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Towards a Sustainable Energy Future for the Cyclades Islands

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Executive Summary

In recent years, there is growing evidence that global warming arises from human activities, and as a result, efforts are being made worldwide to ease the burden on the environment and avoid the worst consequences of climate change. One of the most important interventions is the decrease in carbon emissions from the energy sector.

The Cyclades islands, being a part of Greece and consequently the European Union, have been part of these attempts, mainly based on the policies and directives of the Union. Nevertheless, there is still a very large margin for improvement, especially considering the great potential from renewable energy sources, such as wind and solar. This, combined with the fact that some of the islands are still not part of the national grid, enables the Cyclades to act as a pioneer in the renewable energy transition, at least nationally. While there have been relevant studies for some of these islands, there is not a complete plan for the transition towards sustainable energy.

Therefore, the five-step backcasting framework by Quist is used as a basis in this thesis, along with some elements from the Robinson approach, in order to develop a framework used to answer the main research question:

How can a sustainable energy system in the Cyclades islands be realised by 2030?

A four-step backcasting methodology has been developed from the five steps of the Quist framework to base the research on and answer the main question. The first step is an analysis of all the different and relevant aspects of the energy system currently, as well as of the renewable energy potential available. In the second step, a vision and scenarios are developed for the future energy system, while in the third step the necessary actions and interventions are identified in order to reach the vision and complete the transition. The fourth step deals with the creation of an implementation timeline for the identified changes required to carry out the transition.

The current energy system in the Cyclades is still mostly relying on non-renewable energy sources. Until 2018, the energy for all islands apart from very few was generated using polluting and expensive local oil-powered stations, while after that the majority of the islands are now connected to the mainland grid. Apart from that, demands for heating and transport are almost exclusively covered by oil products. Nevertheless, the silver lining is that the potential of wind and solar energy in total can reach more than four and six times the projected energy demand, respectively.

While there is a lot of ground to be covered in the transition, the slightly short end-point of 2030 is chosen, also to align with the policies of the Greek state. It is envisioned that the energy system by then shall be sustainable, self-sufficient, efficient, and reliable. In the three scenarios developed as part of this vision, a large part of the transition is based on the electrification of the heating and transport sectors (relying on the enhanced attractivity of electric vehicles on the islands due to the small distances), while a few small interconnection

projects between some islands will be necessary to take advantage of the locations with large potential.

After developing the energy mix for each island, a “What-Who-How” backcasting analysis is conducted as part of the backcasting framework, in order to identify the full extent of the necessary interventions. The chief change towards the transition is of course the installation of renewable energy projects, and other, supporting systems, while the development of a strong policy framework is also a key requirement. Moreover, it is important that the public is also included in the transition, educated, and informed. Also, it is worth noting that further attention is being placed on the accommodation sector, owing to its considerable effect brought on by the touristic character of the islands.

Based on the identified actions and interventions, an implementation timeline is developed until the end-point of 2030. The transition is split into three phases, each with a specific goal in mind. In the beginning, the first steps and the preparation for the future will be made, while afterwards the system will be ready to be functioning with the generation of energy by RES. Finally, in the third phase the storage of energy will also be available and the transition will thus be complete.

Overall, transitioning to a sustainable energy system in the Cyclades is technically feasible. Nevertheless, there are quite a large number of both technical and non-technical changes necessary, and they need to be carried out in a rather short amount of time if the target of 2030 is to be attained. It is understandable therefore that a strong policy framework and a keen cooperation between the stakeholders are of utmost importance, in order for the Cyclades to have a sustainable energy system by 2030.

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1 Introduction

1.1 Background

Over the past decade it is safe to say that a consensus among scientists has been reached that the clear warming of the Earth's climate is a result of anthropogenic factors, including greenhouse gas emissions, with a certainty of at least 95% (IPCC, 2014). Therefore, efforts have been made to limit the further increase of the atmospheric temperature, and in turn its widespread impacts.

The European Union is already actively trying to promote the generation of energy from renewable sources; in 2009 it published the Renewable Energy Directive, setting a target to cover 20% of its energy needs using renewable energy sources (RES) by 2020 – along with targets for the individual member states – (European Parliament, 2009) and in 2016 the revised Renewable Energy Directive was published, which increased the target of RES in the final energy consumption to 27% by 2030 (European Commission, 2016).

As a member state, Greece published the National Renewable Energy Action Plan (NREAP) in 2010, outlining its targets for the transition to renewable energy sources (RES) for 2020 and the measures to be taken to reach them (Ministry of Environment Energy and Climate Change, 2010). As shown in Figure 1, the NREAP targets were surpassed from 2009 until 2014, but the RES penetration growth stagnated from 2013 onwards. Consequently, as of 2016, 15% of the gross final energy consumption (GFEC) is covered by RES, a value slightly lower than the NREAP projection, so Greece has not met its target for the penetration of RES in the gross final energy consumption (Ministry of Environment & Energy, 2018a).

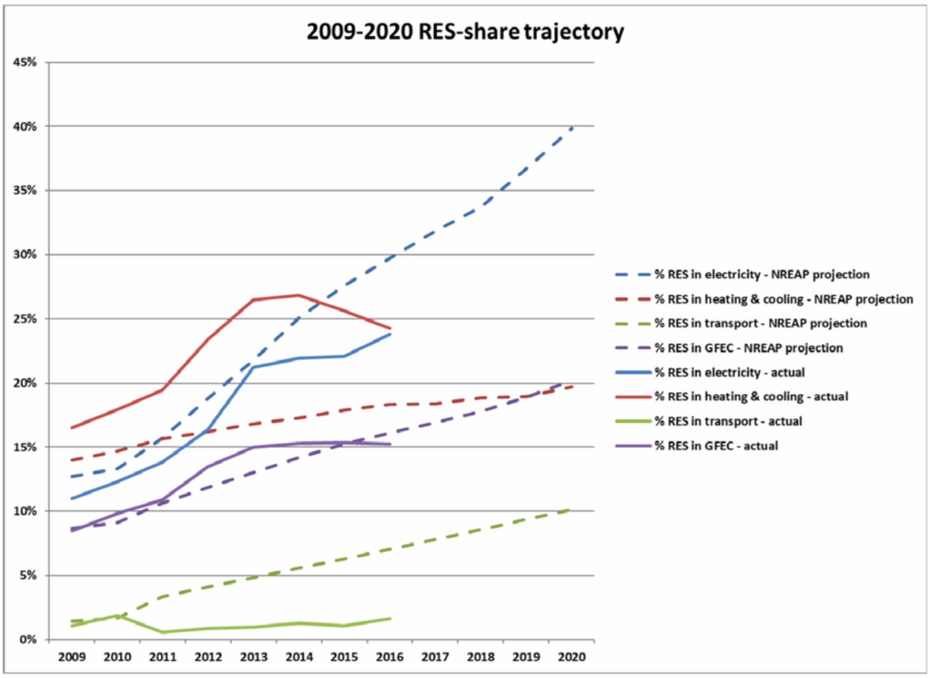


Figure 1 - RES-share in Greece 2009-2020 (Ministry of Environment & Energy, 2018a)

This (slight) underperformance is somewhat disappointing, taking into account the potential of various RES in Greece, mainly solar and wind, but also geothermal and hydro, which already makes up 10-15% of electricity generation (Independent Power Transmission Operator, 2016).

As it can be seen in Figure 2, Figure 3, and Figure 4, Greece – or certain parts of it – rank among the best in Europe for the generation of both solar and wind energy:

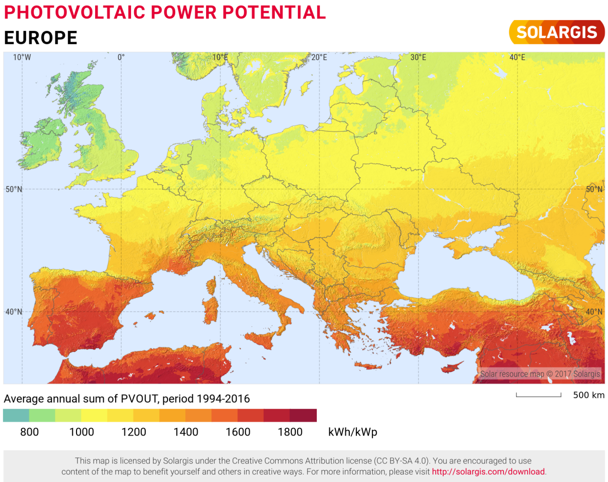


Figure 2 - Photovoltaic Potential in Europe (Solargis, 2017a)

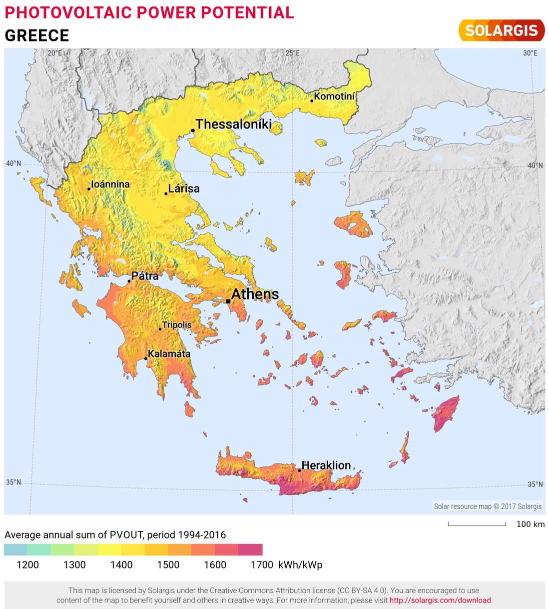
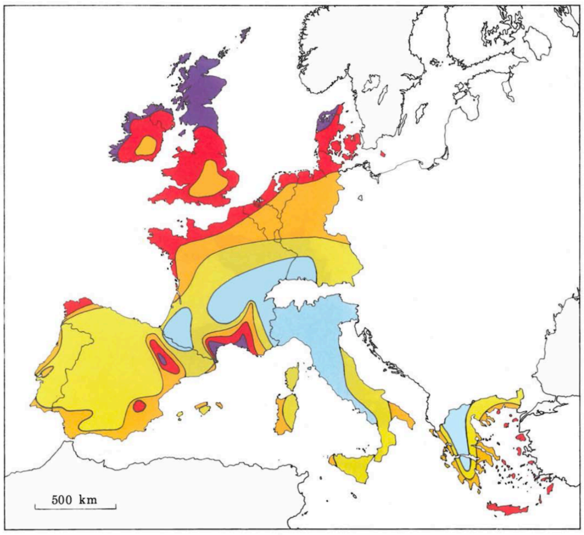


Figure 3 - Photovoltaic Potential in Greece (Solargis, 2017b)



Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2] m s^{-1}	Sheltered terrain[2] Wm^{-2}	Open plain[3] m s^{-1}	Open plain[3] Wm^{-2}	At a sea coast[4] m s^{-1}	At a sea coast[4] Wm^{-2}	Open sea[5] m s^{-1}	Open sea[5] Wm^{-2}	Hills and ridges[6] m s^{-1}	Hills and ridges[6] Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 4 - Distribution of Wind Resources in Europe (Troen & Lundtang Petersen, 1989)

Figure 5 - The Cyclades Islands (red) in Greece
source: 'Nomos Kykladon' by Pitichinaccio (CC0 1.0)

1.2 Problem Definition

A common characteristic of Figures 2, 3, and 4 is that very high potential for the exploitation of RES is found in the group of islands called the Cyclades (shown in Figure 5). It is therefore disheartening that the majority of the electricity needs of many of these islands was or is covered by conventional generators using oil products (Hatziargyriou et al., 2017), and RES only provide about 8% of the electricity annually (Hellenic Electricity Distribution Network Operator, 2017). Apart from the well-known negative effects of the use of fossil fuels, this current situation is undesirable also owing to its financial impact. Because of the expensive oil products used in the autonomous generating units on the islands (compared to the widely-used coal in the rest of the country), the price of electricity is increased, and the extra cost is passed on to consumers all around the country (Hatziargyriou et al., 2017). The fact that two of the Cycladic islands (Sifnos and Amorgos) have been highlighted by the Clean Energy for EU Islands Secretariat (i.e. the Secretariat set up by the European Commission *"to facilitate the clean energy transition on EU islands from the bottom up"*) (Clean Energy for EU Islands Secretariat, 2018) can also be considered as a point of legitimacy for the possibilities and opportunities of a transition to sustainable energy.

