during an average year



Gotland has an exceptional renewable energy potential. The majority of RES installed capacity comes from wind (194 MW), followed by solar PV[17].

The island has also thermal capacity: two gas turbines of 60MW each located in Slite as the main backup power. There is also a diesel power station in Visby producing 36 MW, four gas turbines in Backs of 12 MW and two 10 MW gas turbines operated by Cementa.

Gotland is connected to the Swedish mainland by two HVDC submarine cables (150kV, 130 MW each which can only transmit power in one direction -- from the mainland to Gotland. Over production of wind energy has been leading to curtailments.

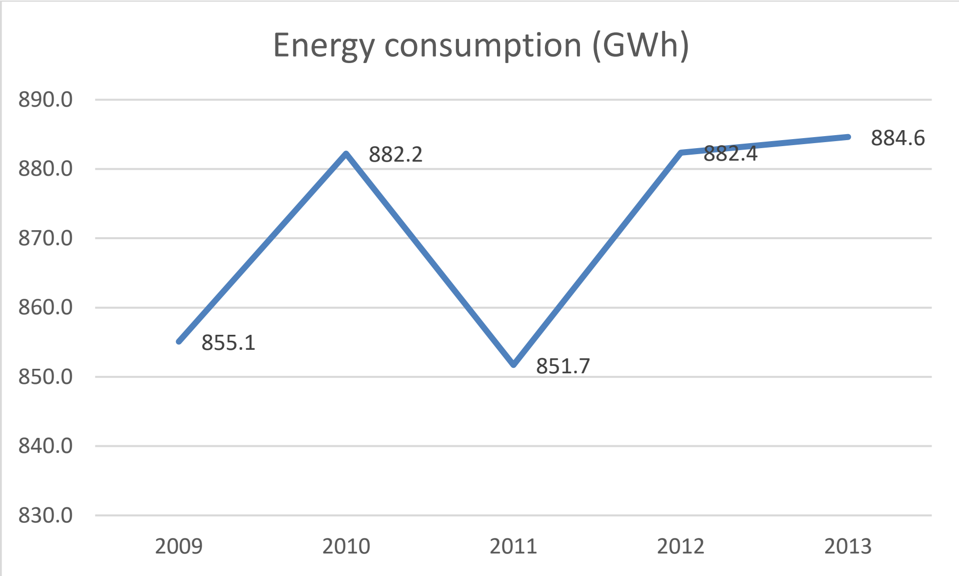
To ensure the reliability and power quality of the system, Gotland Energy AB (GEAB), the DSO, has been forced to stall new wind power capacity on the island. The capacity of RES is currently limited to 195 MW.

Wind power generates over 400 GWh of electricity which corresponds to 45-50% of the island's electricity demand. Solar power is also developing quickly. Heating demand is covered mostly with biofuels, with well over 500 GWh per year.

In order to enable further RES development in Gotland, a new submarine power cable with a capacity of 300 MW will be installed in 2021.

[17] There is no official regional statistics for installed capacity for PV power in Sweden. According to Lindahl (2014) the cumulative installed PV power capacity was 79.4 MW in 2014.

Figure 36: Energy demand in Gotland (GWh)

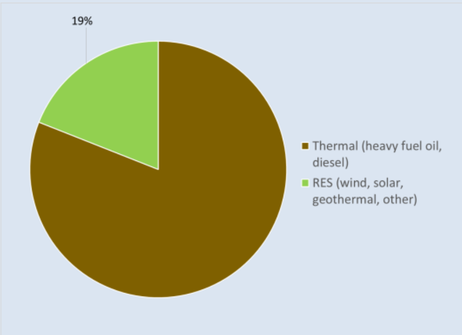


7.1.8 Greek non-interconnected islands

Greece has a total of 58 non-interconnected islands, with a total population of 1,114,803 people (approximately 10% of total Greek population). These islands are grouped into three main regions: South Aegean, including the Cyclades and Dodecanese, North Aegean and Crete. Rhodes and Crete are the two most populated islands and thus the largest energy consumers.

These islands have not been connected to the mainland electricity system yet, due to technical difficulties as well as due to financial constraints as the interconnections are capital intensive projects.

Table 16: Info sheet- non-interconnected Greek islands

Population (2014)	1,114,803
Area (km²)	-
GDP (m. €) (2014)	2,663 (average)
Distance from mainland (km)	-
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	No Partly
Operator	DEDDIE (HEDNO)
Total electricity production (GWh)	5,720
Energy mix (%)	

In all Greek islands power is produced by thermal power plants (heavy fuel oil and/or diesel oil) and a smaller percentage of RES plants (wind and solar).

Local electricity production

The non-interconnected islands system consists of 32 autonomous systems[18]. Some systems consist of a single island (e.g. Crete, Limnos, Ereikousa) and some consist of multiple islands (island groups). The electricity system of the non-interconnected islands is managed by DEDDIE (HEDNO), the Greek distribution system operator, a subsidiary of the incumbent PPC.

The demand of electricity in the non-interconnected islands varies from few hundred MWh in small islands (e.g. Antikythera) to several GWh in Crete.

The peak demand of the non-interconnected islands varies in size and includes:

- 19 small autonomous systems with a peak demand of circa 10 MW;
- 11 medium-sized systems with a peak demand between 10 and 100 MW;
- 2 large systems with a peak demand over 100 MW (Crete and Rhodes).

[18] http://www.rae.gr/site/categories_new/electricity/market/mdn.csp

Table 17: An overview of the autonomous systems of the non-interconnected islands (or island groups)

Autonomous system	Island	Area (km2)	Population	GDP (m. €) (2014)
Crete	Crete	8,303.0	623,065	8,693
Lesvos	Lesvos	1,636.0	86,436	1,351
Rhodes	Rhodes Chalki	1,401.5	115,490 478	3,252[19]
Chios	Chios Oinousses Psara	842.8	51,390 826 458	666
Samos	Samos Fournoi Thymaina	477.9	32,977 1,120 57	543
Limnos	Limnos	476.3	16,992	1,351[20]
Karpathos	Karpathos Kasos	300.2	6,226 1,084	3,252
Kos	Kos Kalymnos Leipsoi Leros Telendos Pserimos Gyali Nisiros Tilos	287.6	33,388 16,005 790 7,917 94 80 21 987 780	3,252
Ikaria	Ikaria	255.3	8,423	543[21]
Skyros	Skyros	206.9	2,994	n/a
Paros	Paros Naxos Antiparos Koufonisi Schinousa Iraklia Sikinos Folegandros Ios	196.3	13,715 17,930 1,211 399 227 141 273 765 2,024	2,741
Milos	Milos Kimolos	158.4	4,977	2,741
Amorgos	Amorgos	121.5	1,973	n/a
Kythnos	Kythnos	99.4	1,456	n/a
Astypalaia	Astypalaia	96.4	1,334	n/a
Mykonos	Mykonos Delos	86.1	10,134 24	2,741[22]
Syros	Syros	84.1	21,507	2,741
Santorini	Santorini (Thira) Thirasia	76.2	15,231 319	2,741

[19] GDP includes the islands of Rhodes, Kalymnos, Karpathos, Kos

[20] GDP includes the islands of Lesvos and Limnos (NUTS region)

[21] GDP includes the islands of Samos and Ikaria

[22] GDP includes the islands of Andros, Thira (Santorini), Kea, Milos, Mykonos, Naxos, Paros, Syros, Tinos

Autonomous system	Island	Area (km2)	Population	GDP (m. €) (2014)
Serifos	Serifos	75.2	1,420	n/a
Sifnos	Sifnos	73.9	2,625	n/a
Symi	Symi	57.9	2,590	n/a
Agios Efstratios	Agios Efstratios	43.3	270	n/a
Anafi	Anafi	38.6	271	n/a
Patmos	Patmos	34.1	2,998	n/a
Gavdos	Gavdos	29.6	152	n/a
Antikythera	Antikythera	20.4	68	n/a
Donousa	Donousa	13.7	167	n/a
Agathonisi	Agathonisi	13.4	185	n/a
Othonoi	Othonoi	10.1	392	n/a
Kastelorizo	Kastelorizo (Megisti)	9.1	492	n/a
Arkoi	Arkoi Marathi	6.7	44 5	n/a
Ereikousa	Ereikousa	4.4	496	n/a

Figure 36 shows that the energy production at non-interconnected Greek islands almost doubles from winter to summer. To meet the increased summer demand there is a need for substantial capacity reserves of thermal generation in several islands. In return, this additional reserve capacity translates to increased capital costs for plants that are essentially utilised only a few weeks each year. The penetration of RES (wind and particularly photovoltaics which operate at their maximum during the afternoons of high demand) have positively contributed in the reduction of capacity in reserve, nevertheless requirements remain.

Table 18: Energy production in the Greek islands, April 2017

	RES installed capacity (MW)	Installed thermal capacity 2016 (MW)	Peak Load 2016 (MW)	RES energy production (MWh)	Thermal energy production (MWh)	RES share/ overall production
Crete	279.40	813.02	627.30	45448.91	158632.17	22.27%
Rhodes	66.71	232.93	200.00	7708.52	39108.74	16.47%
Lesbos	22.79	84.41	67.42	3013.54	17409.90	14.76%
Kos-Kalymnos	23.98	124.45	94.50	3238.14	16786.14	16.17%
Lemnos	4.93	21.58	14.70	611.98	3460.62	15.03%
Milos	3.27	20.60	12.28	328.32	14832.00	2.17%
Paros	17.17	91.18	68.20	2412.58	12169.58	16.54%
Chios	9.08	69.93	46.80	1880.86	12344.57	13.22%
Syros	2.84	35.20	23.70	544.38	6216.11	8.05%
Samos	12.75	47.75	29.60	1486.83	7297.74	16.93%
Karpathos	2.39	17.30	11.30	421.74	1732.17	19.58%
Mykonos	2.24	62.16	41.30	258.24	8480.81	2.96%
Agios Eustratios	0.02	0.76	0.31	0.00	74.26	0.00%
Agathonisi	0.00	0.52	0.20	0.00	56.49	0.00%
Amorgos	0.29	4.22	3.15	45.68	699.75	6.13%
Anafi	0.00	0.80	0.59	0.00	69.61	0.00%
Antikythera	0.00	0.36	0.11	0.00	21.16	0.00%
Arkioi	0.00	0.36	0.14	0.00	19.68	0.00%
Astypalaia	0.32	3.30	2.21	57.83	391.70	12.86%
Gavdos	0.00	0.36	0.12	0.00	33.40	0.00%
Donousa	0.00	0.50	0.36	0.00	49.06	0.00%
Ereikousa	0.00	0.53	0.35	0.00	57.95	0.00%
Thira	0.25	71.92	42.80	93.16	12992.31	0.71%
Ikaria	1.39	13.56	6.70	225.91	1658.36	11.99%
Kythnos	0.91	4.90	2.98	28.20	3369.60	0.83%
Megisti	0.00	1.32	0.91	0.00	215.07	0.00%
Othonoi	0.00	0.44	0.26	0.00	45.60	0.00%
Patmos	1.35	6.60	5.90	146.19	1046.12	12.26%
Serifos	0.10	5.60	3.42	21.23	3979.20	0.53%
Sifnos	0.20	8.80	6.22	49.13	5568.68	0.87%
Skyros	0.32	6.90	4.65	55.99	1091.42	4.88%
Symi	0.19	8.20	3.84	27.00	891.69	2.94%
Rest		139.95		750.31	32331.08	2.27%
Total	**452.89**	**1900.41**		**68854.67**	**363132.74**	**18.96%**