1.3 Research Objective & Approach

It is clear that a transition to RES is both natural and imperative and a roadmap to reaching a sustainable future for the islands would go a long way toward supporting this transition. Investigating the topic of the shift to sustainable energy and developing a robust plan to achieve that is also in line with the objectives of the MSc Sustainable Energy Technology program – according to the relevant page on the TU Delft website: *"a transition to a society based on Sustainable Energy is necessary to be self-sufficient, meet the growing global demand for energy, and address the threat of climate change caused by greenhouse gas emissions"* (TU Delft, n.d.).

Since the transition has not happened yet, nor is it planned with detail, it is impossible to know with certainty the pathway to self-sufficiency. Therefore, it is necessary to visualise the future situation. This can generally be accomplished in two ways: either by forecasting or by backcasting. While forecasting is relatively simple and quite widely used, backcasting is a distinct tool that is typically applied to energy problems, like this one, since solutions to such problems hinge on future targets set by governments and other administrative entities. The term was first introduced by Robinson in 1982 (Robinson, 1982), who later described it as *"the development of normative scenarios aimed at exploring the feasibility and implications of achieving certain desired end-points"* (Robinson, 2003). Put more simply, instead of using available data and predictions like in forecasting, backcasting entails visualising the desirable future situation first (or setting a target) and then working backwards to discover the necessary actions to reach that future (Quist & Vergragt, 2006).

1.4 Research Questions

Following the problem definition and the research objective, the main research question is developed as follows:

How can a sustainable energy system in the Cyclades islands be realised by 2030?

The following sub-questions shall aid in answering the main research question, and are based on the individual steps of the backcasting methodology:

- How is the energy system in the Cyclades organised currently?
- Who are the relevant stakeholders?
- Which are the pertinent macro-environmental factors that can influence the transition?
- What RES are available and what is their potential?
- What would a suitable energy system in 2030 resemble?
- Which is the proper process to achieve this vision?

The manner and methodological steps that will be taken to answer these questions within this thesis report shall be presented in greater detail in Chapter 3 – *Methodology*.

1.5 Thesis Outline

Chapter 2 presents a literature review relevant to the subject of the transition to sustainable energy both in the Cyclades and for other islands generally, with the aim of finding whether there is indeed a knowledge gap present and if so, the extent of it. Additionally, it includes a brief historical review of the backcasting framework and its manifestations over the years. Following, Chapter 3 outlines the methodological framework to be followed during the thesis project, and the previously presented research questions are linked to its specific steps. The Strategic Problem Orientation is presented in Chapter 4; this includes a short presentation of the general characteristics of the islands, the explanation of the energy system at present, a stakeholder and a PESTEL analysis, and finally an examination of the potential of RES. In Chapter 5, using the information of the previous chapter, the vision for the future energy system of the islands is described, and three scenarios based on that are developed. The actual backcasting analysis is produced in Chapter 6, i.e. the three scenarios are analysed, discussed, and in the end a transition roadmap and implementation timeline is presented. Chapter 7 discusses several points and remarks of the thesis project, and Chapter 8 presents the conclusions of the research, by answering the research questions, as well as some recommendations.

2 Literature Review

2.1 Academic Knowledge Gap

In order to establish that the problem identified is an actual challenge worth tackling, it is essential to first investigate and define the current academic landscape and pinpoint the need for additional research, if indeed there is one. A literature review is therefore carried out to determine what other authors have – and have not – explored and through this process to focus on the yet unsolved aspects of the problem.

Since the topic of this thesis project is the transition to RES to cover the needs of the Cyclades islands in Greece, relevant keywords were used in the Scopus database, both isolated and in several combinations, to find articles published in scientific journals regarding the topic: "Cyclades", "Greece", "Aegean", "island(s)", "renewable", "energy", "sustainable", "Mediterranean". The Cyclades are found in the Aegean Sea (i.e. the archipelago between Greece and Turkey), hence the use of the keyword "Aegean". Moreover, other islands in the Mediterranean sea exhibit similar properties with the islands of the Cyclades, thus "Mediterranean" was also used as a keyword. For some of the combinations of keywords presented above (and especially those not including "energy") the search results were too broad; in these cases the search was refined by selecting the option "Energy" in the "Subject Area" panel of the search results screen in Scopus. Apart from scientific journal articles, Scopus also provides results for the relevant keywords that may be conference proceedings or parts of books. Some of these documents provided enough value that they were also considered in the literature review, in combination with the scientific journal articles. It is worth noting that the literature review was not limited to the articles collected through the database search, but instead the "snowballing" process was also used (i.e. publications were also chosen from the reference lists of the initially found ones, and from the recommendations of similar articles by the publishers).

Articles published over the past 15 years routinely conclude that especially the islands of the Aegean Sea present a very high potential for RES (predominantly wind and solar energy) that should be harvested (Hatziargyriou et al., 2016; Mihalakakou et al., 2002; Mondol & Koumpetsos, 2013), while also noting that (in some cases) the annual energy demand could be fully covered by RES (Hatziargyriou et al., 2016; Mondol & Koumpetsos, 2013). Nevertheless, such a situation is not readily attainable. For instance, energy storage would have to play a decisive role in enabling the shift to a RES-based energy system (Hatziargyriou et al., 2017). Apart from technical barriers, the transition to renewable energy sources as a means of covering the energy demand needs to overcome other, macro-environmental obstacles. From the study of the aforementioned articles, the most important difficulty appears to be the complicated legislative framework (Katsaprakakis & Christakis, 2016; Manolopoulos et al., 2016; Michalena & Frantzeskaki, 2013; Mondol & Koumpetsos, 2013), while others include the lack of infrastructure, environmental concerns, and local opposition (Mondol & Koumpetsos, 2013).

Several Cycladic islands have been used in case studies in literature to examine the feasibility and manner of a transition to RES, such as Ios, Sifnos, and Andros/Tinos/Mykonos/Syros/Paros/Naxos. Nanaki and Xydis (2018) consider a hybrid energy system for the island of Ios, intended to minimize the usage of the diesel generator on the island and increase the RES penetration. Besides the existing diesel generator, the system includes wind turbines and solar PV panels, while lead-acid batteries are used as the storage medium, and an electric vehicle aggregator has load-serving responsibilities; such a configuration is able to reach a RES penetration of around 93%, at 40% of the cost of energy compared to the current situation (only diesel generator) (Nanaki & Xydis, 2018). A fully energy autonomous island is also feasible; the island of Sifnos can become such an island, based on a hybrid power plant comprised of a wind farm and a seawater pumped hydro storage system (Katsaprakakis & Voumvoulakis, 2018). While both Ios and Sifnos presently cover their electricity needs using diesel generators and are not connected to the grid on the mainland, some islands of the Cyclades are part of the national electric grid, creating different opportunities for the transition to RES. Zafeiratou and Spataru (2017) propose taking advantage of the stability offered by the national grid to install wind turbines in six of the interconnected islands (Andros, Tinos, Mykonos, Syros, Paros, and

Naxos), without the need for storage. Under this plan, enough electricity would be generated to cover the demand of these islands, and to be exported as well (Zafeiratou & Spataru, 2017).

Owing to the intermittency of the main RES available in the islands, storage and/or alternative use of the generated energy is essential, and could be carried out by the production of hydrogen, apart from the options previously mentioned in the case studies. A configuration of solar PV panels and wind turbines complemented by an electrolyser and a hydrogen storage system has been proposed and investigated for the Kos-Kalymnos autonomous island grid (Kavadias et al., 2018), while another island, Karpathos, can become autonomous via 100% RES and hydrogen (Giatrakos et al., 2009). Both the islands of the Kos-Kalymnos autonomous grid and Karpathos are part of the Dodecanese – another island group in the Aegean, which forms the South Aegean region together with the Cyclades. The similarity of these islands with the Cyclades suggests that such solutions can also find use in the latter.

Overall, the literature review reveals that a great RES potential is undoubtedly available in the area, but there are several barriers that hinder the implementation of projects that could provide the islands with clean energy. Numerous case studies confirm that locally available renewable energy sources such as wind and solar can cover the majority or even the entirety of the energy demand of the islands, but also highlight the need for support by energy storage systems. Despite that, there has been no proper plan for the transition to sustainable energy in the Cyclades as a whole; this thesis aims to fill the gap in the literature by proposing a roadmap including all the essential actions that need to be taken to exploit the RES potential, overcome the relevant obstacles, and usher the islands into a sustainable future.

It is worth noting that after the literature review process was completed, and during the carrying out of this thesis project, an important and very relevant piece of literature was published, namely the Clean Energy Transition Agenda for the island of Sifnos. The Agenda was developed owing to the inclusion of Sifnos in the Clean Energy for EU Islands initiative (as also mentioned previously) and "is a strategic roadmap for the transition process towards clean energy". Due to its relevance, both location- and content-wise, it is a very helpful resource and provides both inspiration and information used in this project.

2.2 Framework Historical Review

The provision of a future based on energy conservation and sustainable forms of energy generation may have attracted great attention recently, but it has been keeping researchers busy for over four decades already. The development of one of the most prominent approaches to the problem started in 1976 with Amory Lovins, who suggested working backwards from a set target and discovering the necessary actions to reach that target, instead of "*extrapolating trend into destiny*" (Lovins, 1976). This idea was – and has remained – the tenet of what is now known as "backcasting". While Lovins brought attention to the concept, it was Robinson who elaborated on it and proposed a formal framework in 1982 (Robinson, 1982). Robinson continued working on the framework, and in 1990 he published an updated version of his six-step methodology (illustrated in Figure 6). He highlighted that backcasting is aimed at investigating the manner with which certain future visions can be realised (instead of a prediction tool), and also expanded the applicability of backcasting to more general sustainability issues (Robinson, 1990).
In short, Robinson's framework entails setting one or more goals for the future and establishing the current situation, before developing a scenario for the future. The following step is to analyse the feasibility and outcomes (be they positive or negative) of the scenario, and depending on the results of the analysis, to reiterate any problematic aspects.

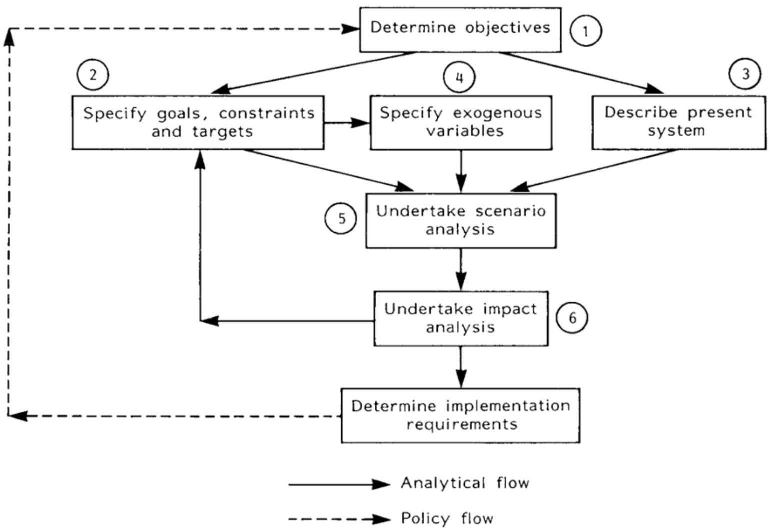


Figure 6 - Backcasting Framework Outline (Robinson, 1990)

Later in the same decade, Dreborg presented a more philosophical view to the backcasting *approach* (and not *method* as it was referred to), in his aptly named paper "Essence of Backcasting" (Dreborg, 1996). He argued that while forecasting could prove useful when analysing short-term problems, its value diminishes if long-term problems are concerned, since it does not include the (sometimes necessary) paradigm shifts typical of long periods of time. Since sustainability problems often require fundamental changes in both technological and societal terms, backcasting is a more suitable alternative. Based on these considerations, Dreborg claims that backcasting is suited to solving problems with the following characteristics: complexity (the problem affects many aspects of the society), need for major change(s), certain elements of the current situation are parts of the problem, externalities, and (reasonably) long time horizon (Dreborg, 1996).

In the same spirit as Dreborg, Höjer and Mattsson also explain why backcasting is a superior choice compared to forecasting, when long-term problems are considered. Even though they agree that the approaches used to analyse or study the future are not mutually exclusive, they limit the role of forecasting to simply an "alarm", and explain that a view into the more profound, constitutional elements of society is necessary in order to find, study, and eventually reverse the troubling tendencies that have led to the current situation (Höjer & Mattsson, 2000). Using a graph (shown in Figure 7), they illustrate their point of view that forecasting (in the form of directional studies or forecasts) is useful to indicate whether certain targets will be met, and if not, backcasting shall be used to establish a future vision and examine the way to attain it (Höjer & Mattsson, 2000).

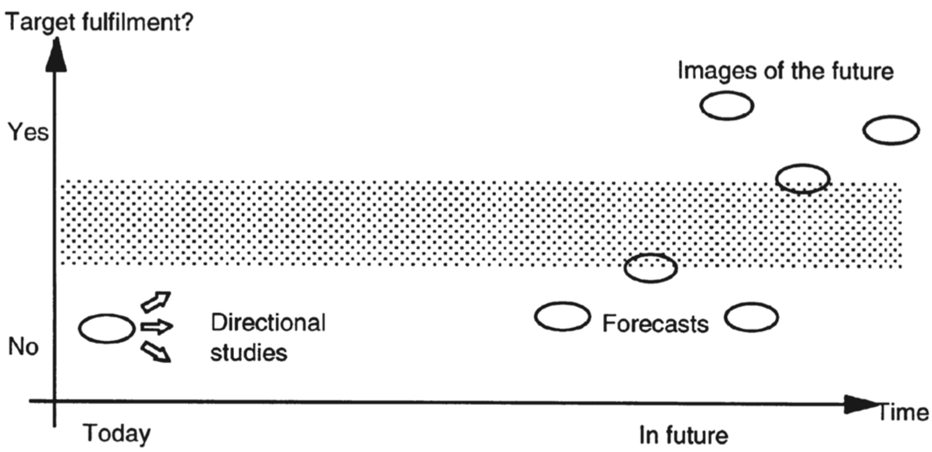


Figure 7 - Applicability of Backcasting (Höjer & Mattsson, 2000)

While Robinson is recognised and credited with the development of an early framework for backcasting, his work is not without its critics. Anderson admits the novelty and importance of Robinson's framework, but worries that it still hinges upon economic predictions for the long term, and thus fails to address some of the problems found in forecasting approaches (Anderson, 2001). In his proposed framework, focusing on the electricity sector only, Anderson suggests that demand and supply are endogenous aspects of the policy-making process, places a greater significance on the role of the government, and includes environmental and social factors in the discussion, as part of a more flexible policy strategy (Anderson, 2001). While fixing some of the issues and updating Robinson's framework, he creates other sources of debate, mainly about the increased responsibilities of the government and the degree to which such an arrangement is attainable.

One common characteristic of the backcasting frameworks presented roughly in the first couple of decades after Lovins' popularisation of the approach is that they lack interaction with the relevant stakeholders. Involving stakeholders in different backcasting phases can create/promote legitimacy and accountability, allow consideration of perceptions and opinions of stakeholders that would otherwise be overlooked, and induce support and involvement in the stages after the backcasting experiment (Quist, 2007). Robinson called such frameworks that attempt to include stakeholders a *"second generation" form of backcasting* (Robinson, 2003), and they are commonly known as *participatory backcasting*.

An example of a participatory backcasting framework was presented by Quist in his 2007 dissertation, and is illustrated in Figure 8.

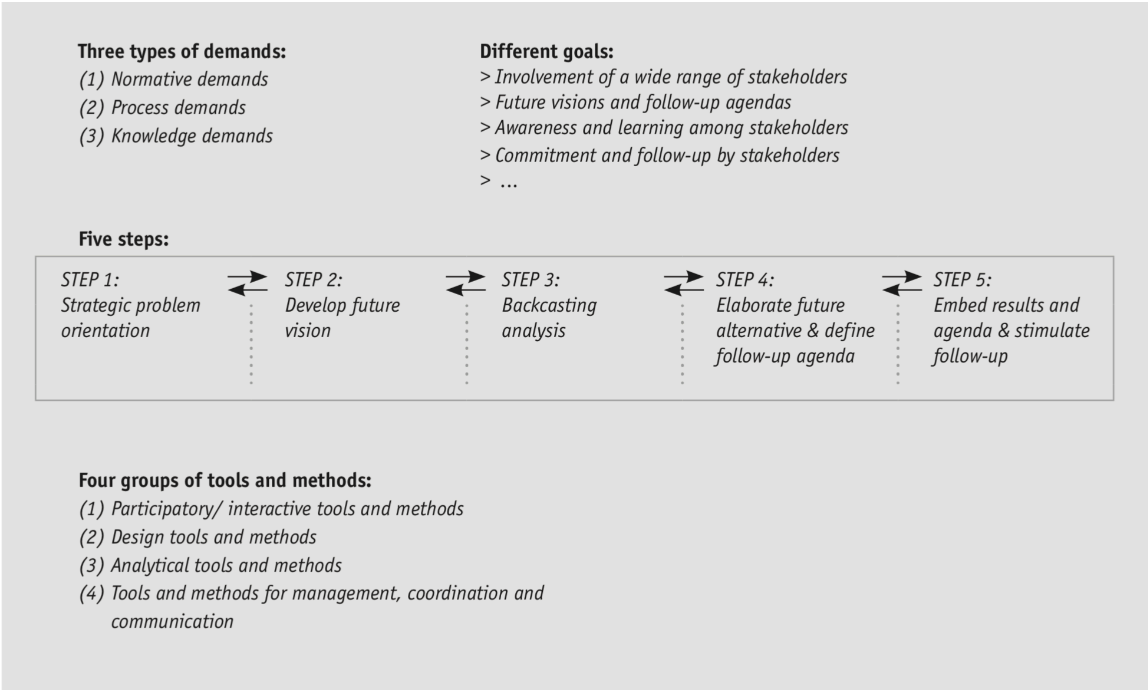


Figure 8 - Participatory Backcasting Methodological Framework (Quist, 2007)

This framework consists of five steps and is based on different backcasting approaches, aiming to serve as a more generalised approach. The first step includes scanning the present situation, finding the relevant stakeholders, and analysing their standpoint. The findings of Step 1 form the basis for the development of future visions or scenarios in Step 2. A backcasting analysis is done in the third step, which entails describing the necessary interventions to make the future vision a reality. In Step 4 the drivers and barriers of the transition are defined, and a follow-up agenda is created. The last step concludes the analysis and consists of developing plans for each stakeholder with necessary actions for the future. It is worth noting that this is an iterative process and that influences between each step do indeed exist. Finally, a useful characteristic of this framework is the provision of four groups of tools and methods that can help carry out the specific steps of the analysis.

To conclude, while backcasting is certainly not a flawless approach to examining and formulating future energy systems, it has developed since its first instances in the 1970s into a compelling alternative to other concepts such as forecasting, considering it does not hinge so strongly upon present circumstances that may well change in the course of years or decades.

3 Methodology

Taking into account the problem characteristics that favour backcasting as presented by Dreborg and explained in the previous section, it is clear that backcasting would greatly aid in finding a solution to a problem such as the transition of the Cyclades to sustainable energy. Therefore, the next step is to settle on a specific, robust framework. Owing to its general and flexible nature, the Quist framework is able to provide the basis of a suitable methodology for this thesis project. A major point to consider is the participatory character of the framework, and since the involvement of stakeholders to a large extent is both impractical and out of the scope of this thesis, the participatory methods will be omitted or replaced by more suitable aspects (such as those in the works of Robinson from 1982 and 1990). As a result, an amalgamation of the frameworks by Quist (2007) and Robinson (1990) will serve as the four-step methodological framework of this thesis, while information presented in the backcasting scheme developed by Quist (2013) will also be utilised (shown in Figure 9). More specifically, the *System and regime analysis*, *Stakeholder analysis*, and *Socio-technical mapping* (in the form of a PESTEL analysis) will be taken from Step 1, the *Idea articulation and elaboration* and *Generation of multiple perspectives* from Step 2, Step 3 will be used as is, with it being the focal point of the framework, and the *Generation of follow-agenda* and *Transition pathway* will be used from Step 4. Also, while the frameworks have a great number of similarities, it should be mentioned that Robinson (1982) refers to the analysis of the RES potentials (albeit as part of his supply analysis step), which will also be used in this thesis. Another important source of influence and information while carrying out this thesis is the body of work developed by previous students working on similar topics and using similar methods and frameworks in their own thesis projects, with the reports of Ricken (2012), García Nodar (2016), and Vallabhaneni (2018) meriting special mention due to the volume of information provided.

Step 1: Strategic problem orientation
Setting demands and basic assumptions
System and regime analysis
Stakeholder analysis
Problem and trend analysis
Socio-technical mapping
Step 2: Generating future visions
Idea articulation and elaboration
Generation of multiple perspectives
Creative techniques
Step 3: Backcasting analysis
WHAT-WHO-HOW analysis: technological, cultural-behavioral, organizational, and structural-institutional changes
Stakeholder identification: required stakeholders and actions
Drivers and barriers analysis
Step 4: Elaboration and define follow-up agenda
Scenario elaboration (turning vision into quantified scenario)
Scenario sustainability analysis
Generation of follow-agenda
Transition pathway
Step 5: Embed results and stimulate follow-up
Dissemination of results and policy recommendations
Generation of follow-up proposals
Stakeholder meetings

Figure 9 - Methods and Tools for Backcasting (Quist, 2013)

Step 1 - Strategic Problem Orientation

The Strategic Problem Orientation is the step in which all the relevant information regarding the energy landscape in the Cyclades is gathered, to form the basis of the following steps and mainly the backcasting analysis. Firstly, the present energy system in the islands will be studied, with the aim of understanding its manner of operation so that the relevant and necessary interventions to reach the goal of sustainability can be identified in the following steps. To this end, there are several pieces of information needed and thus shall be the focus of a desk research and greatly based on the book "Introduction to Energy Analysis" by Blok & Nieuwlaar: the energy consumption of every island in the form of electricity, heat, and for transport, for electricity especially it is worth knowing the share generated by conventional generators and by renewable energy sources, and also, since the focus is on islands, whether their electricity systems are part of the main grid of the country or whether they are completely autonomous. A simple energy balance of the islands shall also be composed, in order to identify the flows of energy. Moreover, since the transition is a complex undertaking with a lot of parties involved, a stakeholder analysis is essential so as to reveal the roles of all parties associated with the energy system, and will be carried out based on the method of actor analysis by Hermans. In order to find out more about the macro-environmental factors, a PESTEL analysis will also be performed based on the work by Dočkalíková. Finally, as it is easily understood, knowing the potential of renewable energy sources present in the islands is also crucial to design a sustainable energy system; the technical potential shall be examined (however there will also be attention paid to the protected areas of the islands), either by literature research or by simple calculations in the case of limited available information in the literature.

With the conclusion of Step 1 it shall be possible to answer four of the research questions of this thesis project: *How is the energy system in the Cyclades organised currently?*, *Who are the relevant stakeholders?*, *Which are the pertinent macro-environmental factors?*, and *What RES are available and what is their potential?*.

Step 2 - Future Vision & Scenario Development

After going through Step 1, the overall energy situation of the Cyclades islands will have been revealed, and that will allow for the start of the planning for the future. Step 2 is where the vision for the future will be established; this means that the new characteristics of the desired sustainable energy system shall be outlined, taking into account the characteristics of the present system, as well as all the information gathered in Step 1. While the creation of a future vision can in principle have no time horizon, in this case it will also be needed to affix the plans for the future to a certain, sensible end-point so that all planning can work towards that. Further, in order to be able to fully visualize the future energy system, it is also vital to know what the requirements for energy shall be at the chosen end-point. Of course predicting such elements with certainty is impossible, so in Step 2 the anticipated growth rates of energy consumption shall be researched and used to calculate an estimate of the future energy demand. Finally, since there is a theoretically infinite number of ways to reach the future vision, which can of course not be examined, there will instead be a small number of representative and realistic scenarios developed based on all collected data, information, and knowledge so far (including the present energy landscape, the RES potentials, the future vision, and the future energy demand), that shall be useful in gaining an understanding of how the realization of this vision could manifest itself.

After Step 2, another of the research questions will have found an answer: *What would the ideal energy system in 2030 resemble?*.

Step 3 - Backcasting Analysis

Having established a vision for the future, an end-point by which that vision shall be realized, and developed a few scenarios accordingly, it is time for arguably the centrepiece of the thesis project, the core backcasting analysis in Step 3. As explained in Section 2.2, backcasting starts from a definite point in the future and works backwards to the present in order to describe the actions required to indeed achieve the target set for that point in the future. This analysis will be carried out for all the scenarios that will have been developed in the previous step, which will be compared against the present energy situation and the necessary interventions will be determined using the WHAT-WHO-HOW analysis (as shown in Figure 9), working backwards. The aim of the WHAT-WHO-HOW analysis, as mentioned by Quist (2013), is to identify the sort of actions and changes required, the manner with which these shall be carried out, and also the stakeholders responsible for their execution. These changes can be technological, institutional, or cultural-behavioral and will be categorized as such. As part of the backcasting analysis, a brief study shall also be carried out regarding the location of the RES projects that will be implemented on the islands. To do that, first the areas with the highest possible potential will be chosen based on relevant maps, and then they will be narrowed down depending on whether they are already utilized, their proximity to inhabited areas (especially for wind turbines), and whether they (or parts of them) are protected by any laws, directives, or other regulations and are thus unavailable for use.