Source: HEDNO

Figure 37: Energy production in non-interconnected islands

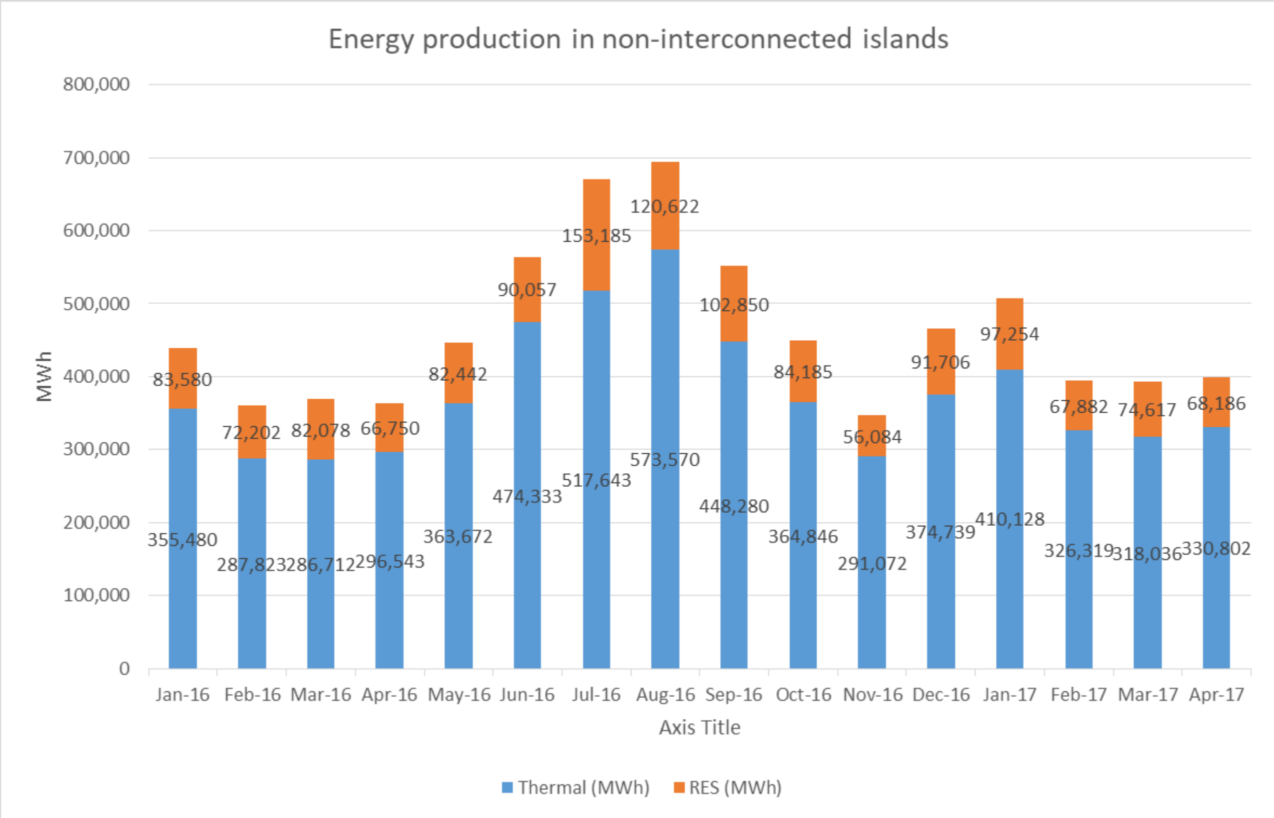


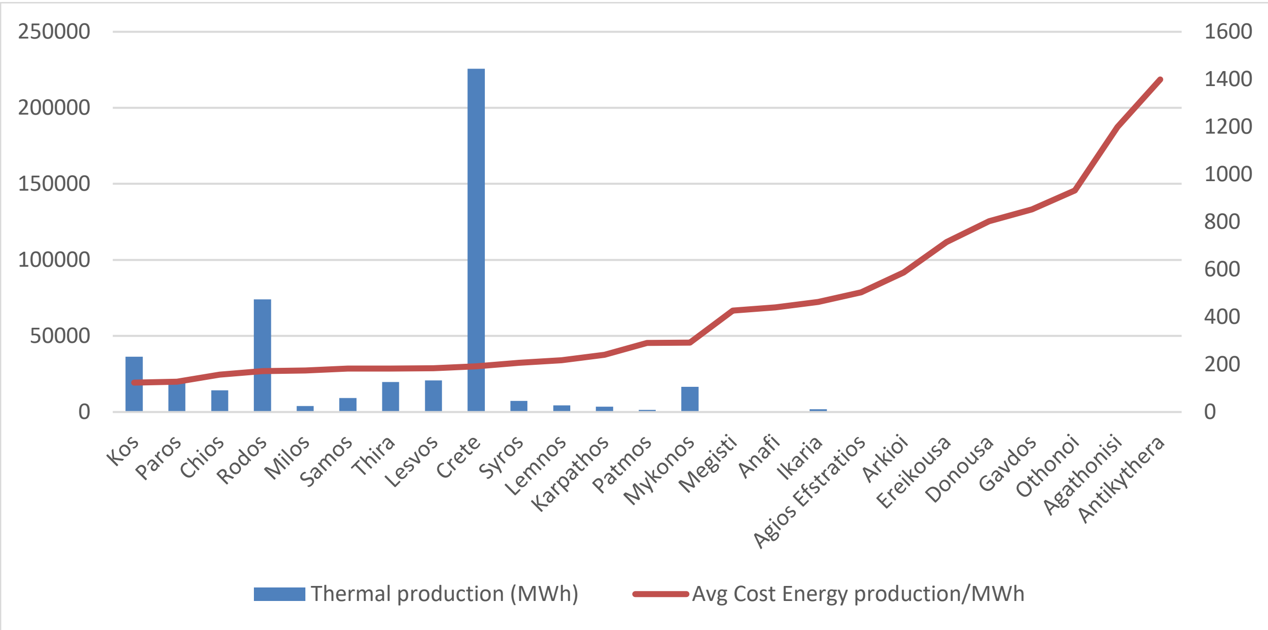
Figure 38: Wind and solar power installed capacity

In April 2017, 98 wind farms were operating in the non-interconnected islands, reaching a total capacity of 322.25 MW. Therefore, islands roughly represent 14% of total wind power capacity installed at national level. Crete and Rhodes are the two biggest markets for both solar and wind energy, accounting for over 70% of the total wind and solar power capacity installed.

The figure below reports on the cost of electricity generation in several non-interconnected Greek islands on June 2017 per MWh of produced electricity. This cost includes solely fuel and running costs of thermal plants in each island and ranges from a lower level of just above 100 euros per MWh in the island of Kos with a thermal power plant firing heavy fuel oil to a maximum of over 1000 euros per MWh at the small islands of Othonoi, Agathonisi, Antikythera. The figure has been drawn from the respective data published by the Greek island grid operator (HEDNO). It should be noted that during the same month the mean system marginal price (SMP) paid by suppliers in the Day Ahead Market of the interconnected system was of the order of 50 euros/MWh thus more than a magnitude lower than the cost of many islands.

The incumbent PPC carries out a Public Service Obligation in all non-interconnected Greek islands (hereafter, 'NII'). The obligation consists in the supply of electricity to consumers on the NII at a price equal to that charged to consumers on Greece's interconnected grid. A compensation mechanism ensures that PPC is compensated for the higher costs incurred for producing and purchasing power generated on the NII (in comparison to the costs it would have experienced if power was produced in the interconnected system). The compensation methodology is developed and decided by the Greek regulatory authority RAE and foresees that the PSO amount is collected through a levy imposed upon all electricity customers in the Greek territory. The PSO amount due to the electricity production at the NII's is of the order of 600-700 million EUR per annum.

Figure 39: Average cost of energy production/island (June 2017)

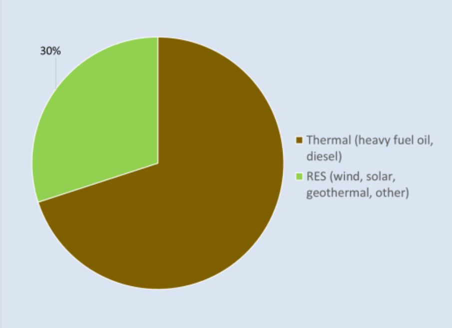


7.1.9 Madeira (Portugal)

Madeira is an archipelago comprising two inhabited islands: Madeira and Porto Santo.

Figure 40: Madeira

Table 19: Info sheet- Madeira

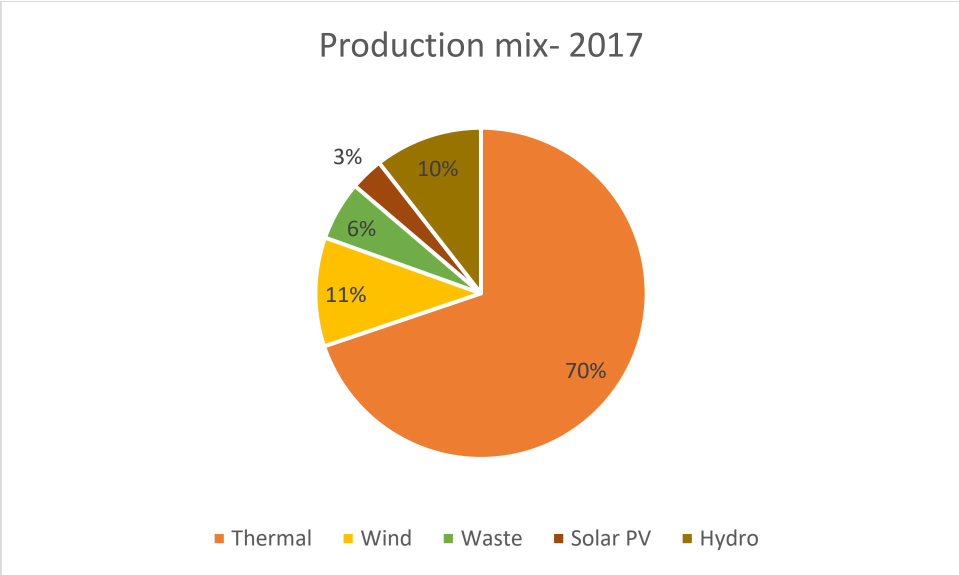
Population (2015)	258,686
Area (km²)	801
GDP (m. €) (2014)	4,124
Distance from mainland (km)	900 from mainland Portugal
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	No No
Operator	Electricidade de Madeira
Local electricity production (GWh)	
Local electricity production mix (%)	
Imported electricity from mainland (GWh, 2015)	0

Local electricity production

Despite Madeira's location and natural conditions favouring the development of renewable energy projects; the island has still significant external dependency.

The maximum peak load for 2017 was registered in January for Madeira (164 MW) and in August for Porto Santo (7.9 MW). The difference might be due to different seasonal activities as Porto Santo has emerged recently as a tourist destination while Madeira has a steadier profile throughout the year.

Figure 41: Production mix- 2017 (%)



Source: Electricidade da Madeira (EEM)

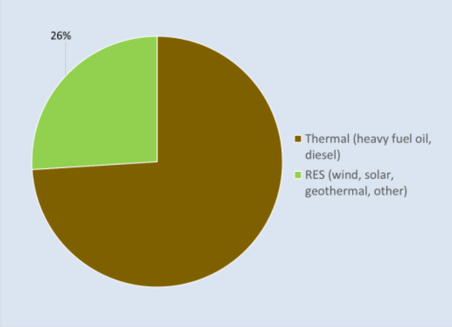
The production mix is mainly thermal- based (around 70%). Wind and hydro represent the most important energy sources by 10-11% of share each.

7.1.10Sardinia (Italy)

Sardinia is the second largest island in Europe (after Sicily) and one of the most favourable regions in Italy and Southern Europe for renewable energy development.