Step 3 takes care of answering the final sub-question: *Which is the proper process to achieve this vision?*

Step 4 - Roadmap

The final step, after having also carried out the backcasting analysis of the scenarios, corresponds to the objective of this thesis project and outlines the way all actions required to advance the transition to sustainable energy in the islands shall be carried out, and also assigns them to a point in time during the transition. Put more simply, a transition roadmap is established, along with an implementation timeline for all the necessary interventions identified and explained in the backcasting analysis. This represents the culmination of the research and can be considered the end product of this project.

The main research question is answered with the completion of Step 4: *How can a sustainable energy system in the Cyclades islands be realised by 2030?*.

In summary, the four methodological steps followed lead to the answering of the research questions presented in Section 1.4 as follows:

Step 1 (Strategic Problem Orientation):

- How is the energy system in the Cyclades organised currently?
- Who are the relevant stakeholders?
- Which are the pertinent macro-environmental factors?
- What RES are available and what is their potential?

Step 2 (Future Vision & Scenario Development):

- What would the ideal energy system in 2030 resemble?

Step 3 (Backcasting Analysis):

- Which is the proper process to achieve this vision?

Step 4 (Roadmap):

- ***How can a sustainable energy system in the Cyclades islands be realised by 2030?***

4 Strategic Problem Orientation

4.1 Cyclades General Information

The Cyclades are a group of more than 33 islands and islets in the southern Aegean Sea (shown in Figure 10), of which 24 are inhabited (Cyclades Chamber of Commerce, n.d.); the most populated ones are listed in Table 1. According to the 2011 census, the total population of the Cyclades is 119,280 inhabitants (Hellenic Statistical Authority, 2011), and the key economic sector is tourism, while other income sources are mining, agriculture, and fishing. Owing to their location, the islands experience a relatively mild climate, with temperatures ranging from 10 to 16 °C in the winter and from 24 to 30 °C in the summer (Cyclades Chamber of Commerce, n.d.).

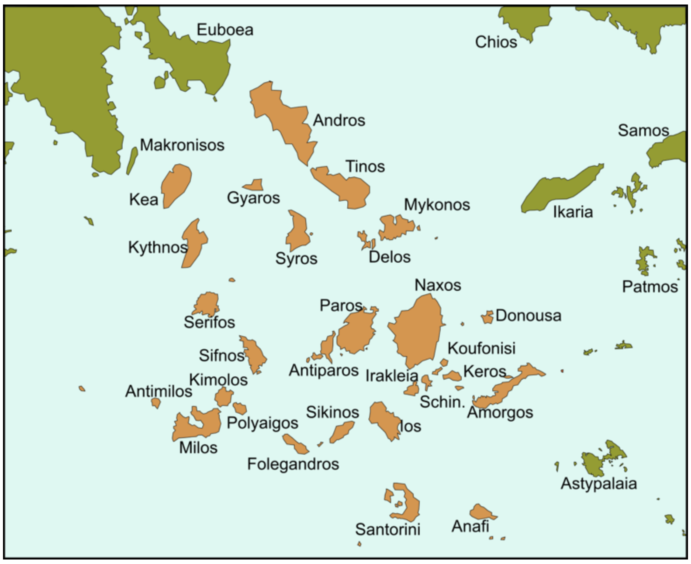


Figure 10 - Map of the Cyclades islands (in brown) (Cplakidas [CC BY 3.0 (https://creativecommons.org/licenses/by/3.0)], via Wikimedia Commons

Table 1 - Major islands in the Cyclades (Hellenic Statistical Authority, 2011a)

Island	Population	Area (km²)
Syros	21,507	84.1
Naxos	18,904	429.8
Thira (Santorini)	15,550	76.2
Paros	13,715	196.3
Mykonos	10,134	86.1
Andros	9,221	379.2
Tinos	8,636	194.6
Milos	4,977	158.4
Sifnos	2,625	73.9
Kea	2,455	131.7
Ios	2,024	108.7
Amorgos	1,973	121.5
Kythnos	1,456	99.4
Serifos	1,420	75.2
Antiparos	1,211	35.1

4.2 Energy System

4.2.1 Electricity

Interconnections

Serving an island group, the fundamental aspect shaping the energy system in the Cyclades is the connection (or lack thereof) to the main grid of the country. Despite being relatively close to the Greek mainland, only 3 of the islands were connected to the national grid prior to 2018: Kea, Andros, and Tinos, i.e. about 17% of the population of the Cyclades. The rest of the islands were divided into smaller, autonomous Non-Interconnected Island Power Systems (NIIPS); each NIIPS is either a sole island or a group of interconnected islands formed around a power station located on one of the islands. The first column in Table 2 presents the NIIPS represented by the island on which electricity is generated, while the second column contains the island(s) corresponding to each NIIPS.

Table 2 - Non-Interconnected Island Power Systems in the Cyclades prior to 2018 (Regulatory Authority for Energy, 2018)

Non-Interconnected Island Power System (NIIPS)	Corresponding Island(s)
Amorgos	Amorgos
Anafi	Anafi
Donousa	Donousa
Thira	Thira (Santorini)
	Thirasia
Kythnos	Kythnos
Milos	Milos
	Kimolos
Mykonos	Mykonos
	Delos
	Rineia
Paros	Paros
	Naxos
	Antiparos
	Koufonisi
	Schinoussa
	Irakleia
	Sikinos
	Folegandros
	Ios
Serifos	Serifos
Sifnos	Sifnos
Syros	Syros

The generating units on the main island of each NIIPS run on heavy or light fuel oil and provide the vast majority of electricity for the NIIPS (Hatziargyriou et al., 2017), complemented by RES (solar and wind) up to 8% on average yearly (Hellenic Electricity Distribution Network Operator, 2017). Despite the benefits of connecting the Cycladic islands to the mainland grid, technical and technological difficulties prevented the realisation of such plans, as did the high costs associated with projects of that size (Regulatory Authority for Energy, 2019b).

These obstacles were finally overcome and in 2014 the agreements for the Phase A of the interconnection of the Cyclades with mainland Greece were signed, with the project being completed in May 2018, at a cost of around € 240 mil. ("Cycladic islands hook up to the mainland power grid" Kathimerini, 2018). As illustrated in Figure 11, the island of Syros was connected to the mainland grid, and serves as a hub for connections with the islands of Tinos (already connected to the grid via Andros), Mykonos, and Paros (whose generating unit provided 8 additional islands with electricity). This brings the number of inhabited islands still relying on their own power generators from 21 down to 10 (Amorgos, Donousa, Anafi, Santorini, Thirasia, Kythnos, Milos, Kimolos, Serifos, and Sifnos).

According to the Regulatory Authority for Energy, advantages of the interconnection include the improvement in energy security, the decrease of costs owing to the use of oil products (estimated to range between € 500 mil. and 800 mil. annually), the environmental enhancement of the islands (by retiring the oil-powered generating units), and the possibility of achieving energy autonomy for the islands through RES at the lowest feasible cost, among others (Regulatory Authority for Energy, 2018).

Figure 11 - Phases of the Interconnection of the Cyclades (adapted from Ministry of Environment & Energy, 2018b)

Generation

As mentioned above, the electricity consumed by the NIIPS was predominantly generated using conventional generating units with oil products as fuel. The graph in Figure 12 presents the electricity generated in the NIIPS in 2017 per month and illustrates an important feature of the energy system in the Cyclades, namely the seasonality pattern induced by the heavy touristic activity that every island experiences during the summer months. Starting in May the electricity generation is increased, peaking in the two busiest months of the holiday season (July and August). Coincidentally, these are the two months with the largest RES electricity generation (28.50 TJ in July and 32.87 TJ in August), a fact that is however not translated in the percentage of RES generation (7.82% in July and 8.80% in August compared to more than 10% in February, March, October, and December) (Hellenic Electricity Distribution Network Operator, 2017).

Overall, 2,771.20 TJ of electricity were generated in 2017 in the Cycladic NIIPS, of which 2,555 TJ came from conventional generators (92.2%) and 216 TJ were provided by RES (7.8%).[1] The total installed capacity of generating units in 2017 was 336.41 MW, with conventional generating units making up 90.9% (305.88 MW compared to 30.53 RES); data for each NIIPS is presented in Table 3.

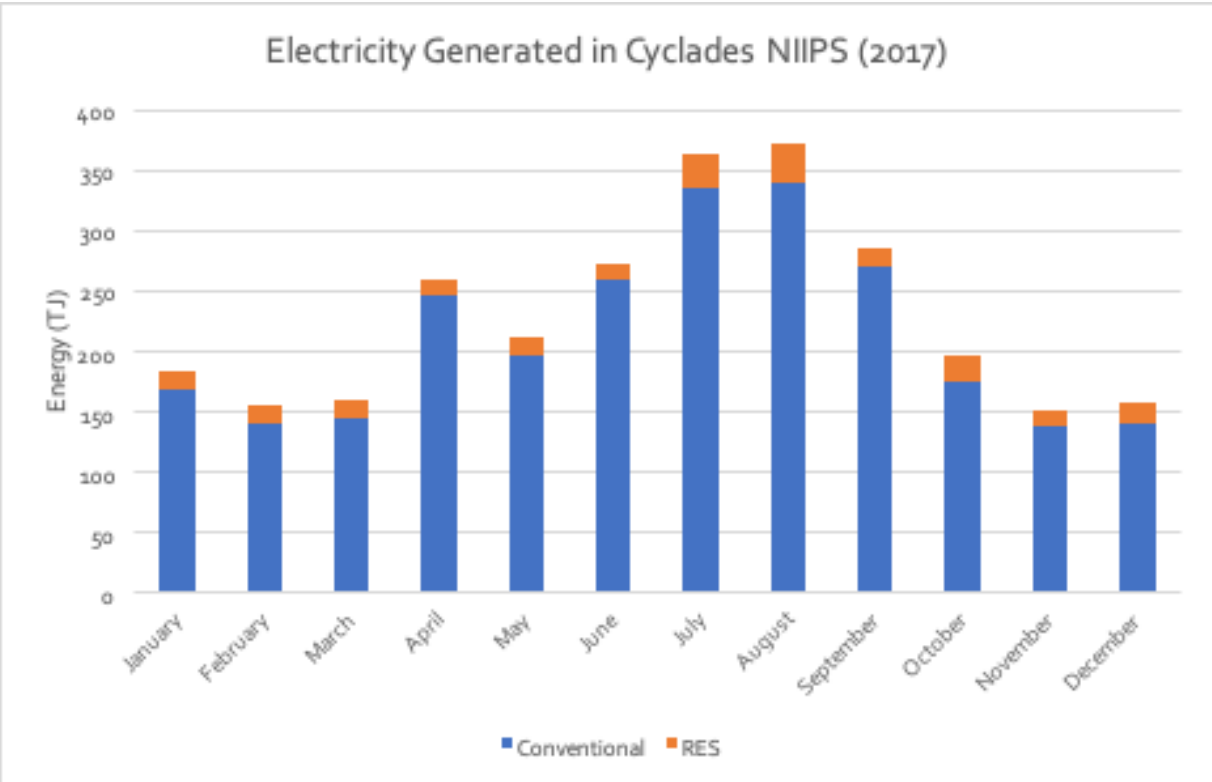


Figure 12 - Electricity Generation in the Cyclades NIIPS in 2017 (using data from Hellenic Electricity Distribution Network Operator, 2017)

[1] There is an irregular increase of electricity generation in April, possibly due to the Easter holiday period.

Table 3 - Installed Capacity for Electricity Generation in the Cyclades NIIPS in 2017 (Hellenic Electricity Distribution Network Operator, n.d.)

NIIPS	Conventional (MW)	RES (MW)	Total (MW)
Amorgos	4.22	0.31	4.53
Anafi	0.80	-	0.80
Donousa	0.50	-	0.50
Thira	71.92	0.61	72.53
Kythnos	4.90	0.90	5.80
Milos	20.60	3.34	23.94
Mykonos	62.16	2.29	64.45
Paros	91.18	18.01	109.19
Serifos	5.60	0.14	5.74
Sifnos	8.80	0.38	9.18
Syros	35.20	4.54	39.74
Total	**305.88**	**30.53**	**336.41**

As far as the consumption of electricity is concerned, a conclusion can be drawn based on the data available for one of islands, Sifnos. In Sifnos, the sector of tertiary (non-municipal) buildings, i.e. chiefly hotels, but also businesses and offices, is responsible for 60% of the total electricity consumption, which is by far the largest share (Clean Energy for EU Islands Secretariat, 2019). The rest of the electricity consumption is split between residential buildings (25%), public lighting (9%), municipal buildings (5%), and agriculture/forestry/fisheries (1%) (Clean Energy for EU Islands Secretariat, 2019). Owing to the similarity of the character of the Cyclades islands, it is expected that the profile of the electricity consumption is also analogous, and thus any further calculations will be based on the statistics for Sifnos.