Figure 42: Sardinia

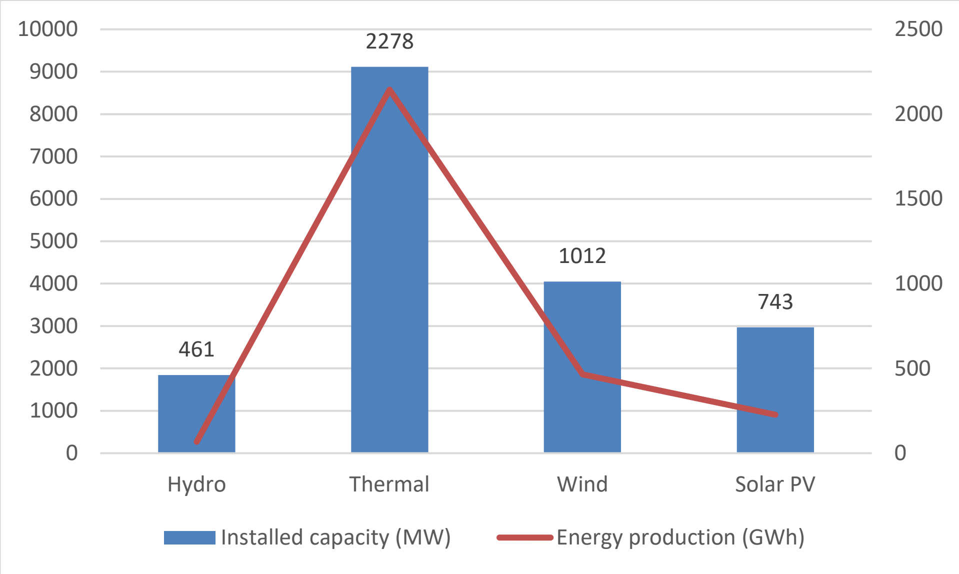
Table 20: Info sheet- Sardinia

Population (2014)	1,658,138
Area (km²)	24,090
GDP (m. €) (2014)	32,481
Distance from mainland (km)	240 from mainland Italy
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	Weak Yes
Operator	TERNA (TSO)
Local electricity production (GWh)	11,459
Local electricity production mix (%)	

Local electricity production

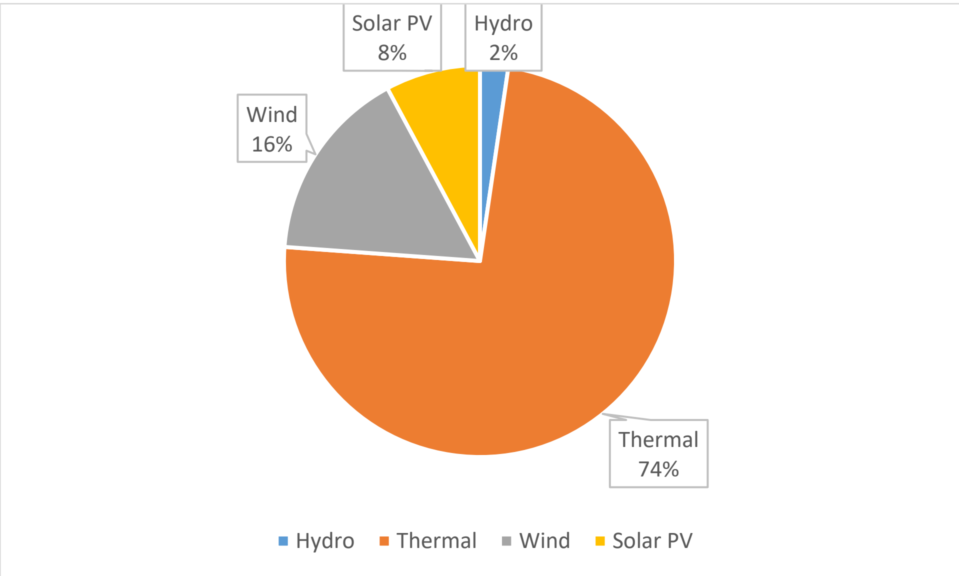
In 2016, total installed capacity amounted for 4,493.6 MW.

Figure 43: Key energy data, Sardinia, 2016



Source: TERNA

Figure 44: Annual generation breakdown, Sardinia- 2016

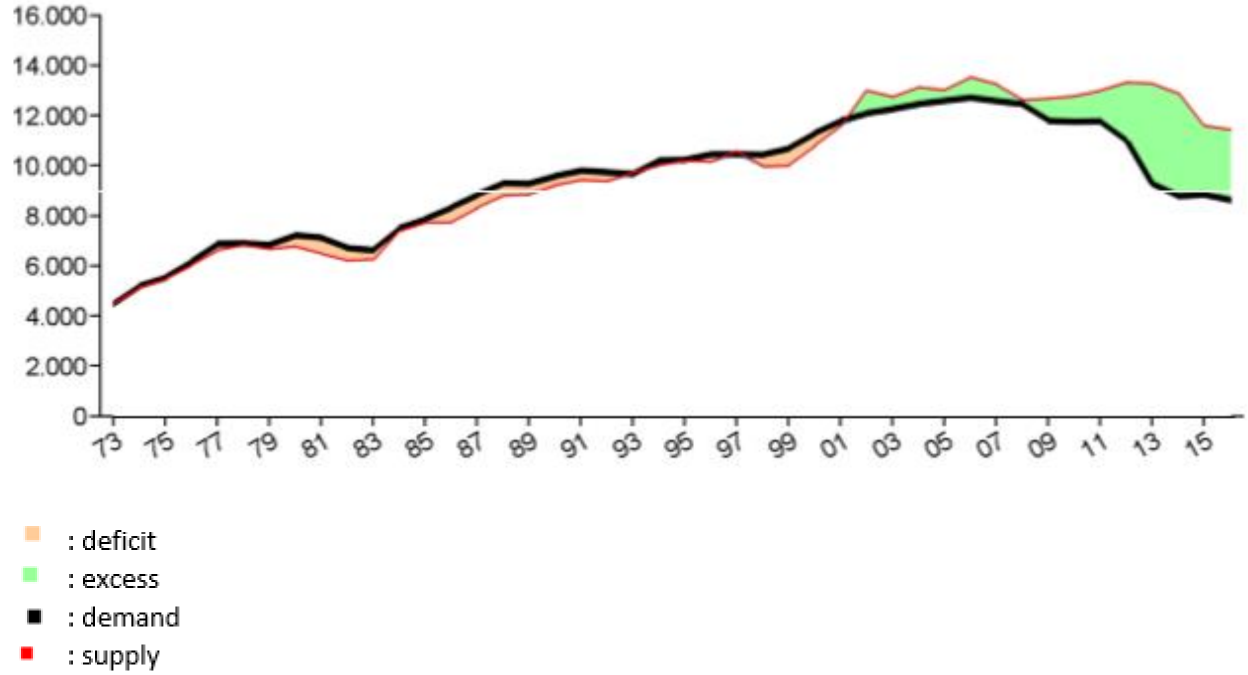


Source: TERNA

In 2016, thermal energy production accounted for 74% of total production, followed by wind energy (16%) and solar PV (8%).

In 2016, the annual energy demand reached 8,643.3 GWh. Net energy production for end-users (excluding pumping) was at 11,459.4 GWh, thus creating an excess of 2.816,1 GWh (see on the next page).

Figure 45: Historical demand- supply, Sardinia

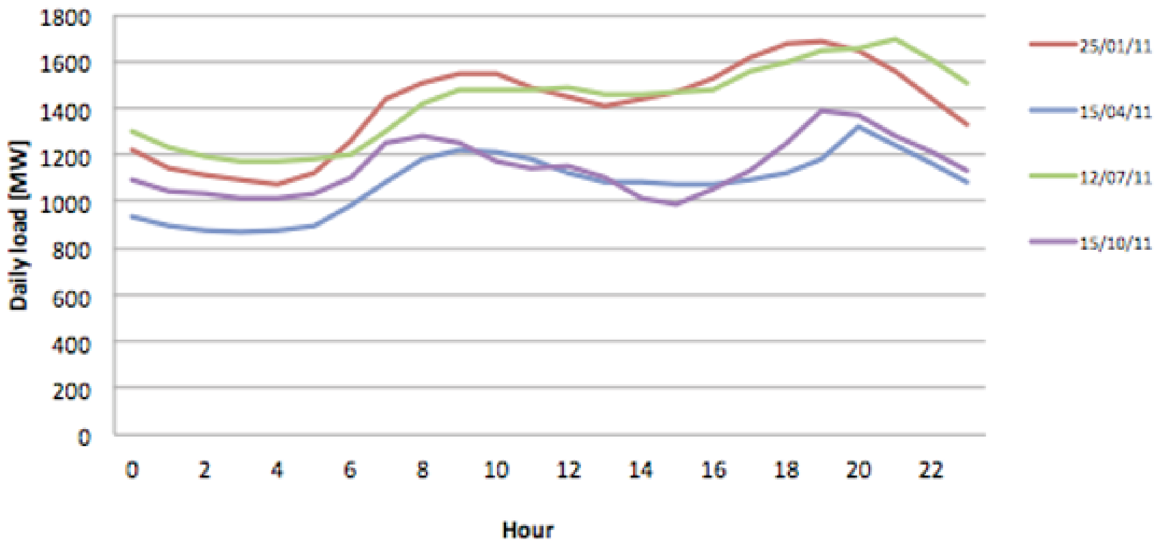


Sardinia is connected to the mainland via 2 DC lines: the +/- 500 kV 1,000 MW HVDC link called SA.PE.I. (Sardinia- Italian peninsula) and the 200 kV 300 MW HVDC link named SA.CO.I. (Sardinia- Corsica- Italy). The latter was built in the 60s and is characterized by a limited transmission capacity and poor operation flexibility. A further AC link (SAR.CO.) connects Sardinia and Corsica.

Figure 46: The Sardinian power system

The peak demand in 2011 was 1,700 MW and registered in July. The maximum peak load is registered in summer instead of winter because of the use of air conditioning. The maximum peak load appears around 8-9 pm during summer and the minimum around 2-4 am during spring (figure below).

Figure 47: Seasonal daily load profile in Sardinia



Source: Celli G., Mocci S. et al (2013)

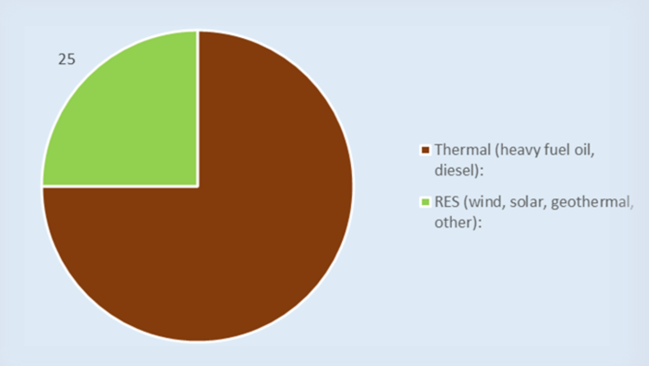
A number of studies have looked at a pair of extreme conditions for grid operation with high RES penetration Those studies conclude that large scale RES into the electric power system is possible only if the transmission infrastructure is reinforced in order to allow exports and eliminate congestions on the local grid.

7.1.11Sicily (Italy)

Sicily is the largest island in the Mediterranean Sea. It is also the most solar irradiated among Italy's regions. The annual average horizontal irradiation reaches 1,800 kWh/m^2 while in Lombardia (second largest region) is 1,100 kWh/m^2.

Figure 48: Sicily

Table 21: Info sheet- Sicily

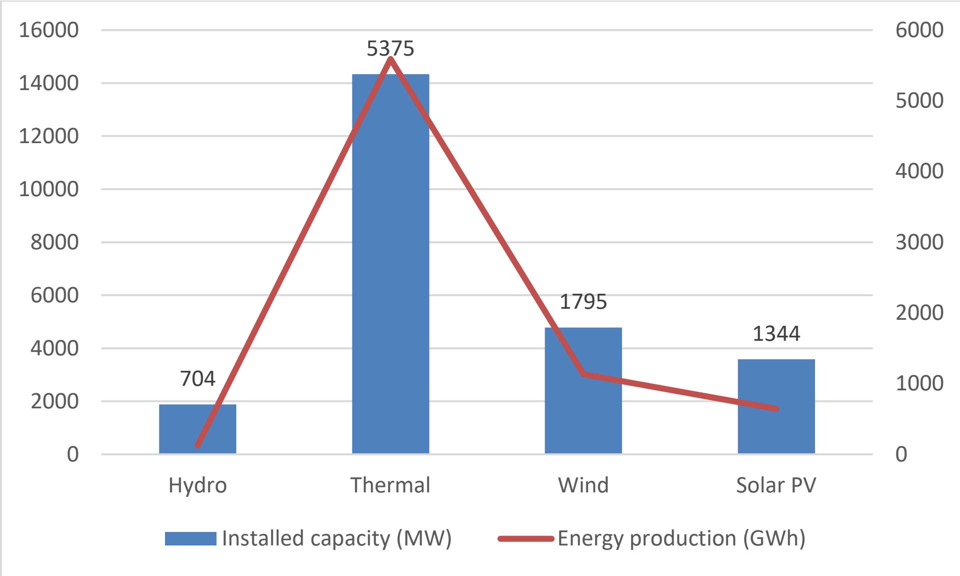
Population (2016)	5,074,261
Area (km²)	25,711
GDP (m. €) (2014)	87,383
Distance from mainland (km)	8 from mainland Italy
Seasonality in electricity demand	Yes
Interconnection (with mainland) **Interconnection (with other islands)**	Weak No
Operator	TERNA (TSO)
Local electricity production (GWh)	19,708
Local electricity production mix (%)	

Local electricity production

Thanks to recent policy support, Sicily has seen an impressive renewable energy deployment over the last decade (wind energy capacity reached 1.8GW in 2016 from 0.8 in 2008). RES deployment has therefore pushed for investments to reinforce the grid infrastructure, particularly the connection to the Italian peninsula.