4.2.2 Heat

Owing to the lack of data regarding the heat consumption in the Cyclades islands, unfortunately a clear picture does not exist. An assumption that can be made is that due to the absence of heavy industry on the islands, the demand for heat originates only to cover the needs of space heating in buildings. Based on that assumption and the data available for Sifnos, an estimation can be made for the thermal energy demands of every island. Specifically, thermal energy consumption for space heating in Sifnos amounts to 10.1 TJ annually, which is covered predominantly by heating oil (Clean Energy for EU Islands Secretariat, 2019), which translates to 0.004 TJ per capita given that the population of the island is 2,625. Considering the favourable climate and weather conditions on the islands especially in the summer, coinciding with the tourist season, it is sensible to expect that the heat demand results only from the permanent population in the winter months. Therefore, taking into account the per capita energy consumption for heating of Sifnos and the population of the islands, the relevant consumption for all the islands of the Cyclades can be estimated, for a total sum of 471 TJ.

4.2.3 Transport

Before examining the current, vague situation also in the transport sector, it is important to note that as there are no railways on the islands or connections by air between them, and the ferry connections are predominantly carried out by vessels bunkering in ports on the mainland, only road transport is considered. The energy demand for transport in the Cyclades can be gauged by using again the relative information with regard to Sifnos. The primary energy consumed for transport on the island is 62.21 TJ annually (Clean Energy for EU Islands Secretariat, 2019), and this value can be used to approximate the energy demand for transport in the islands. First the average distance in each island is assumed based on its geography and location of settlements and places of interest, and then the annual mileage is calculated as a round trip of the average distance 5 days a week. Following that, the proportion between the average annual mileage of a vehicle in Sifnos and in the Cyclades as a whole is determined, with this ratio being used to find the energy consumption for transport in total in the Cyclades, i.e. 1,721 TJ. A reverse calculation using the principle of the proportion between the average annual mileage of a vehicle in an island and in the Cyclades as a whole can be performed to estimate the energy consumption per island. It is worth noting at this point that the above calculations and estimations are rather crude and based on largely arbitrary values, so they shall be used cautiously.

4.3 Stakeholder Analysis

Since an issue of such size and complexity as the transition to sustainable energy in the Cyclades cannot be solved singlehandedly by one entity, it is essential to analyse the relevant stakeholders and their interests and objectives. Taking this information into account enables the proper development of a plan, as well as facilitates the allocation of specific actions to be performed so that the desired outcome is achieved. Based on the method of actor analysis by Hermans presented in Chapter 4 of the book *Policy Analysis of Multi-Actor Systems* (Enserink et al., 2010), the actors were identified and are divided into seven broad categories, depending on their function, so that the analysis of their interests is simplified. An overview of the stakeholders and their functions and/or interests is given in Table 4, while Figure 13 illustrates the relationships between them (orange arrows indicate a one-way influence, while green arrows indicate a more cooperative relationship).

Policymakers & Authorities

The European Union (EU) and its institutions (such as the European Parliament, the Council of the European Union, and the European Commission) play an influential role in shaping the energy policy by proposing and implementing laws and setting targets for the member states, one of which is Greece. Its main interests are guaranteeing energy security, sustainability, and affordability for the citizens of Europe (European Commission, n.d.). In that spirit, it signed the Political Declaration on Clean Energy for EU Islands in 2017, with several member states (Greece amongst them), and pledged to promote and support the transition to sustainable energy in European islands, such as the Cyclades (European Commission, 2017).

The Government of Greece is in charge of designing the energy strategy on the national level, in conjunction with the EU policy. Through the relevant ministries, such as the Ministry of Environment and Energy and the Ministry of Economy and Development, it formulates legislation and stipulates its own targets, in publications such as the National Energy and Climate Plan. The objectives laid out in the latest version of the Plan complement those of the EU: decrease of greenhouse gas emissions, increase in RES penetration, and further energy savings (Ministry of Environment & Energy, 2019).

Another important stakeholder is the Regulatory Authority for Energy, an independent authority whose primary goal is to oversee the domestic energy market, while advising the relevant state bodies and with power to take measures to achieve the liberalisation of the electricity and gas markets, to comply with the pertinent EU Directives (Regulatory Authority for Energy, 2019a). Its responsibilities regarding the RES field include (among others) evaluating and deciding upon production license applications, monitoring the projects granted a production license, and cooperating with the Ministry of Environment and Energy to draft a biennial report on the penetration of RES in the national energy system (Regulatory Authority for Energy, 2019c).

Further down the administrative structure of the country are the South Aegean Region, comprising of and responsible for the Cyclades and Dodecanese island groups, and the 19 local municipalities of the Cyclades islands. Neither have extensive power, and they depend on the legislation passed by the

Government of Greece, but they can promote small-scale local actions and measures, and offer administrative help with bureaucratic matters.

Companies

Before the EU Directives mentioned above concerning the unbundling of the electricity market in member states, the Public Power Corporation (PPC) (controlled by the Greek government which owns the majority of its shares) was the largest company of the electricity market in Greece, handling the production, transmission, and distribution of electricity. However, its different responsibilities have gradually been passed on in the last decade to newly formed companies. These are often subsidiaries of the PPC, but independent to the degree required by the EU's Third Energy Package.

The Independent Power Transmission Operator is the Transmission System Operator (TSO), and its responsibility is the management of the transmission system under the principles of "respecting man, the environment, and benefiting system users and society as a whole" (Independent Power Transmission Operator, 2019). Besides, the Independent Power Transmission Operator is responsible for the connections to the national grid, and also collects and publishes data regarding the RES power stations currently operating throughout the country (Independent Power Transmission Operator, 2019).

The role of the Distribution Network Operator (DNO) is filled by the Hellenic Electricity Distribution Network Operator. Apart from its main mission of managing the electricity distribution network in Greece, its more relevant responsibility concerning the Cyclades islands is the development and operation of the electricity system in the NIIPS (Hellenic Electricity Distribution Network Operator, 2019). Furthermore, it reports monthly on the electricity generation statistics in the non-interconnected islands.

As far as electricity production is concerned, the Public Power Corporation is still the largest producer (and retailer), albeit with a declining market share after the liberalisation of the market. It owns the autonomous power stations in the NIIPS, and has indicated its growing focus on RES by setting up PPC Renewables, a 100% subsidiary operating wind farms, solar parks, and other RES power stations (PPC Renewables, 2019).

The competitors of the PPC can be divided into two categories, based on whether or not they operate their own generating units. Large conglomerates such as Mytilineos, Terna Energy, and Copelouzos Group, among others, have been producing electricity using both thermal and RES stations, and selling it via their subsidiaries. It is worth noting that the majority of the projects carried out by these firms are RES-based. Examples of electricity retailers offering self-produced electricity include Protergia, Heron, KEN, Elpedison, and others. Other retailers, including but not limited to Volterra, nrg, and Watt + Volt, offer electricity they purchase from the PPC.

Apart from the above producers and retailers, there are also many companies active at the supply chain of wind and solar energy in Greece and, as a result, in the Cyclades. While the list is too extensive to be mentioned here, they are generally organized in associations, such as the Hellenic Wind Energy Association (HWEA) and the Hellenic Association of Photovoltaic Companies (HELAPCO). Members of the HWEA include Enercon, GE Renewable Energy, Siemens Gamesa Renewable Energy, Vestas, EDF Renewables, Eunice Energy Group, Total EREN, and others, while companies such as ENGIE, Huawei, JinkoSolar, and more are members of the HELAPCO.

Considering the large share of petroleum products used in the still operating fuel-powered generating stations on some islands as well as in the transport sector in the Cyclades, as shown in 4.1.2, the oil companies active in the Greek energy market also represent a significant stakeholder, since they control the imports of energy into the islands. Hellenic Petroleum and Motor Oil Hellas own the refineries operating in Greece and supply the fuels used in the aforementioned sectors. Both companies have placed emphasis on sustainable development practices but have only made small steps venturing into the renewable energy sector so far, contrary to several other companies in the petroleum industry abroad.

Other types of companies with stakes in the sustainable energy transition in the Cyclades islands include consultancies and technical companies.

Research Institutes

There are several universities and technical universities in Greece with departments dedicated to energy, environmental, and climate research, but none of them is based in the Cyclades. Nevertheless, the research and publications of these universities are frequently focused on (as case studies) or contain information about the islands, even though no research unit is focused exclusively on RES for the Cyclades. The National Technical University of Athens with its Environmental & Energy Management research unit, the Technical University of Crete with the Renewable and Sustainable Energy Systems Lab, and the University of West Attica's Laboratory of Soft Energy Applications and Environmental Protection are amongst the institutions focusing on renewable energy. More broadly, the Local and Island Development Lab of the University of the Aegean provides support regarding the sustainable development of the Greek islands.

The Center for Renewable Energy Sources and Saving is another institute publishing research results and reports. It supervised by the Ministry of Environment and Energy and its objective is "the research and promotion of renewable energy sources/rational use of energy/energy saving applications at a national and international level, as well as the support of related activities" (Center for Renewable Energy Sources and Saving, 2017).

Users

One of the most essential stakeholder groups in the transition to sustainable energy are the users of energy, i.e. almost every citizen. Nevertheless, users can be amongst the most passive stakeholders, not realising their power. In the past decade in the Cyclades, there have been instances of citizens installing solar PV panels on their houses, or small solar parks in unused fields, but the number of such installations is still far from the level of the more common and established solar water heating systems. Some inhabitants of the islands are more active, however, when confronted with the news of a new wind farm, coming together and vocalising their opposition. While the majority agrees that sustainable energy can be beneficial in dealing with the present and future environmental problems, they do not seem to be motivated or informed enough to instigate a change.

A notable subset of this category of stakeholders are the citizens active in the accommodation sector, and more importantly those in positions of power, such as owners and managers of hotels, resorts, and other lodgings. Owing to the touristic character of the islands mentioned above, as well as the share of electricity consumption by that relevant sector, these stakeholders can also influence the transition, especially if they act as examples and innovators in making their properties more sustainable.

Interest Groups

The responsibility of prompting a shift to sustainability often falls to the several interest groups, falling into one of the following categories: non-governmental and/or non-profit organisations, institutions, networks.

Some such groups active internationally include the Clean Energy for EU Islands Secretariat, the European Federation of Agencies and Regions for Energy and the Environment (FEDARENE), and the Covenant of Mayors for Climate & Energy. Formed by the European Commission to support the Political Declaration on Clean Energy for EU Islands mentioned above, the Clean Energy for EU Islands Secretariat serves as a framework to support the Clean Energy for EU Islands initiative and facilitate the assembly of the members and exchange of information (Clean Energy for EU Islands Secretariat, 2018). The FEDARENE is an association of regional authorities focusing on energy and environmental issues, and is comparable to (but more general than) the Clean Energy for EU Islands Secretariat, functioning as "a liaison between local/regional authorities and the European Institutions" and "a forum of discussion for stakeholders of the energy sector" (European Federation of Agencies and Regions for Energy and the Environment (FEDARENE), n.d.). The FEDARENE was also involved in the founding of the Covenant of Mayors for Climate & Energy, whose members submit their Sustainable Energy and Climate Action Plans outlining the measures to be taken to reach several sustainability targets, thus taking practical action towards the shift to RES (Covenant of Mayors for Climate & Energy, n.d.). Several of the Cyclades islands are members and/or have been featured in the plans of all the above organisations.

There are interest groups working on the sustainability of islands domestically as well: the DAFNI Network, the Aegean Energy & Environment Agency, and the Smart Islands Initiative are some of the largest ones, all including the Cyclades, but also other Greek islands. The DAFNI Network is a non-profit company of the insular municipalities and administrative regions of Greece with the goal to support the sustainable development of the islands by smartly exploiting the natural resources and infrastructure of the islands and by utilising the natural and cultural resources of the islands for sustainable tourism purposes (DAFNI Network, 2019b). The DAFNI Network established the Aegean Energy & Environment Agency, a non-profit, in order to facilitate the implementation of European energy and climate measures at the local level (DAFNI Network, 2019a); the Agency is a member of the FEDARENE and acts as "the technical and political advisor of islands in their participation in European projects and networks" (Aegean Energy & Environment Agency, 2009). The DAFNI Network is also involved as coordinator in the Smart Islands Initiative: an association of authorities and communities of European islands, aiming at promoting the islands as "laboratories for technological, social, environmental, economic and political innovation" (Smart Islands Initiative, n.d.). An admirable effort focusing completely on one island of the Cyclades is the Sifnos Island Cooperative, a civil cooperative whose objective is the sustainable development of the island based on RES (Sifnos Island Cooperative, 2016a). Among other actions, the Cooperative has already submitted an application to the Regulatory Authority for Energy to operate its own autonomous power station consisting of a wind farm and a pumped storage plant (Sifnos Island Cooperative, 2016b).