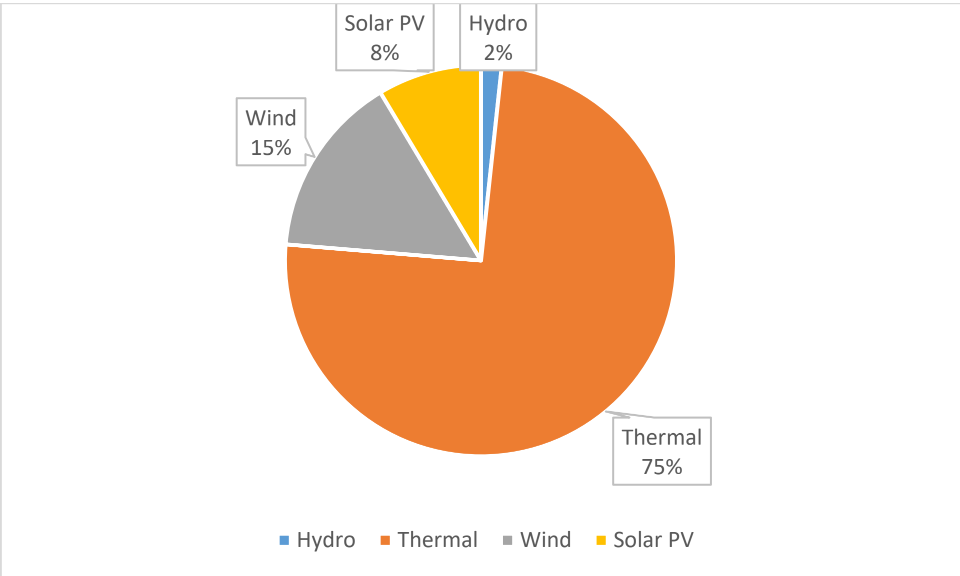
In 2016, energy production in Sicily was composed as follows:

Figure 49: Key energy data, Sicily



Source: TERNA

Figure 50: Annual generation breakdown, Sicily- 2016

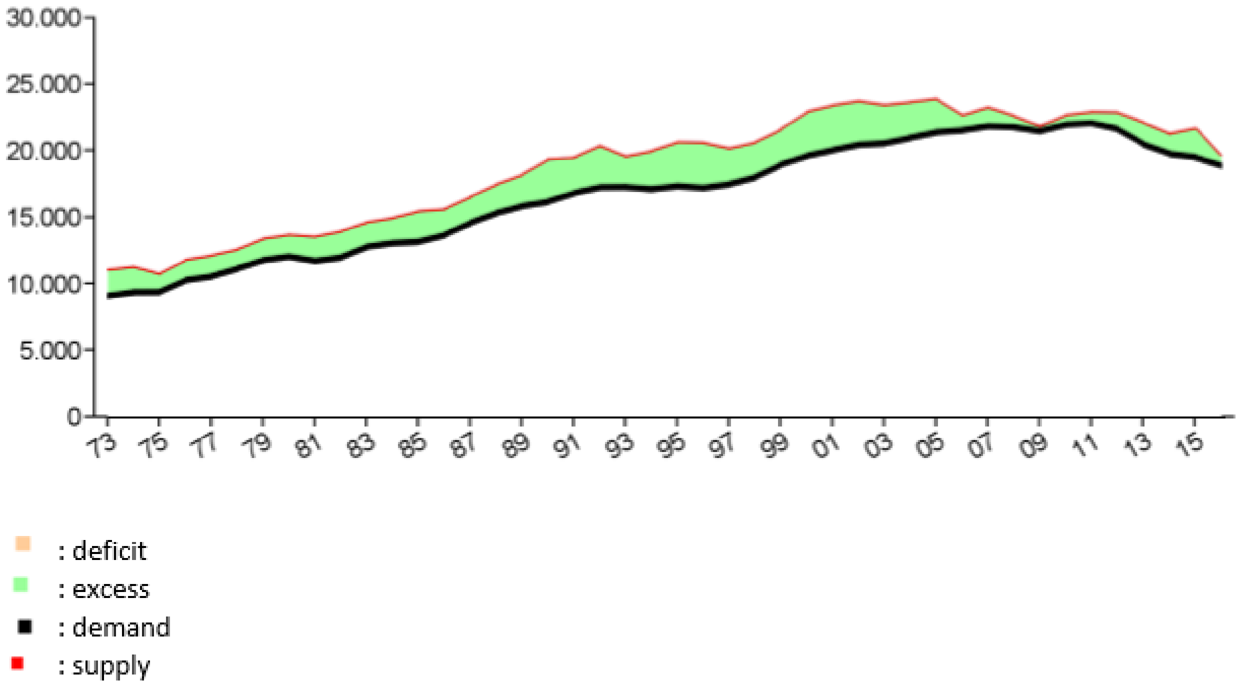


Source: TERNA

In 2016, thermal energy production accounted for 75% of total production, followed by wind energy (15%) and solar PV (8%).

In 2016, the annual energy demand was at 18,893.3 GWh. Net energy production for end-users (excluding pumping) was at 19,707.8 GWh, thus creating an excess of 814.5 GWh.

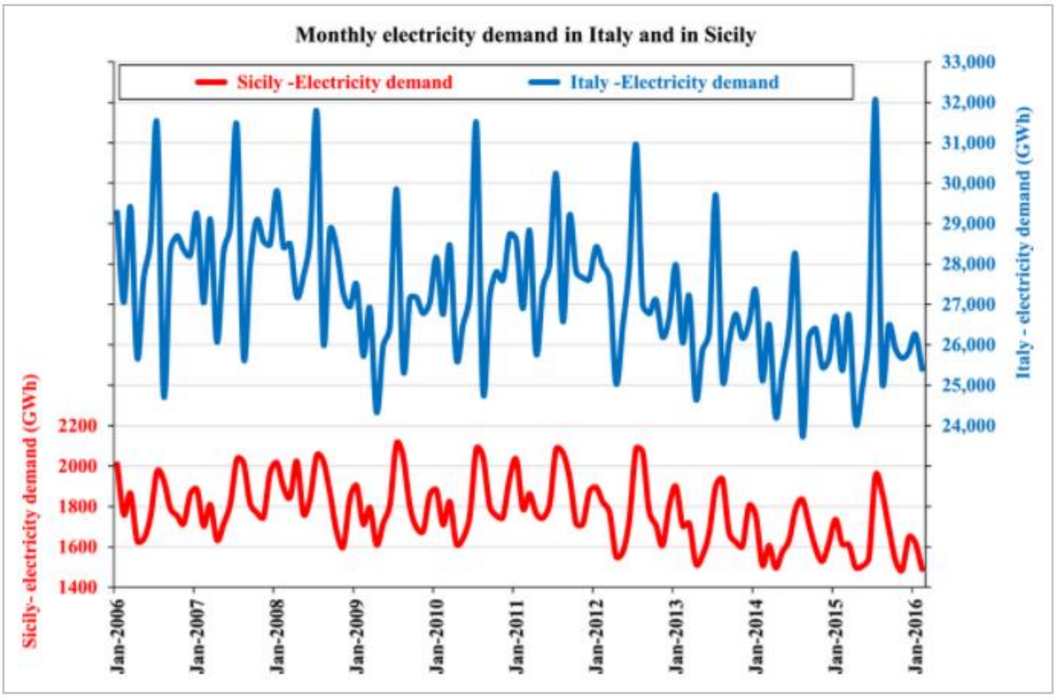
Figure 51: Historical demand- supply in Sicily



Sicily is interconnected to the mainland by one 380 kV AC link; however, the island has been always capable to meet its own demand (see Figure 8) and create excess generation capacity.

TERNA is planning to reinforce the transmission capacity of Sicily by investing in a 38-km submarine cable which will connect Sorgente (Messina- Sicily) and Rizziconi (Reggio Calabria). The connection is almost completed (end of 2016- tbc).

Figure 52: Monthly power demand in Italy and in Sicily[23]



7.2 Annex 2: Basic mapping of islands

Below there is a detailed mapping of the islands presented in Section 2.2. It includes islands from eleven countries: Denmark (plus Faroe Islands), Estonia, Finland (plus Aland islands), France, Greece, Ireland, Italy, Malta, Portugal, Spain and Sweden.

Data for German and Croatian islands could not be retrieved. Cyprus and Ireland (main islands) are not included in the mapping because of the EUROSTAT Islands definition.

7.2.1 DENMARK

Overall, 3.6 million people are estimated to live on the Danish islands (including Faroe).

[23] Source: Meneguzzo et al (2016) The remarkable impact of renewable energy generation in Sicily onto electricity price formation in Italy.

Table 22: Danish small islands

Island	Population (2017)	Area (km2)
Sjælland (Zealand)	2,287,740	7,031.0
Agersø	174	
Amager	196,047	95.3
Bogø	1,156	13.0
Dybsø	0	
Egholm	0	
Enø	392	3.4
Eskilsø	6	
Farø	4	
Gavnø	35	
Glænø	44	
Hesselø	0	
Klaus Nars holm	2	
Langø	2	
Lindholm	0	
Masnedø	182	1.7
Musholm	0	
Møn	9,385	218.0
Nekselø	19	
Nyord	41	
Omø	162	
Orø	893	15.0
Saltholm	2	
Sejerø	340	12.4
Slotsholmen	15	
Sprogø	0	
Trekroner	1	
Tærø	0	
Albuen	0	
Askø	34	
Barneholm	0	
Enehøje	0	
Falster	42,738	514.0
Fejø	434	16.0
Femø	112	
Hyllekrog	0	
Lilleø	6	
Lindholm	0	
Lolland	60,214	1,243.0
Rågø	0	
Skalø	0	

Island	Population (2017)	Area (km2)
Slotø	0	
Vejlø	0	
Vejrø	4	
Bornholm	39,695	588.0
Christiansø	0	
Frederiksø	0	
Christiansø + Frederiksø	78	
Funen archipelago (aggregated)	494,049	2,985.0
Avernakø	114	
Birkholm	9	
Bjørnø	32	
Brandsø	0	
Bågø	24	
Drejø	69	
Dræet	0	
Ejlinge	0	
Fænø	2	
Halmø	0	
Hjelmshoved	0	
Hjortø	6	
Illumø	0	
Langeland	12,384	284.0
Lyø	99	
Romsø	0	
Siø	15	
Frederiksø	1	
Skarø	31	
Store Svelmø	0	
Strynø	179	
Strynø Kalv	0	
Thurø	3,525	7.5
Tornø	4	
Torø	0	
Tåsinge	6,146	70.0
Vigelsø	0	
Æbelø	0	
Ærø	6,168	88.0
Agerø	28	
Alrø	142	7.5
Als	49,976	312.0
Anholt	137	
Barsø	20	

Island	Population (2017)	Area (km2)
Egholm	47	
Endelave	162	
Fanø	3,345	56.0
Fur	771	22.0
Gjøl	0	
Hindø	0	
Hirsholm	2	
Hjarnø	113	
Hjelm	0	
Jegindø	415	7.9
Kalvø	12	
Langli	0	
Livø	10	
Læsø	1,793	101.0
Mandø	43	
Mors	20,637	368.0
Rømø	584	129.0
Samsø	3,724	112.0
Spirholm	0	
Store Okseø	1	
Tunø	111	3.5
Vendsyssel-Thy	295,407	4,685.0
Venø	192	
Vorsø	1	
Årø	154	5.7
	3,540,641	

7.2.2 Faroe Islands

The table below present key economic data for Faroe Islands.

Figure 53: Key economic data for Faroe Islands

Population (2017)	Area (km^2)
50,250	1,399

7.2.3 ESTONIA

Overall, 45,287 people are estimated to live on the Estonian islands.

Table 23: Estonian small islands

Island	Population	Area (km^2)
Abruka	33	8.8
Aegna	11	2.9
Hiiumaa	9,451	989.0
Kassari	113	19.3
Kessulaid	5	1.7
Kihnu	701	16.4
Krasuli	0	0.2
Koinastu	1	2.6
Manilaid	50	1.9
Muhu	1,867	198.0
Naissaar	8	18.6
Osmussaar	5	4.7
Suur- Pakri+ Vaike-Pakri	5	24.5
Piirissaar	102	7.8
Prangli	185	6.4
Ruhnu	154	11.4
Saaremaa	32,150	2,671
Vahase	1	0.7
Vilsandi	30	8.8
Vormsi	415	92.9

Source: ESIN, www.saared.ee

7.2.4 FINLAND

Below there is a list of islands with a population greater than 30.

Table 24: Finnish small islands

Island	Population	Area (km²)
Esko- Jarvon-Angson	36	7.6
Hailuoto Karlo	983	195.4
Hitislandet	65	4.1
Houtskar	350	34.7
Hogsara	47	5.3
Inio	108	74.1
Jumo	54	3.6
Kasnas	64	8
Keistio	41	10
Kirjais	31	10.2
Korpo kyrkland	656	63.9
Kuutsalo	40	7.7
Lillpellinge	55	2.8
Lomso-Kivimo	33	5.9
Miehilsholm	70	5.9
Mossala	68	7.2
Nagu Lilland	296	38.4
Nagu Storland	924	72.9
Norrskata	76	14.4
Orslandet	57	11.6
Palva	56	2.9
Rosala	142	8.2
Saverkeit	43	8.6
Simsalo	32	1
Skarlanet	190	13.6
Storpellinge	178	12.9
Suomenlinna	799	0.8
Uto	33	0.8
Vartsala	96	31
Velkuanmaa	33	7.1

Source: ESIN

7.2.5 ALAND ISLANDS

The 2016 population was registered at 28,983 people. Below there is a list of small islands which have been included in the overview.

Table 25: The Aland Islands

Island	Population	Area (km^2)
Anderso	3	
Asterholma	11	
Baggholma	12	
Bjorko	13	
Bjornholma	13	
Brando	108	
Busso	6	
Degerbylandet	201	
Dano	19	
Eckero	978	
Enklinge	89	
Finholma	21	
Finno	17	
Fisko	40	
Flisolandet	109	
Hamno	25	
Hasterbodalandet	93	
Helso	81	
Huso	5	
Isakso	19	
Jurmo	53	
Jyddo	8	
Karlby	79	
Korso	20	
Kumlinge	215	
Kyrkogardso	10	
Lapp	46	
Ledsora	36	
Mickelso	38	
Noto	17	
Sando	40	
Seglinge	41	
Simskala	39	
Sonboda	82	
Sottunga	108	
Torsholma	89	
Tofto	104	
Ulverso	23	
Vardo	184	
Ava	85	

Island	Population	Area (km²)
Overboda	36	
Overo	17	

7.2.6 FRANCE

Overall, 344,000 people are estimated to live on the French islands (Corsica and small islands). The mapping doesn't include islands from the overseas and outermost regions.

During summer, most of the small islands see their population increasing from four- fold to even ten- fold (e.g. Ile d'Arz, Hoerdic).

There is no sufficient information on whether small French islands are interconnected to the mainland.

Table 26: French small islands

Island	Area (km²)	Population
Ile d' Yeu	23.3	4,636
Belle-ile	85.6	5,293
Groix	14.8	2,233
Ouessant	15.6	877
Ile-aux-Moines	3.2	611
Batz	3.1	494
Brehat	3.1	406
Porquerolles	12.5	200
Houat	2.9	246
Molene	0.8	169
ile- d-Arz	3.3	249
Aix	1.3	245
Sein	0.6	216
Ile du Levant	0.9	186
Hoedic	2.1	119
Ile des Embiez	0.9	127
Ile St Honorat	0.6	56
Port Cros	0.7	48
Mt St Michel	4.0	41
Gd Ile Chausey	0.7	6
Ile St Marguerite	2.7	16
		16,474

Source: ESIN

7.2.7 GREECE

Overall, 1,376,270 people are estimated to live on the Greek islands.

Table 27: Overview of non- interconnected Greek islands

Island	Area (km^2)	Population
Crete	8,303	623,065
Lesvos	1,636	86,436
Rhodes	1,401.5	115,490
Chios	842.8	51,390
Samos	477.9	32,977
Limnos	476.3	16,992
Naxos	429.8	17,930
Karpathos	300.2	6,226
Kos	287.6	33,388
Ikaria	255.3	8,423
Skyros	206.9	2,994
Paros	196.3	13,715
Milos	158.4	4,977
Amorgos	121.5	1,973
Kalymnos	110.6	16,005
Ios	108.7	2,024
Kythnos	99.4	1,456
Astypalaia	96.4	1,334
Mykonos	86.1	10,134
Syros	84.1	21,507
Santorini	76.2	15,231
Serifos	75.2	1,420
Sifnos	73.9	2,625
Kasos	66.4	1,084
Tilos	61.5	780
Symi	57.9	2,590
Leros	54.1	7,917
Ag. Efstratios	43.3	270
Sikinos	41.7	273
Nisyros	41.3	987
Psara	40.5	458
Anafi	38.6	271
Kimolos	37.4	910
Antiparos	35.1	1,211
Patmos	34.1	2,998
Folegandros	32.4	765
Fournoi	30.5	1,120
Gavdos	29.6	152
Chalki	27	478
Antikythera	20.4	68
Iraklia	18.1	141
Leipsoi	15.8	790

Island	Area (km^2)	Population
Pserimos	14.6	80
Donousa	13.7	167
Oinouses	14.4	826
Agathonisi	13.4	185
Othonoi	10.1	392
Thymaina	57.4	57
Thirasia	9.2	319
Kastelorizo	9.1	492
Schinousa	8.1	227
Arkoi	6.7	44
Koufonisi	5.8	399
Telendos	4.6	94
Giali	4.6	21
Ereikousa	4.4	496
Delos	3.5	24
Marathi	0.4	5
		1,114,803

Source: ESIN, EUROSTAT, HEDNO

Table 28: Overview of interconnected Greek islands[24]

Island	Area (km^2)	Population	Island group
Adelphoi	1	11	Sporades
Agkistri	13	1,142	Argosaronic
Aigina	87	13,552	Argosaronic
Alatas	1	5	Sporades
Alkionides	1	35	
Alonissos	130	2,750	Sporades
Amouliani	7	499	North Aegean
Andros	380	9,170	Cyclades
Antipaxos	4	61	Ionian
Corfu	611	102,071	Ionian
Dokos	12	8	Argosaronic
Elafonisos	20	1,041	Ionian
Farmakonisi	4	74	Dodecanese
Hydra	50	1,982	Argosaronic
Ithaca	96	3,107	Ionian
Kalamos	25	465	Ionian
Kastos	5.9	80	Ionian
Kea (Tzia)	104	1,783	Cyclades
Kefalonia	734	35,801	Ionian
Kythera	278	3,017	Ionian
Meganisi	20	1,240	Ionian
Mathraki	3	297	Ionian
Megisti	9	271	Dodecanese
Passas	2	5	North Aegean
Paxoi	25	2,207	Ionian
Ro	1	15	Dodecanese
Samothrace	178	2,859	North Aegean
Saria	20	22	Dodecanese
Skiathos	50	6,160	Sporades
Skopelos	97	4,696	Sporades
Spetses	22	3,618	Argosaronic
Spetsopoula	2	11	Argosaronic
Thasos	380	13,770	North Aegean
Tinos	194.5	8,630	Cyclades
Tourlis	1	35	
Trikeri	3	91	Sporades
Trizonia	3	126	

[24] Evoia and Lefkada have been excluded due to a ‘fixed link to mainland’ (Eurostat definition). Poros and Salamina have been excluded as they are both located less than 1 km away from the mainland.

Island	Area (km^2)	Population	Island group
Zakynthos	406	40,760	Ionian
		261,467	

Source: ESIN, EUROSTAT, HEDNO

7.2.8 IRELAND

Overall, 3,000 people are estimated to reside on the Irish islands (excluding main island).

Table 29: Small Irish islands

Island	Population	Area (km^2)
Arrain Mhor	516	43
Bere island	210	12
Clare	160	130
Clynish	4	7
Collanmore	0	38
Dursey	6	20
Gabhla	15	
Heir	22	97
Inis Bigil	24	20
Inishbofin- Gal	180	4
Inishbofin- Don	36	4
Inis Oirr	249	32
Inishbeg	8	13
Inishfree Upper	9	30
Inishkeeragh	7	30
Inishlyre	3	5
Inish Meain	157	50
Inish Mor	824	108
Inishmuclohy	6	18
Inishnee	43	96
Inishturk	53	25
Islandmore	0	12
Lambay island	6	6
lond island	6	36
Oilean Chleire	125	121
Rutland	0	9
Sherkin	106	151
Tory island	144	14
Whiddy	20	10
	2,939	

Source: ESIN

7.2.9 ITALY

Overall, 6.8 million people are estimated to live on the Italian islands (Sicily, Sardinia, non-interconnected small islands and other islands):

- Sicily population: 5.08 million
- Sardinia population: 1.66 million
- Other: 0,04 million

Table 30: Non-interconnected Italian islands

Island	Area (km^2)	Population
Capraia	19.3	410
Giglio	21.5	1,466
Ponza	7.6	3,360
Ventotene	1.4	745
Capri	10.4	14,117
Tremiti	2.5	486
Favignana	20	3,407
Levanzo	5.8	208
Marettimo	12.4	684
Pantelleria	84.8	7,846
Ustica	8.2	1,332
Alicudi	5.1	105
Filicudi	9.3	235
Lipari	37.6	9,000
Panarea	3.4	241
Salina	26.2	2,534
Stromboli	12.6	400
Vulcano	21.1	715
Lampedusa	20	5,866
Linosa	5.3	433
		53,590

Source: ESIN (mainly)

Table 31: Other islands

Island	Area (km²)	Population
Giudecca	3	255
Burano	21	2,777
Caprara	3	496
Isola san Michele	0.5	15
Nisida	1	300
San Stefano	4	10
San Domino	2.6	215
San Nicola	2	119
Tavolara	5	25
Torcello	1	20
Vivara	1	5
Vulcano	25	10
		4,247

Source: ESIN

7.2.10 MALTA

Excluding the main island, the analysis considered Gozo and Comino islands (NUTS code: MT002).

Table 32: Population of small Maltese islands

Island	Area (km²)	Population
Gozo and Comino		31,592

7.2.11 PORTUGAL

The table below presents the number and population of islands.

Table 33: number and population of Portuguese islands

Island	No of islands	Population
Azores	9	246,353
Madeira	2	258,686

7.2.12 SPAIN

The table below presents the number and population of islands.

Table 34: Number and population of Spanish islands

Island	No of islands	Population
Balearic Islands	4	968,950
Canary Islands	7	2,126,144

7.2.13SWEDEN

According to ESIN, there are 391 small islands in Sweden. Mapping analysis excluded artificial islands, river islands and those with a surface less than 22 km^2.

Table 35: Swedish small islands

Island	Area (km^2)	Population
Gotland	2,968	56,656
Öland	1,343	24,984
Orust	344	14,562
Hisingen	197	147,200
Värmdö	179	57,497
Tjörn	147	14,024
Väddö and Björkö	128	1,711
Fårö	109	503
Gräsö	95	665
Selaön	95	1,758
Tosterön and Aspön	77	3,590
Ekerön and Munsön	68	15,369
Alnön	68	8,530
Torsö	62	516
Ingarö	62	6,855
Ljusterö	62	1,473
Ammerön	59	103
Kållandsö	57	929
Hemsön	54	130
Ornö	48	211
Frösön	41	10,570
Gotska Sandön	36	0
Utö	29	191
Adelsön	26	741
Visingsö	25	750
Rånön	25	0
Sandön	25	53
Holmön	23	59
Blidö	22	598

Island	Area (km^2)	Population
		370,228

Source: ESIN, SCB

7.3 Annex 3: Overview of NUTS-2 and NUTS-3 REGIONS

The source of the overview is the EUROSTAT database, available at: http://ec.europa.eu/eurostat/web/nuts/nuts-maps-.pdf