As an organisation concerned with the development of the Cyclades, the Cyclades Chamber of Commerce is also an important stakeholder, and has taken steps to promote the sustainable energy transition in the islands. The Chamber of Commerce is a member of the Group of Chambers of Commerce for the Development of Greek Islands, and the Network of the Insular Chambers of Commerce and Industry of the European Union (INSULEUR), and represented the latter in a Clean Energy for EU Islands conference in March 2018 (Cyclades Chamber of Commerce, 2018).

Media

While not necessarily an active stakeholder, the media can substantially affect the public opinion regarding the shift to sustainability, either positively or negatively. While there are several local television and radio stations and newspapers in the Cyclades, as well as numerous websites, none of them are focusing exclusively on energy matters. They do report, however, on significant energy news, and can promote specific viewpoints about them. There are Greek media concentrating on energy, mostly online, but they do not extensively cover the Cyclades.

Table 4 - Overview of the relevant stakeholders and their functions and/or interests

Stakeholder Group	Stakeholder	Functions/Interests
Policymakers & Authorities	European Union	Guaranteeing energy security, sustainability, and affordability for the citizens of Europe
	Ministry of Environment and Energy/Government of Greece	Decreasing greenhouse gas emissions, increasing RES penetration, furthering energy savings
	Regulatory Authority for Energy	Overseeing the domestic energy market, managing applications for RES production
	South Aegean Region, Local Municipalities	Promoting small-scale local actions and measures, offering administrative help with bureaucratic matters
Companies	Independent Power Transmission Operator	TSO, managing the transmission system, responsible for connections to the grid
	Hellenic Electricity Distribution Network Operator	DNO, managing the electricity distribution network, developing and operating the electricity system in the NIIPS

	Public Power Corporation (PPC)	Owning and operating the autonomous power stations in the NIIIPS, electricity retailer
	PPC Renewables	100% subsidiary of the PPC, responsible for developing and operating RES power stations
	Large owners of generating units (incl. Mytilineos, Terna Energy, and Copelouzos Group)	Owning and operating power stations, predominantly based on RES
	Electricity retailers (incl. Protergia, Heron, KEN, Elpedison, Volterra, nrg, and Watt + Volt)	Selling electricity (either from own generating units or purchased from the PPC)
	Hellenic Wind Energy Association & Hellenic Association of Photovoltaic Companies, and their members	Active at every step of the supply chain of wind and solar energy
	Oil companies (Hellenic Petroleum, Motor Oil Hellas)	Owning and operating refineries, active in the oil market
	Other companies (consultancies, technical companies)	Advising clients, preparing (technical) reports, carrying out projects
Research Institutes	Universities (incl. National Technical University of Athens, Technical University of Crete, University of West Attica, University of the Aegean)	Research on RES, the energy transition, sustainable development, etc.
	Center for Renewable Energy Sources and Saving	Researching and promoting RES/rational use of energy/energy saving applications, supporting related activities
Users	All users of energy, i.e. almost every citizen	Relatively informed, but not organized or active enough on a large scale
Interest Groups	Clean Energy for EU Islands Secretariat	Supporting the Clean Energy for EU Islands initiative, facilitating the assembly of the members and exchange of information

	European Federation of Agencies and Regions for Energy and the Environment (FEDARENE)	Acting as a liaison between local/regional authorities and the European Institutions and a forum of discussion for stakeholders of the energy sector
	Covenant of Mayors for Climate & Energy	Supporting the energy transition and evaluating the Sustainable Energy and Climate Action Plans of member-localities
	DAFNI Network	Supporting the sustainable development of the Greek islands by smartly exploiting the natural resources and infrastructure of the islands and by utilising the natural and cultural resources of the islands for sustainable tourism purposes
	Aegean Energy & Environment Agency	Facilitating the implementation of European energy and climate measures at the local level, advising the islands in their participation in European projects and networks
	Smart Islands Initiative	Promoting the islands as laboratories for technological, social, environmental, economic and political innovation
	Sifnos Island Cooperative	Managing and promoting the sustainable development of Sifnos island based on RES
	Cyclades Chamber of Commerce	Promoting the sustainable development of the Cyclades, active in the Clean Energy for EU Islands initiative

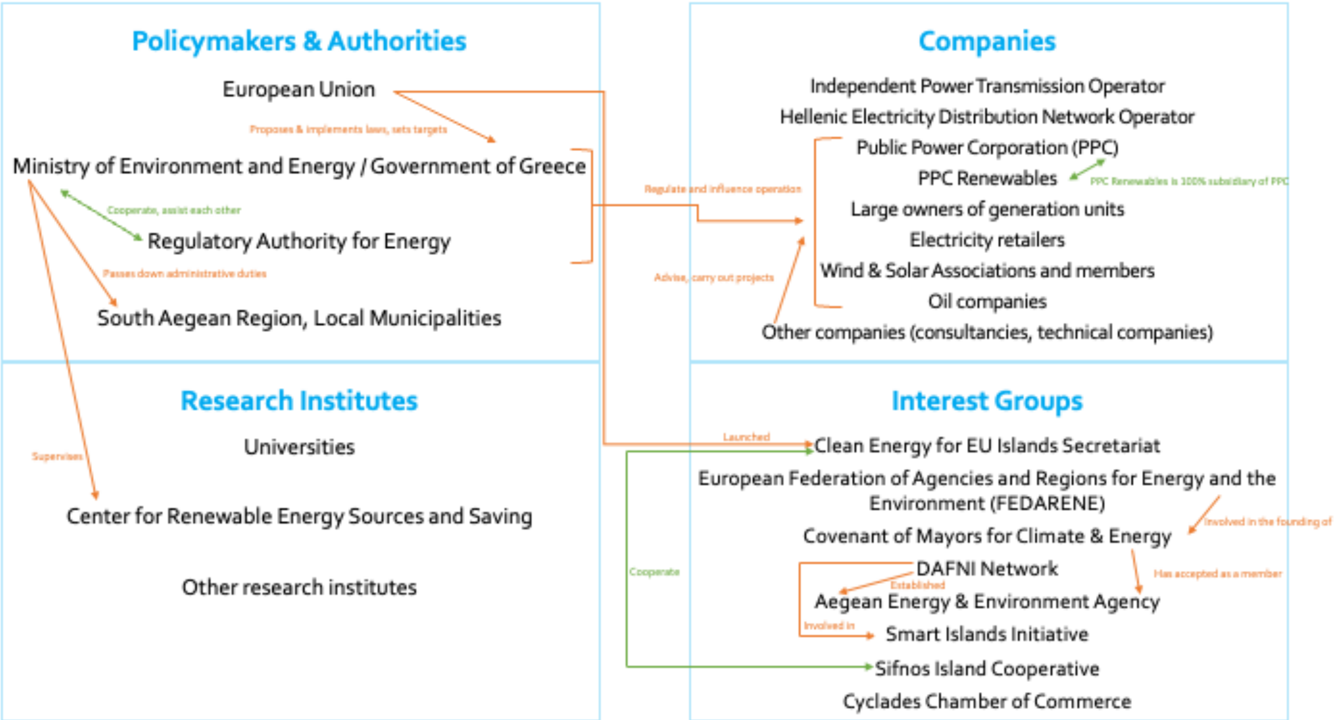


Figure 13 - Relationships between the stakeholders active in the energy transition in the Cyclades

4.4 PESTEL Analysis

While knowledge of the system characteristics and of the relevant stakeholders is paramount in developing a roadmap for the realisation of a sustainable energy system in the Cyclades, there are also several other factors in play in the macro-landscape that can affect the planning. These factors are explored using the so-called PESTEL analysis; in such an analysis, the political (P), economic (E), social (S), technologic (T), environmental (E), and legal (L) factors are studied and the environment around the energy landscape is presented. Table 5 is a summary of the analysis.

Political factors

In accordance with the European Union requirements and suggestions, the Greek government has been introducing policies and measures to support renewable energy, including civilians being able to cooperate to produce and sell electricity up to 1 MW using RES. Nevertheless, these programs are often hindered by bureaucracy and inadequate informing of the general public. Apart from such policies, there are also targets being set for 2030 regarding the increased use of RES, the decrease of energy consumption, and the penetration of electric vehicles, among others, as presented in the National Energy and Climate Plan (Ministry of Environment & Energy, 2019). As far as the Cyclades are concerned, an important project that is being promoted is the last two phases of the interconnection of some of the islands to the mainland (European Commission, 2019).

Economic factors

Despite being one of the most affluent regions of the country owing to its large tourism sector, the Cyclades were still affected by the Greek debt crisis that followed the worldwide financial crisis of 2008, arguably the most defining characteristic of the past decade for the country. While by some metrics the Greek economy has been gradually improving over the past couple of years, the impacts of the crisis (e.g. declining GDP and GDP per capita, increasing unemployment, rising taxation, etc.) are still shaping the financial landscape and hence the energy sector, even after the country has exited the bailout programs. The high tax rates and unattractive investment opportunities had dampened the introduction of renewable energy projects, but there have been attempts recently to attract capital, supported by the (seemingly) improving views of the Greek economy (Kathimerini, 2020).

Social factors

The general consensus is that renewable energy sources should at some point replace fossil fuels, but a push towards RES by the public is almost non-existent. It could be argued that the majority of the people are neither familiar with the manner in which they as individuals can contribute, nor adequately informed regarding sustainable energy projects carried out at a large scale, unless in their extreme vicinity. While it may not be the opinion held by the majority of the inhabitants of the Cyclades, citizens of islands on which wind turbines are set to be installed get generally quite vocal against such projects, especially if they are located in areas with a touristic interest. It is worth noting, however, that a sizeable number of households all over Greece, and especially in a sunny region such as the Cyclades, have been covering their hot water needs using solar water heating systems. While primarily motivated by cost considerations, it is nevertheless an example of recognising the potential of solar energy. Another important social factor is the fluctuation of the inhabitants of the islands throughout the year. A large number of tourists visit the Cyclades in the summer months, along with temporary workers to cover the increased needs of the commercial, hospitality, and food service sectors, increasing the population, and thus the energy requirements, of the islands.

Technological factors

Before the interconnection with the mainland grid, the majority of the demand in the islands was met through oil- and diesel-powered electricity stations, with a maximum of 20% covered through RES, mostly wind and solar energy, as explained in detail in section 4.2.1. The interconnection can offer a boost to the development of renewable energy on the islands by providing a baseload, considering that for most islands a reliable energy source to complement solar and wind energy is not present. On the other hand, however, it can become a trap if it causes the deceleration of renewable energy investments now that the negative effects of the power stations are not immediately visible.

Environmental factors

As mentioned above, the fact that the polluting stations on the islands will be taken out of service is a positive step towards easing the burden on the environment, and one that most people will appreciate owing to its health and aesthetic impact. As far as the local effects of the predominant worldwide environmental problem – climate change – are concerned, it appears that while the Cyclades islands will likely not suffer as much from increased temperatures (and their consequences for the energy sector) as other parts of the country (Giannakopoulos et al., 2011), they will likely be faced with rising sea levels in the future (Kokkali et al., 2012).

Legal factors

The Cyclades are not an administrative unit themselves, instead being part of the South Aegean administrative region, which has limited involvement in the energy sector of the islands. The regulations and legislation are therefore passed down from the central government, which has been introducing policies and passing bills regarding RES, as mentioned before. During the economic recession years, several grants, subsidies, and tax exemptions were decreased or halted, but even if they return, they may require navigating an often unclear legislative environment and securing an extensive number of licenses and other certificates that can needlessly complicate matters and diminish the advantages.

Table 5 - Overview of the PESTEL factors

Political factors	Measures introduced, hindered by bureaucracy. Interconnection to mainland grid.

Economic factors	Greek debt crisis in the past decade. Currently attempts to attract investments.
Social factors	Public not informed or motivated enough about RES. Local resistance against RES projects (e.g. wind farms). Solar water heating systems common. Large increase of the population (and energy consumption) in the summer.
Technological factors	Interconnection as baseload Can also thwart RES development
Environmental factors	Phasing out of oil-powered generating units encouraging. Climate change – rising sea levels likely an issue.
Legal factors	Often unclear legislative environment, bureaucracy.