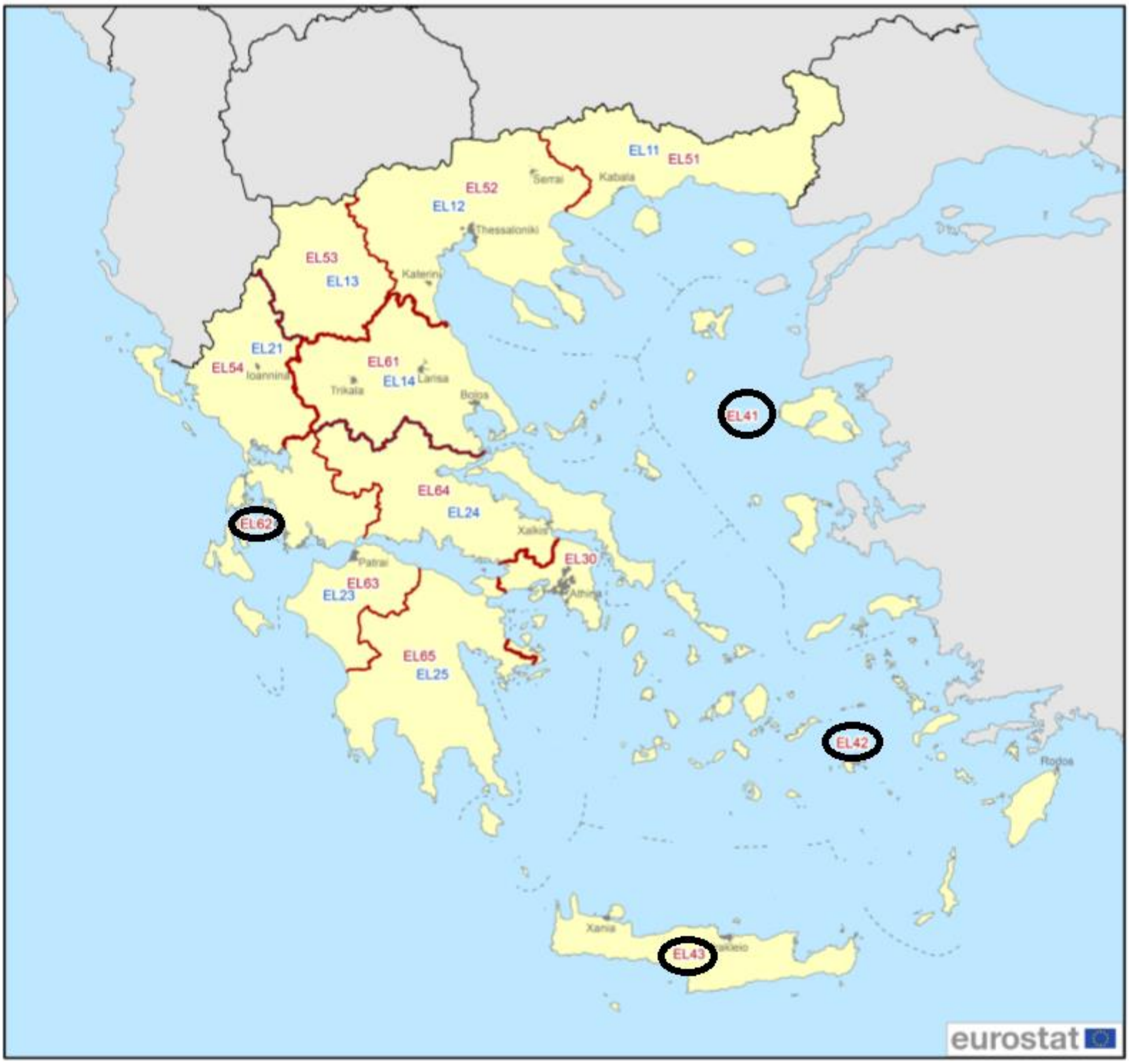
7.3.1 NUTS 2 regions

7.3.1.1 Finland

7.3.1.2 France


FR30
FR22
FR23
FR25
FR10
FR21
FR41
FR42
FR52
FR51
FR24
FR26
FR43
FR53
FR63
FR72
FR71
FR61
FR62
FR81
FR82
FR83
Guadeloupe
FRA1
FR91
Martinique
FRA2
FR92
Guyane
FRA3
FR93
Réunion
FRA4
FR94
Mayotte
FRA5
eurostat

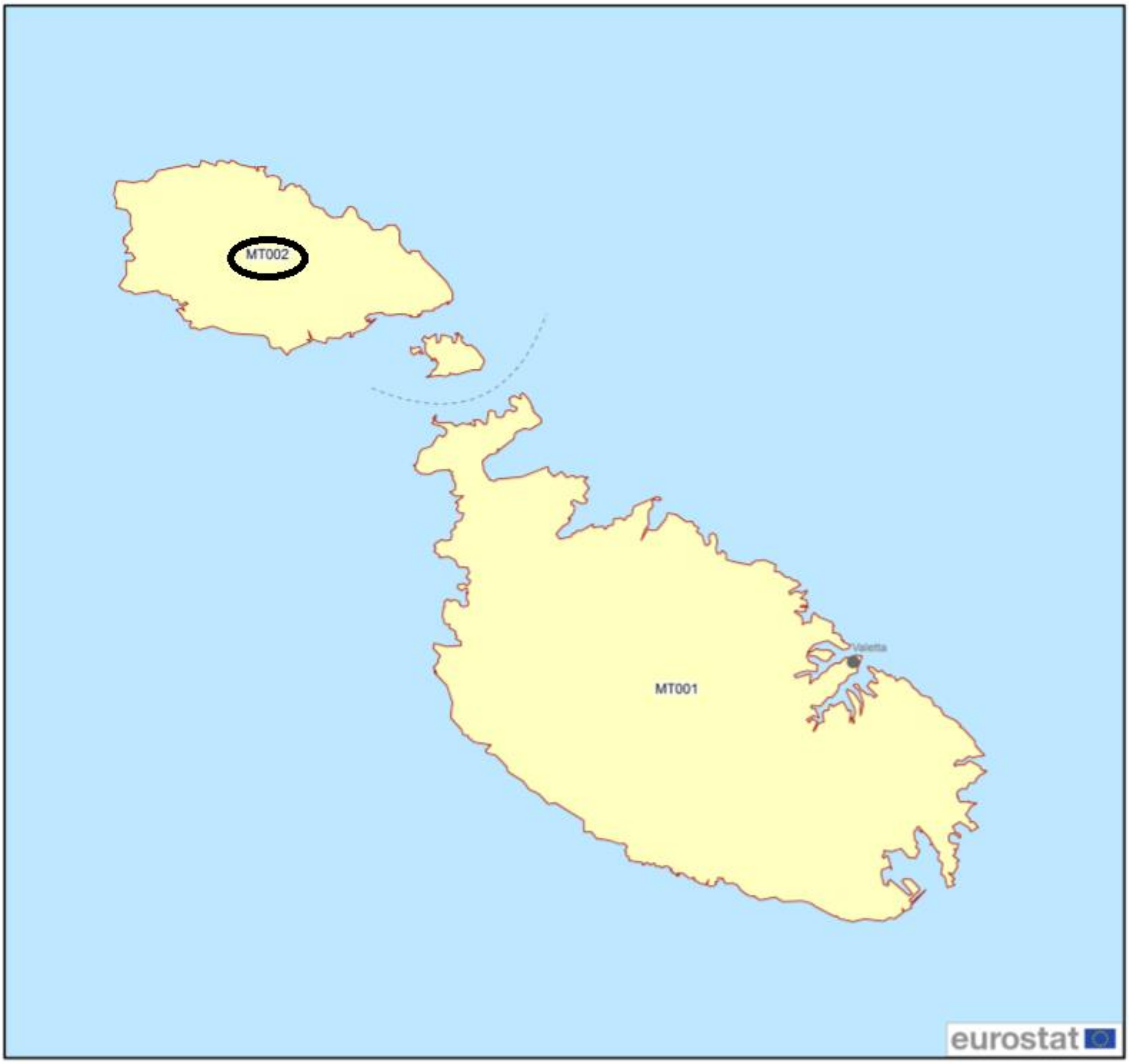
7.3.1.3 Greece


EL11
EL51
EL52
EL12
EL53
EL13
EL21
EL54
EL61
EL14
EL41
EL64
EL24
EL62
EL30
EL63
EL23
EL65
EL25
EL42
EL43
Serrai
Kabala
Thessaloniki
Katerini
Ioannina
Larisa
Trikala
Bolos
Xalkis
Patrai
Athina
Rodos
Xania
Irakleio
eurostat

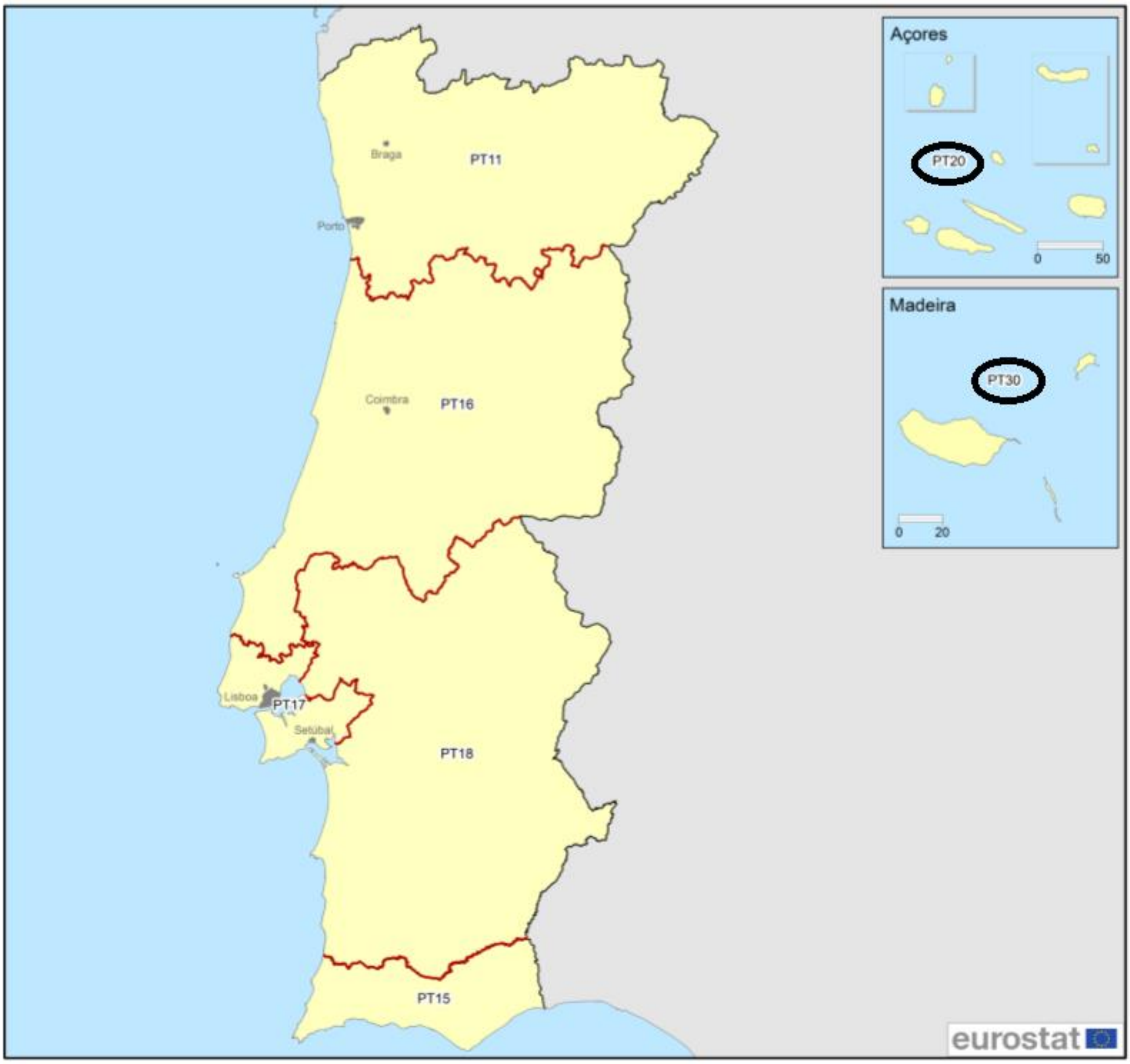
7.3.1.4 Italy


ITH1
ITH2
ITH3
ITH4
ITH5
ITC1
ITC2
ITC3
ITC4
ITI1
ITI2
ITI3
ITI4
ITF1
ITF2
ITF3
ITF4
ITF5
ITF6
ITG1
ITG2
eurostat

7.3.1.5 Malta



7.3.1.6 Portugal



7.3.1.7 Spain

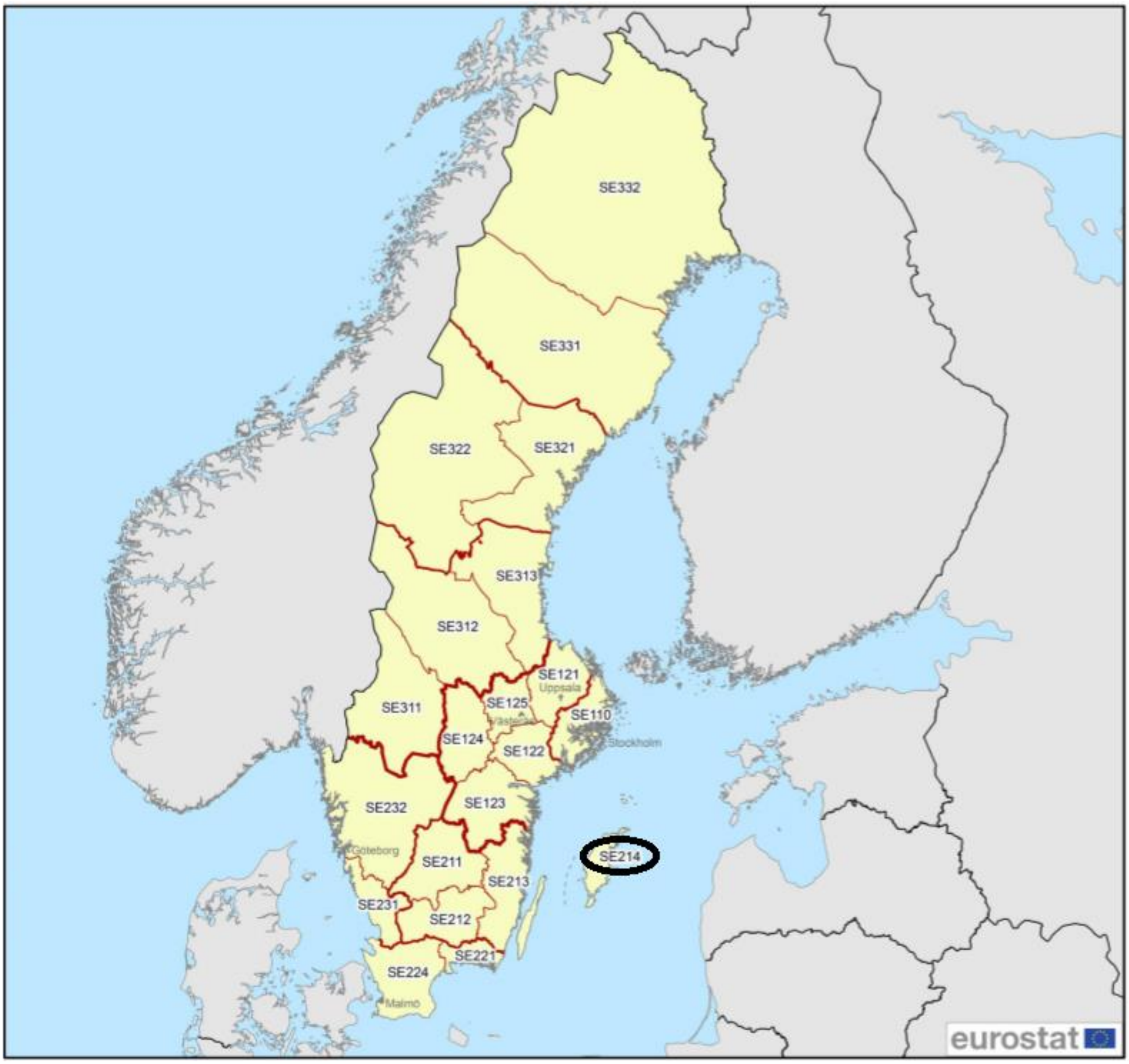

Canarias
ES707
ES708
ES709
ES704
ES706
ES705
ES703
Santander
ES111
ES112
ES120
ES130
ES213
ES212
ES211
ES220
ES114
ES113
ES413
ES412
ES230
ES241
ES414
ES513
ES512
ES511
ES419
ES418
ES417
ES243
Barcelona
ES416
ES514
ES415
ES424
ES411
ES242
Madrid
ES300
ES522
ES533
ES432
ES425
ES423
ES532
ES523
ES531
ES431
ES422
ES421
ES521
Alicante
ES613
Cordoba
ES616
ES620
ES615
Sevilla
ES618
ES614
Cartagena
Granada
ES611
ES617
Cádiz
ES612
ES630
ES640
eurostat

7.3.2 NUTS- 3 regions

7.3.2.1 Croatia

7.3.2.2 Denmark

7.3.2.3 Sweden


SE332
SE331
SE322
SE321
SE313
SE312
SE311
SE121
Uppsala
SE125
SE110
SE124
SE122
Stockholm
SE232
SE123
SE214
Göteborg
SE211
SE213
SE231
SE212
SE221
SE224
Malmö
eurostat

7.4 Annex 4: The case of Crete

Crete is the largest non-interconnected Greek island and amongst the five biggest islands in the Mediterranean Sea. It has a population of 623,065 inhabitants (2015 data). In early 2017, thermal capacity accounted for 813 MW while RES capacity accounted for 279.4 MW. Peak load was at 627.3 MW. RES production accounted for 23% of the total energy production in the 1st half of 2017. Crete has a high RES potential (for wind and solar).

The Long-Term Energy Planning Study for Crete, prepared by E3MLab of NTUA, has quantified scenarios which illustrate the development of the strategic energy approach for Crete. The future of energy in Crete can be secure, clean, affordable and attractive for tourism and local business and employment.

7.4.1 Description of selected scenarios

The table below presents the overview of the analysed scenarios.

Table 36: Overview of scenarios considered for Crete

	Decentralised Approach	Centralised approach	Mid-way ….
BAU	**Oil-green**	**ELC-M2W**	**GAS+Interconnection**
No interconnection, fuel oil and diesel used for power generation, no compliance to Directives	Energy efficiency, biomass and other resources (hydro small scale)	High scale RES, mainly wind (200 MW by 2020, 800 MW by 2030 and 2,300 by 2050)	Natural gas deployment (540 MW available as of 2020), FSRU, small scale LNG combined with 2*350 MW interconnection
Very limited RES development due to saturation of the autonomous system	Decentralised RES, mainly solar PV, smart systems	2 * 500 MW DC interconnection and a 220 MW AC.	Solar PV, wind less than in the centralized approach
RES by 2050: 505 MW, with a huge untapped potential of wind and solar	RES by 2050: 1,250 MW Oil and gas capacity: 792 MW	RES by 2050: 2,750 MW No need of introducing gas. Power plants stay as backup	Biomass, efficiency and other resources developing less than in the decentralized case

Crete considerably depends on tourism and agriculture. A green island based on smoothly dispersed renewables visible in touristic services and areas is attractive to tourism development in the future. Also, agriculture can benefit from renewables, such as exploitation of biomass, solar energy and small-scale wind. Local maintenance and development services can support the new activity effectively.

Security of supply is under threat, firstly because of the incompatible oil-burning practice, secondly, because the electricity supply is at a distance from full reliability as long as Crete is an isolated system. The isolation deprives tapping on the local and sustainable energy resources, due to electric stability effects.

7.4.2 Key findings of the study

The study brought the following conclusions:

- Regarding the local renewable energy resources, maximum benefits can be reached only of the development of renewables is dispersed, integrated with activity and living conditions and operated as much as possible by the local economy agents. Developing only large-scale wind parks for exporting energy to the mainland is important for the overall renewables balance of the country but is in contrast with local interest in getting business benefits for the local economy. Large wind-parks are also poorly acceptable by the neighbouring communities. A balanced approach to the development of renewables is best for growth and sustainability. The ambition about renewables to develop can be significantly high, thanks to the potential and the possibilities enabled by the electrical interconnection with the mainland.
- Relying solely on the electrical connection and a full dependence on imports of energy from the mainland is not an attractive solution. Such a prospect leaves unexploited the vast sustainable energy resources of the island and misses collecting economic and employment benefits from the local energy-related activity.
- Therefore, energy isolation of the island is not an option. Electrical connection with the mainland, based on sufficient and redundant capacity and routing, is of utmost importance and is urgent, due to the limitations of oil-firing power generation.
- A green island also needs to develop renewables and energy efficient solutions in all sectors, not only in electricity generation. To this respect, greening the transport sector is of great importance. For example, electrifying mobility at a large scale can serve as a flagship of efficiency and citizen-friendly development in the island and the cities.

7.4.3 Key energy data for scenarios developed for Crete

The figures below present key data for power supply, cost of power generation and related emissions for each of the analysed scenarios.

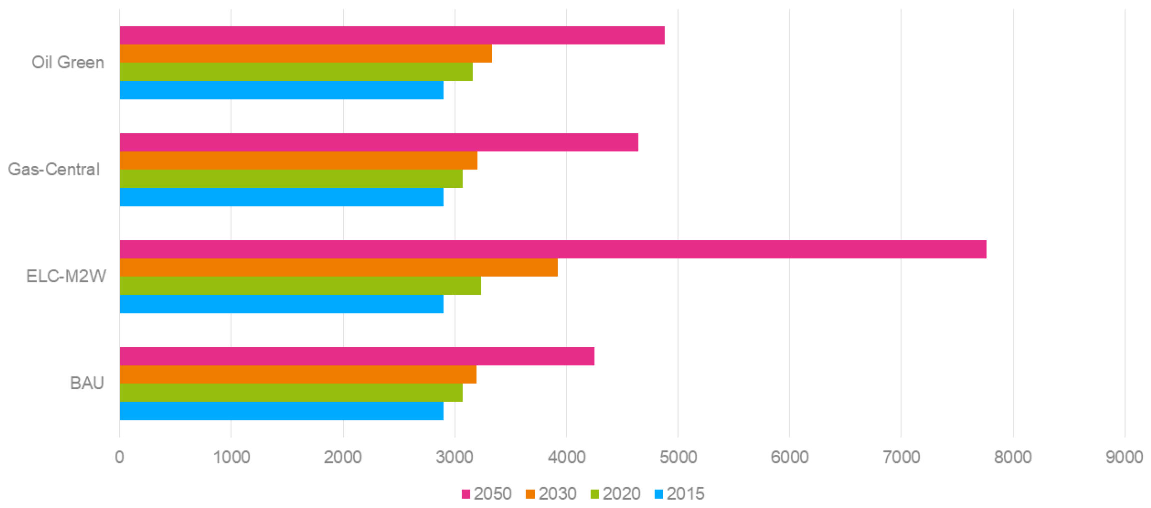


Figure 54: Total electricity supply (in GWh)

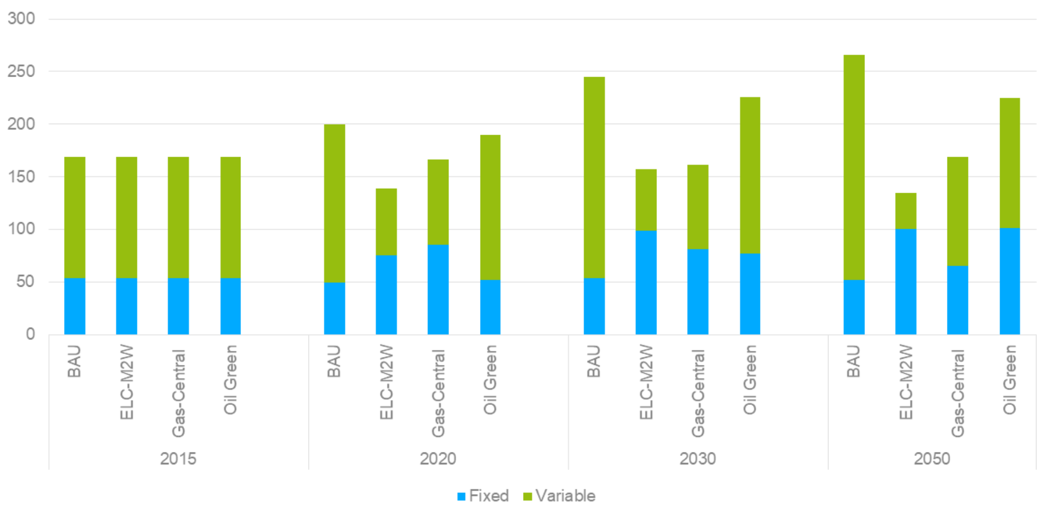


Figure 55: Average cost of electricity generation (in EUR/MWh)

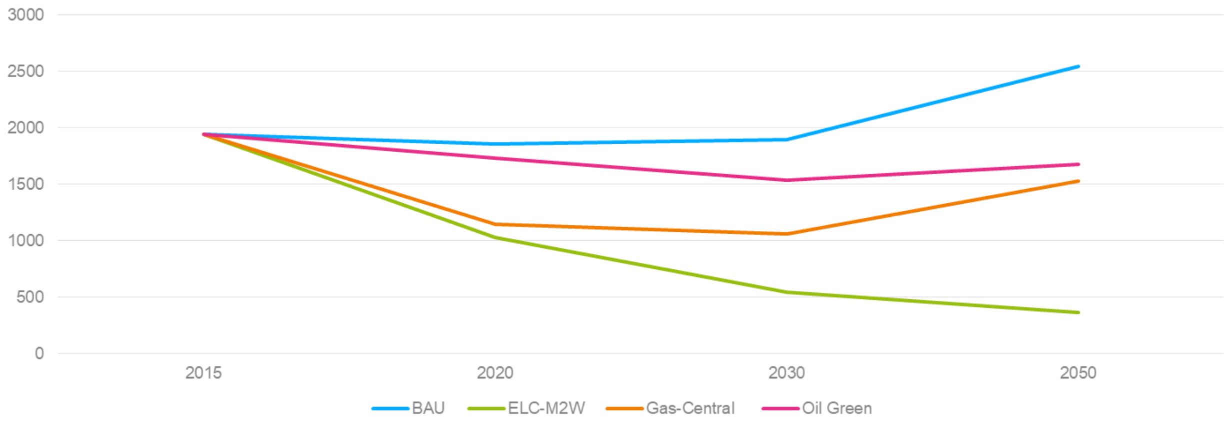


Figure 56: Emissions from electricity production (ktCO_2)

7.5 Annex 5: Detailed analysis of past and ongoing European R&I projects

7.5.1 Past EC-funded R&I projects under FP7 program

One demonstration of the Twenties project (Demo 2) took place in the Faroe Islands [35] [36]. These islands, part of the Kingdom of Denmark, are located between the Norwegian Sea and the North Atlantic, about halfway between Norway and Iceland. The corresponding power system is isolated with a peak load of about 45 MW at the moment of the project, with a high share of wind power that increased significantly during the project (from 5% in 2012 to 25% in 2014). The main challenge is thus to cope with the wind variability, especially when the wind speed suddenly goes over the cut-off speed of wind turbines (frequent storms). Several innovative solutions were developed within the Twenties project to cope with the challenges: improved wind forecasts, smart wind turbines, and a Virtual Power Plant (VPP) system called "Power Hub".