4.5 RES Potential

As mentioned in the Introduction, there is a high potential for the exploitation of renewable energy sources in Greece and in the Cyclades specifically. Wind and solar are the most promising energy sources, while there is some potential from biomass and geothermal fields.

4.5.1 Wind

The Cyclades are a region with excellent wind potential in view of experiencing an annual average wind velocity at a height of 100 m estimated to be exceeding 7 m/s. As shown in Figure 14, several islands (such as Tinos, Mykonos, Amorgos, Sikinos, and Anafi) exhibit wind velocities of more than 9 m/s on average over a year (Regulatory Authority for Energy, n.d.). Such high velocities make them prime candidates for the development of wind farms, although all islands do merit consideration, since an annual average wind velocity of more than 6-7 m/s is recognized as favourable for the installation of a wind turbine.

Despite the presence of large regions with encouraging wind speeds, it is worth acknowledging that typically only a very small percentage of the area is suitable for the development of wind farms, as there are often other uses already established or taking precedence. In a technical report by the University of Thessaly, commissioned by the Regulatory Authority for Energy (see section 4.3), the practical exploitable area for the purposes of installing wind turbines has been calculated. The first step of this calculation identifies the areas of the islands where installation of RES projects is not allowed due to zoning & building regulations as well as due to the provisions of the Special Framework for Spatial Planning and Sustainable Development for RES, while the second step further narrows down the available areas based on their touristic character categorization (and resulting limitations) made by the Special Framework for Spatial Planning and Sustainable Development for Tourism. Then, it is estimated that the maximum amount of wind turbines that can be installed in the Cyclades islands in total ranges between 518 (3 MW, 112 m rotor diameter turbine) and 1,371 (1 MW, 55 m rotor diameter turbine) (University of Thessaly, 2010). As such, wind turbines with a maximum total installed capacity between 1,371 and 1,554 MW can be installed (University of Thessaly, 2010). Taking into account the capacity factor values at the annual average wind velocity for each island, wind can provide the Cyclades islands with approximately 22,000 TJ of energy annually; the 2017 electricity consumption of 2,771.20 TJ in the Cyclades NIIPS represents 12% of the potential energy that can be generated from wind. For 2-MW-turbines with a rotor diameter of 85 m, the specific values for the number of wind turbines, installed capacity, annual energy, and the capacity factor are listed in Table 6.

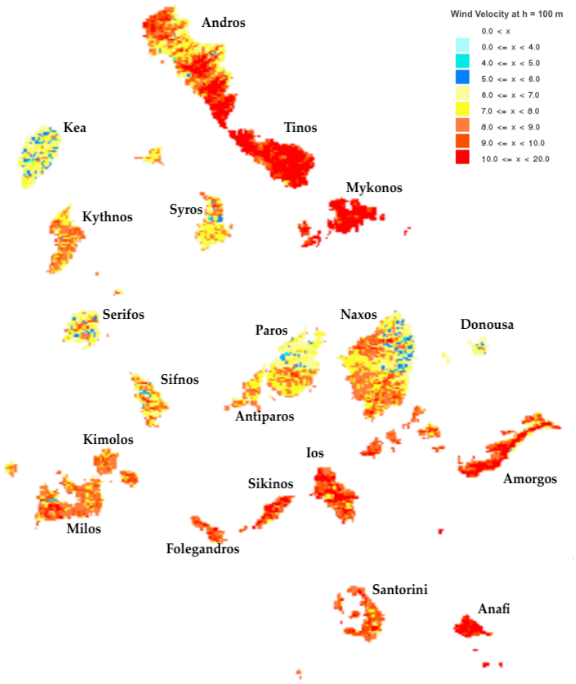


Figure 14 - Annual average wind velocity at 100 m (adapted from Regulatory Authority for Energy, n.d.)

Table 6 - Wind Potential Data (2 MW Turbine, 85 m Rotor Diameter) (using data from University of Thessaly, 2010, Center for Renewable Energy Sources and Saving, 2001)

Island	Capacity Factor	Wind Turbines	Installed Capacity (MW)	Annual Energy (GWh)	Annual Energy (TJ)
Amorgos	50%	1	2.4	10.5	37.84
Anafi	50%	0	-	-	-
Andros	47%	191	382.4	1,574.40	5,667.90
Antiparos	43%	0	-	-	-
Thira	47%	5	9.5	39.1	140.81
Ios	47%	58	115.6	475.9	1,713.41
Kea	38%	4	8.8	29.3	105.46
Kimolos	43%	28	56.4	212.4	764.81
Kythnos	43%	53	106.2	400.0	1,440.12
Milos	47%	37	74.9	308.4	1,110.16
Mykonos	50%	26	51.6	226.0	813.63
Naxos	47%	202	405.4	1,669.1	6,008.81
Paros	43%	15	31.0	116.8	420.37

Serifos	38%	8	15.3	50.9	183.35
Sikinos	47%	22	43.6	179.5	646.24
Sifnos	43%	21	42.3	159.3	573.61
Syros	43%	18	37.0	139.4	501.74
Tinos	50%	46	91.7	401.6	1,445.93
Folegandros	47%	17	34.1	140.4	505.43
Total		**752**	**1,508.2**	**6,133.2**	**22,079.62**

4.5.2 Solar

As a result of their location, the Cyclades are also enjoying sunny conditions for more than 6-7 months a year, so solar is also a renewable source that can cover the energy needs of the region. Figure 15 illustrates the yearly sum of global irradiation at the optimum angle, with all of the islands reaching values above 2100 kWh/m².

Based on the fact that the calculations made by the University of Thessaly regarding the potential of wind energy (cited above) have considered only areas where it is possible to place wind turbines, rigorously following government instructions, they can be used to approximate the potential of solar energy using photovoltaic panels in those areas, since unfortunately no analogous report has been published for solar energy. It is therefore important to note that the following data is the result of an assumption, as well as that due to the nature of the calculation, harnessing the potential of wind and solar energy is mutually exclusive.

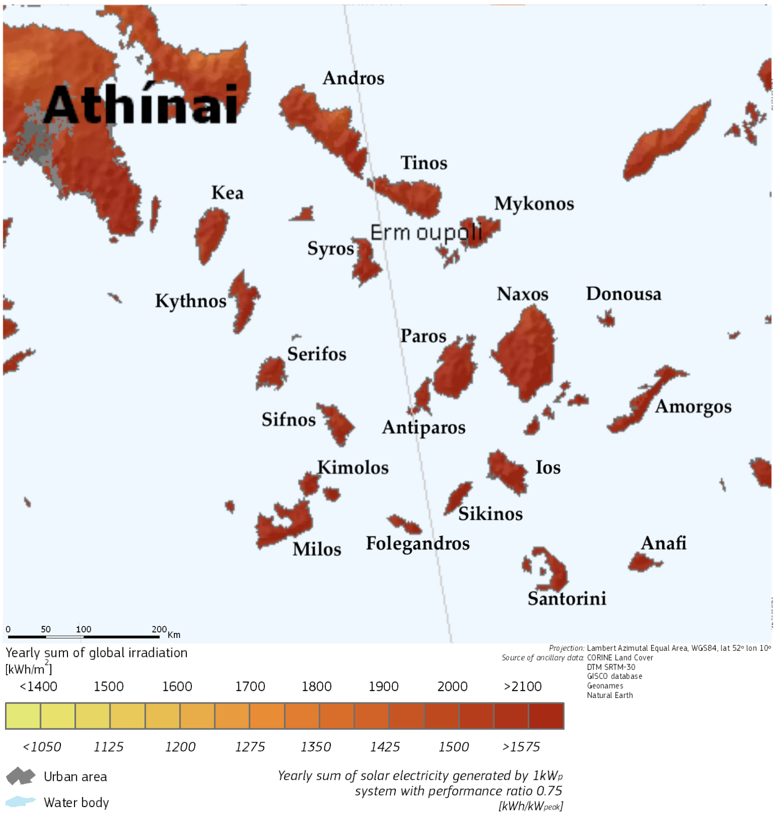


Figure 15 - Yearly sum of global irradiation in the Cyclades (adapted from PVGIS - European Commission, 2017a)

If SunPower SPR-P19-395-COM panels are used (with a nominal power of 395 W), and taking into account that as a rule of thumb an area of approximately 9.3 m^2 is required per 1 kW of installed capacity, the maximum number of panels that can be installed in every island can be calculated, along with the resulting capacity. The expected annual generated electrical energy corresponding to this capacity can be computed with the help of the Photovoltaic Geographical Information System of the European Commission (2017b). As it can be seen in Table 7, potentially more than 30,000 TJ of electricity can be generated on an annual basis in the Cyclades.

Table 7 - Solar Potential Data (SunPower SPR-P19-395-COM, 395 W Panels) (using data from University of Thessaly, 2010, SunPower, 2017, PVGIS - European Commission, 2017b)

Island	Exploitable Area (km^2)	Percentage of Total Area	PV Panels	Installed Capacity (MW)	Annual Energy (GWh)	Annual Energy (TJ)
Amorgos	0.1	0.1%	27,250	10.8	17.6	63.36
Anafi	-	-	-	-	-	-
Andros	14.3	3.8%	3,896,808	1,539.2	2,270.0	8,172.00
Antiparos	1.5	4.3%	408,756	161.5	238.0	856.80
Thira	0.2	0.3%	54,500	21.5	35.9	129.24
Ios	3.3	3.0%	899,263	355.2	576.0	2,073.60
Kea	0.2	0.2%	54,500	21.5	34.8	125.28
Kimolos	1.6	4.3%	436,006	172.2	275.0	990.00
Kythnos	3.5	3.5%	953,764	376.7	620.0	2,232.00
Milos	1.7	1.1%	463,256	183	299.0	1,076.40
Mykonos	1.2	1.4%	327,004	129.2	209.0	752.40
Naxos	13.7	3.2%	3,733,305	1,474.7	2,370.0	8,532.00
Paros	0.7	0.4%	190,752	75.3	115.0	414.00
Serifos	0.3	0.4%	81,751	32.3	52.5	189.00
Sikinos	2.3	5.5%	626,759	247.6	397.0	1,429.20
Sifnos	1.0	1.4%	272,504	107.6	172.0	619.20
Syros	0.8	1.0%	218,003	86.1	140.0	504.00
Tinos	2.1	1.1%	572,258	226	360.0	1,296.00
Folegandros	1.1	3.4%	299,754	118.4	187.0	673.20
Total	**49.6**		**13,516,193**	**5,338.9**	**8,368.8**	**30,127.68**

4.5.3 Biomass

Despite the high potential of both wind and solar energy, their intermittent nature is a very important obstacle if they were to be used as primary energy sources of an autonomous island, thus introducing the need for a baseload energy source, such as biomass. Unfortunately the generally rough terrain and the small size of most of the islands limits the exploitation of arable land to the islands of Naxos, Paros, and Andros, while a significant amount of vineyards can be found in Thira. The different sources of agricultural solid waste in the Cyclades, as well as their annual production and resulting energy potential, have been compiled by the Center for Renewable Energy Sources and Saving (Center for Renewable Energy Sources and Saving, 2015). Table 8 presents the annual potential of agricultural solid waste, where it is seen that only a small amount of energy can be generated through such sources (approximately 174 TJ) compared to the annual consumption in the Cyclades (upwards of 6,000 TJ). Apart from agricultural solid waste, municipal solid waste (MSW) can also be converted to energy. Taking into account that 500 - 600 kWh of electricity can be produced per ton of MSW (Waste-to-Energy Research and Technology Council, n.d.), the 102,727 tons of MSW produced annually in the Cyclades (Solid Waste Management Organization of the South Aegean Region, 2016) could provide the islands with 50 to 60 GWh (180 to 216 TJ) of electricity per year.

Table 8 - Energy Generation Potential from Agricultural Solid Waste (in TJ) (using data from Center for Renewable Energy Sources and Saving, 2015)

Island	Point sources of biomass	Arable crops	Greenhouse crops	Tree crops	Vines	Total
Amorgos	-	0.12	-	1.61	0.15	1.88
Anafi	0.0002	0.06	-	0.15	0.17	0.38
Andros	0.008	4.78	0.0048	21.59	4.53	30.91
Antiparos	-	0.65	0.0058	0.36	1.00	2.01
Thira	-	1.43	0.0049	0.63	17.52	19.59
Ios	-	0.18	-	0.27	0.05	0.50
Kea	-	0.10	-	6.51	0.23	6.85
Kimolos	0.0025	0.10	-	1.77	0.10	1.98
Kythnos	-	0.37	-	1.52	1.01	2.90
Milos	-	1.33	0.0043	0.52	1.23	3.08
Mykonos	-	-	0.0498	0.17	0.48	0.70
Naxos	0.0163	9.37	0.4953	35.00	9.16	54.03
Paros	0.012	6.83	0.1542	11.62	9.65	28.26
Serifos	0.0001	0.01	-	0.18	1.28	1.47
Sikinos	0.001	0.01	-	0.07	0.04	0.12
Sifnos	0.0008	0.64	-	1.01	0.50	2.15
Syros	0.0025	0.93	1.0489	5.48	2.41	9.87
Tinos	0.0035	1.72	0.007	3.71	1.13	6.57
Folegandros	-	0.13	-	0.16	0.02	0.32
Total	0.05	28.76	1.77	92.32	50.67	**173.57**

4.5.4 Geothermal

In the Cyclades, two of the main islands and their volcanoes – Thira (Santorini) and Milos – are part of the South Aegean Volcanic Arc, which is generally a positive sign of the presence of geothermal energy potential.