Smart wind turbines can operate at higher wind speeds, can ramp down slowly in case of a storm, can be set to a fixed output power level and can contribute to frequency control. Power Hub, the cornerstone of the Demo, proved that the VPP technology could improve the system security through the coordinated control of Distributed Energy Resources (DERs) and Demand Response (DR). In particular, the VPP Power Hub can indeed reduce or shed loads from three industrial sites in less than one second, in order to avoid frequency collapse in case of failure at a power plant or a sudden drop in wind power generation. Beyond the demonstration of the added value of the VPP technology, the two main findings of the project are the following: firstly, it is a challenging task to mobilize industrial units to participate in VPPs because the unit owner has to be given an attractive and simple economic offer and has to understand the (limited) impact of its participation on the industrial output; secondly the existence of regulatory and market barriers. Note that, at the end of the project, the installation of a battery at a wind park was a solution under development to cope with the small intra-hour variations in wind production. The overall Twenties' budget was €57 million, but Demo 2 was only one of the six demonstration projects.

The EcoGrid project, co-funded by the Danish ForskEL program, aimed at demonstrating on the Bornholm Island a market designed to incorporate demand response as a resource to balance energy systems with a high proportion of fluctuating energy sources [37] [38]. Bornholm is a

Danish island in the Baltic Sea with a population of about 40,000 inhabitants. This project showed that a real-time price signal can lead to a significant load reduction (e.g. a five-minute real-time signal reduced the total peak load by 1.2%) with a large share coming from households having equipment that controlled their heating system to respond automatically to price signals (i.e. 87% of the peak load reduction). This flexible DR can be forecasted, but not perfectly: good forecasts of the demand response are difficult to make for a small population. The operational feedback gained in this project led to the following conclusions (among others): (i) technology standardization (in particular standards for operability), plug-and-play functionalities, and user friendliness for smart meters and automatic control apparatus for DR devices are prerequisites for large-scale deployment; (ii) because customers are at the very center of smart systems, it is crucial to ensure the willingness of the population to be part of smart systems, by developing appropriate motivating factors, including financial incentives and a communication strategy related to environmental benefits, and by a good training of the technical and social skills of the installers and support staff; (iii) adequate market models allowing demand-side participation in the power balancing markets of small customers must be implemented. The EcoGrid budget was €21 million.

The Grid4EU project aimed at testing innovative system concepts and technologies through real-size demonstrators in order to study how distribution system operators could dynamically manage electricity supply and demand, while avoiding violations of operational limits and of security constraints [39]. It did not focus on energy islands, but the Demo 6 – "Nice Grid" – took place in the French PACA region (town of Carros in the outskirts of Nice) which can be viewed as an electrical peninsula [40]. Furthermore, island operation was also studied. Consequently, lessons learned can also be of interest for energy islands. Nice Grid focused on the optimization of PV integration into the LV grids by using PV and load forecasts, flexible loads and electricity storage. It must be noted that, in all cases studied in Nice Grid, the economic result of flexibility is negative, probably due to the fact that the price of electricity from the HV grid is low compared to energy islands.

Among the main conclusions of that demo, three of them are worth to be mentioned: (i) similarly to the EcoGrid project, customers are willing to participate to the demand response program for two main reasons: an economic dimension (control of the consumption and financial incentives) and a desire to take action for the environment: (ii) consumption and renewable generation forecasts are of paramount importance to plan flexibility activation and storage use, but real-time adjustments are necessary to correct and update the planned schedule because forecast errors do exist; (iii) energy storage systems are not perfectly reliable (availability of approximately 90% in that case), which means that the system operation needs a backup solution in case of unavailability of a storage system. The overall Grid4EU budget was €52 million, but Demo 6 was only one of the 6 demonstrations.

7.5.2 Ongoing EC-funded R&I projects under H2020 program

Under the Horizon 2020 (H2020) programme funded by the European Commission, eleven main projects are dealing with islands: NETfficient (2015-2018), TILOS (2015-2019), GRIDSOL (2016-2019), Storage4Grid (2016-2019), WiseGRID (2016-2020), InterFlex (2017-2019), INVADE (2017-2019), inteGRIDy (2017-2020), and SMILE (2017-2021).

The NETfficient project aims at demonstrating how local renewable energy generation and energy storage can ensure a supply independence and CO_2 emission reduction on the Island of Borkum (Germany) [41]. The demonstration part consists in five different use cases. The first use case consists in using a high-capacity storage system to perform peak shaving (energy arbitrage) and to provide frequency support (synthetic inertia and primary reserve) to the grid. The second use case consists in balancing the energy consumption and generation of forty homes equipped with energy generation units, smart meters and energy storage devices, through an energy management platform. The third use case is similar to the second one, except that larger buildings which might be owned and used by several parties are studied. The fourth use case consists in developing smart street lighting based on streetlamps with integrated micro-photovoltaic modules, smart meters and storage batteries, in order to use the energy supplied by the sun during the day for lighting during the night. The fifth use case consists in controlling the water temperature of the Borkum aquarium at a value of 12°C using mainly solar PV energy with the help of thermal energy storage (i.e. in order to use PV energy even during the night by thermal energy time-shifting). The pilot testing in NETfficient has just started in spring 2017 and no operational feedback is thus available at the moment of writing. The NETfficient budget is €11.4 million.

The TILOS project aims at maximizing the use of RES in covering the electricity needs of the Tilos Island through energy storage and active network management [42]. Tilos is a small Greek island located in the Aegean Sea with about 500 inhabitants and annual electricity consumption close to 3 GWh. For the moment, the electricity needs of Tilos are covered by a liquid-fuel-based thermal generator located in the island of Kos, through an undersea interconnection. Within the project, a new generation system based on a medium-scale wind turbine of 800 kW, a small-scale of 160 kW and a battery storage system of 2.4 MWh will be developed and operated on Tilos. In July 2017, the main components of the system (e.g. battery storage system, wind turbine, PV power plant, forecasting server) have been installed, but no operational feedback is thus available at the moment of writing. Note that a dedicated WP focuses on population engagement. The TILOS budget is €13.7 million.

The GRIDSOL project aims at developing "Smart Renewable Hubs", where a core of renewable synchronous generators (CSP and biogas combined-cycle) are integrated with PV to provide self-regulating flexible generation and ancillary grid services on a single output [43]. The innovative parts of the project are the development of a Dynamic Output Manager of Energy (DOME) to manage the operation of these smart renewable hubs, and a multi-tower CSP concept to reduce related costs and improve the efficiency. These smart renewable hubs constitute a concept that goes beyond energy islands, but a specific work package (WP6) is dedicated to the study of the integration of these hubs in the electric power system of European Islands, in particular to the best way to combine the technologies from the economic and environmental point of views. No specific demo is envisaged within that project. The overall GRIDSOL budget is €3.4 million, but WP6 is only a part of the project.

The Storage4Grid project aims at progressing globally in the modelling, planning, integration and operation of distributed energy storage systems (i.e. between the distribution grid level and the end-user level) [44]. The demo "Storage Coordination" will take place in the Island of Fur, a small Danish island with less than 900 inhabitants. Installation of grid-side storage systems at the MV/LV substations and of prosumer-side storage systems at the household level is considered by the local DSO as a potentially interesting solution to help integrating RES while avoiding heavy investments in strengthening the grid. Nevertheless, to be efficient, the planning and the operation of storage units at both levels must be coordinated. The main objective of the demo is to study methodologies for planning, evaluating and controlling distributed storage installations at user premises and at substation level in a coordinated fashion. The demo involves five houses having PV installations and storage units connected radially to the same distribution feeder and a storage system in that substation. The control of all units will be interconnected with the DSO SCADA system, thus enabling cooperative behaviors in the storage systems. The first deliverables are expected to be publicly available after May 2018. The overall Storage4Grid budget is €3.6 million, but the demo "Storage Coordination" is one of the three demos.

The WiseGRID project aims at developing advanced ICT services and systems in the energy distribution grid in order to progress in the deployment of secure, sustainable and flexible smart grids. Developed solutions will be implemented in four large scale demonstrators. One of the pilot sites is Kythnos, an island in the Western Cyclades with a population of about 1600 inhabitants. Kythnos has a thermal installed capacity of 4.97 MW with a peak power consumption of 2.7 MW. That demo will incorporate smart and innovative technologies in the fields of energy, water, waste and mobility in order to move towards the smart and sustainable development of the island. No operational feedback is available at the moment of writing. The overall WiseGRID budget is €17.6 million, and Kythnos is one of the four pilot sites.

The InterFlex project aims at investigating the interactions between the different sources of flexibility in smart grids, in particular energy storage systems, smart charging of electric vehicles, demand response, islanding, grid automation and the integration of different energy carriers (gas, heat, electricity). According to a press release of January 2017, one of the real-scale demonstrators should consist of islanding a portion of the distribution grid in Norway, to test a "peer-to-peer" approach and to assess the benefit of advanced control of local energy systems for the distribution system operator [45]. However, the project is currently in its early phase and the specific scope and location of the demonstrators could still change.

The INVADE project aims at using renewable energy more effectively, optimizing the supply of electricity and making services more end-user centric by using a cloud-based flexibility management system, energy storage technologies, electric vehicles and novel business models. The developed solution will be implemented in large-scale pilots in five European countries (Norway, Germany, Spain, The Netherlands and Bulgaria), but none of them will take place in an island. However, the pilots will globally aim at increasing the share of renewable energy produced locally for self-consumption and the lessons learned might be of interest also for energy islands. The INVADE budget is €22.8 million.

The inteGRIDy project aims at coordinating DR, energy storage and synergies with transport and heat networks through a Cross-Functional Platform in order to increase stability and flexibility in the grid. One of the pilot projects will take place at the Isle of Wight, an island of the English Channel with about 139,800 inhabitants. In order to be self-sufficient in electricity produced from local RES, 170 MW of RES are required. To date, approximately 80 MW have been installed, but technical difficulties to go beyond appear. These difficulties could be solved through an additional interconnector, but that solution appears unaffordable. The specific objective of the inteGRIDy project for this island is thus the test of dedicated smart flexibility solutions such as the development of EV rapid charging stations to help in balancing the network, and new models for DR. The overall inteGRIDy budget is €15.8 million, and the Isle of Wight is one of the ten pilot projects.

The SMILE project aims at studying the use of innovative technological and non-technological solutions to move towards smart grids and flexible electricity systems. The technological solutions comprise integration of battery technology, power to heat, power to fuel, pumped hydro, electric vehicles, electricity stored on board of boats, an aggregator approach to demand side management (DSM) and predictive algorithms. There will be three large-scale smart grid pilots in the Orkney, Samsø and Madeira islands that will demonstrate stable grid operation, implementing solutions for demand response, intelligent control and automation of distribution networks. As the project just started in May 2017, there is at the moment of writing no detailed information publicly available on these demonstrators. The overall SMILE budget is €14.0 million.

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