In the cluster of Milos and its neighbouring Kimolos, the temperature in the wells at a depth of around 1 km is in the range of 300 °C, and it has been estimated that the field has a power capacity of 120 MW (PPC Renewables, 2013). Assuming a typical capacity factor for geothermal power plants of 80% (IRENA, 2017), the Milos-Kimolos geothermal field could potentially provide up to 3,027.46 TJ of electricity on an annual basis.

As far as the potential in Santorini is concerned, measurements show that temperatures of about 90 - 150 °C are expected to be found in the southern part of the island, and even higher temperatures (> 150 °C are probable inside the caldera of the volcano, although these are deemed too impractical to be exploited (Papachristou et al., 2016). Nevertheless, while the presence of the geothermal field in southern Santorini is confirmed, its exploitation for applications including, but not limited to, power generation hinges upon further research and as such is arguably out of the timeline of this project.

4.5.5 Other RES

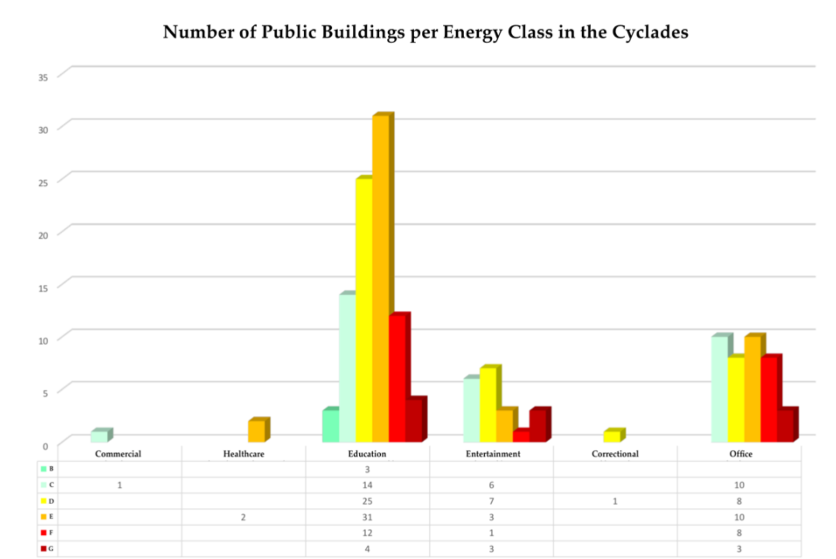
Excluding the previously mentioned, unfortunately no other renewable energy sources, seem to have the potential to dependably cover (some of) the energy needs of the Cyclades.

Aside from the small amount of rainfall they receive, the islands are also relatively small so there are no rivers or other running water bodies to harvest hydropower from. Nevertheless, pumped hydro installations could prove useful on occasion, taking advantage of the often abrupt height gradients on the coasts of the islands and using the sea as the low reservoir.

Marine energy forms such as wave energy or ocean thermal energy conversion (OTEC) are also either not attractive or feasible. The wave energy values in the Cyclades range between 2-3 kW/m (compared to 20-70 kW/m in the best available locations), and the technology is not mature enough to rely upon in the short-to-medium term (Soukissian et al., 2011). As far as OTEC is concerned, a temperature gradient of 20 °C and depths of around 1 km are necessary, while the depths found in the Cyclades rarely surpass 200 m (Soukissian et al., 2017).

4.5.6 Energy Savings

Apart from and complementing the potential of RES, the potential for energy savings can be another important driver of the energy transition. As indicated before, the domestic and commercial are the sectors with the highest energy consumption (particularly for electric energy and heat), thus the prime candidates for the application of energy measures are the buildings of these sectors. As it can be seen in Figure 16, Figure 17, and Figure 18, the vast majority of the buildings in the Cyclades do not fall into the high energy classes, especially as far as the residential sector is concerned.



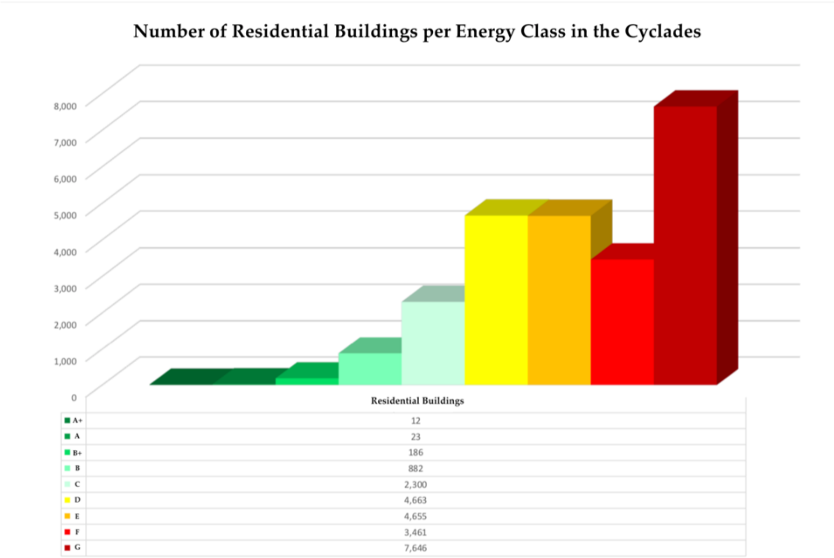
	Commercial	Healthcare	Education	Entertainment	Correctional	Office
B			3			
C	1		14	6		10
D			25	7	1	8
E		2	31	3		10
F			12	1		8
G			4	3		3

Figure 16 - Energy Class Distribution of Public Buildings in the Cyclades (adapted from Inspectorate of Environment Construction Energy and Minerals, 2019a)

As a result, there is still a very large number of buildings for which energy saving measures can be applied, and substantial gains to be made. For instance, based on the latest version of the Regulation on the Energy

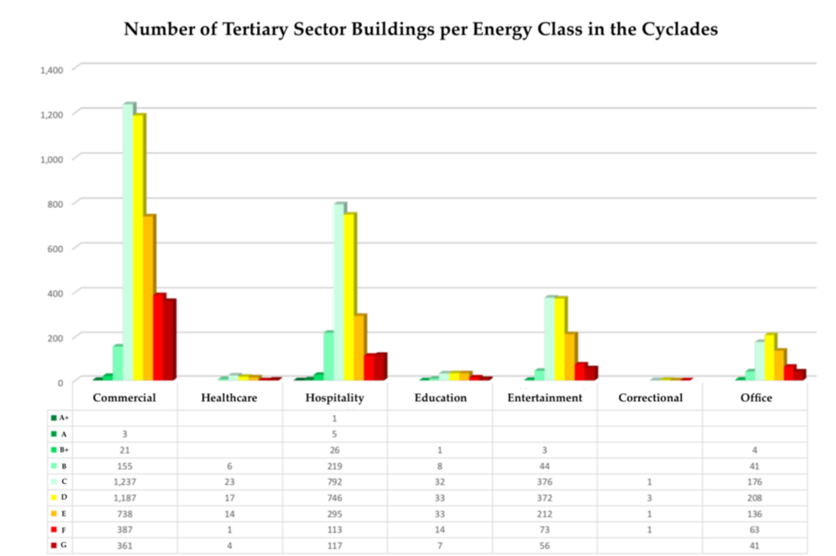
Performance of Buildings (published in 2017), energy saving percentages of 33 to 63% can be realized in the climatic zone of the Cyclades islands, with the largest of them relating to single- and multi-residence buildings – 62.47% and 54.10% respectively (Energy Inspection Department, 2018). If (as calculated previously) the electricity demand by tertiary, residential, and municipal buildings is 1,669, 695, and 139 TJ respectively, and the heat demand is 470 TJ, then the energy demand by buildings currently amounts to 2,973 TJ; in this case an energy saving percentage of 33% decreases that value to 1,962 TJ (1,011 TJ saved), while at the other end an energy saving percentage of 66% means that buildings require 981 TJ (1,992 TJ saved).

The energy saving measures exhibiting the largest potential for the buildings in the relevant climatic zone are the thermal insulation of external walls, the air sealing of windows, and the installation of double-pane windows, among others (Institute for Environmental Research and Sustainable Development, 2016).



	Residential Buildings
A+	12
A	23
B+	186
B	882
C	2,300
D	4,663
E	4,655
F	3,461
G	7,646

Figure 17 - Energy Class Distribution of Residential Buildings in the Cyclades (adapted from (Inspectorate of Environment Construction Energy and Minerals, 2019b)



	Commercial	Healthcare	Hospitality	Education	Entertainment	Correctional	Office
A+			1				
A	3		5				
B+	21		26	1	3		4
B	155	6	219	8	44		41
C	1,237	23	792	32	376	1	176
D	1,187	17	746	33	372	3	208
E	738	14	295	33	212	1	136
F	387	1	113	14	73	1	63
G	361	4	117	7	56		41

Figure 18 - Energy Class Distribution of Tertiary Sector Buildings in the Cyclades (adapted from Inspectorate of Environment Construction Energy and Minerals, 2019c)

4.5.7 Energy Storage

On top of the potential of renewable energy sources and energy savings in the Cyclades islands presented above, the possibilities of energy storage need to also be examined before moving onto the creation a plan for the transition, owing obviously to the intermittent nature of the main RES found on the islands (wind & solar).

As explained in 4.2.1, the majority of the islands are already connected to the mainland grid; this is an excellent driver for the realization of a system based on RES. For those islands, the storage of energy can theoretically be overlooked (at least on a short-term scale), as any deficits created by a possible underperformance of the installed wind and/or solar systems shall be covered by the generation of energy on the mainland. Practically, a limited amount of e.g. batteries will most likely be necessary to prevent blackouts in case of malfunction regarding the interconnection.

As far as the rest of the islands are concerned, i.e. those still relying on localized generating units, energy storage solutions are absolutely essential. At this point time, though, there have been no reports presenting data regarding the potential for the installation of such solutions on the Cyclades. Nevertheless, there have been a few small-scale projects already carried out on Greek islands, such as Kythnos (Varta, 2019), Tilos (Eunice Energy Group, 2019), and Ikaria (Off Grid Energy Independence, 2019). In the first two cases batteries were chosen as the energy storage medium, while a pumped hydro system is used in Ikaria. Apart from Kythnos, another island in the Cyclades – Sifnos – is also aiming to install an energy storage system, in this case a seawater pumped hydro system in conjunction with a wind farm (Katsaprakakis & Voumvoulakis, 2018). Aside from batteries and pumped hydro, the solution of hydrogen has also been investigated for an island in Greece (Karpathos), albeit not in the Cyclades (Giatrakos et al., 2009).

All of the above point to the feasibility of energy storage methods on the islands, more specifically, batteries, pumped hydro, and hydrogen, although there is not a clear picture as far as solid values for the potential of storage (similar to those for wind, solar, biomass, and geothermal presented above) are concerned. Hence, the inclusion of energy storage in the transition framework for the islands will have to be assumed and approximated on a case-by-case basis.

4.6 Summary

To summarize this chapter, as far as the electricity sector is concerned, the most striking characteristics of the islands is firstly that most of them were relying on local oil-powered stations for the generation of energy until 2018, that RES were covering only a very small percentage of that, and also the fact that the heating and transport sectors were almost exclusively powered by oil products.

In the energy system of the Cyclades there are quite a few stakeholders active that could influence the transition. Some of the most important ones are the Ministry of Environment and Energy as a part of the Greek government, which is of course cooperating with and following the directives of the European Commission, the Regulatory Authority for Energy, the Transmission System and Distribution Network Operators, several companies active as producers, retailers, or in the field of wind and solar energy, as well as a few interest groups such as NGOs, networks, etc.

Taking the energy landscape into a broader view, several factors can be identified that affect the transition to a sustainable energy system, both positively and negatively. To start with the first, in the recent years there are efforts made to attract investments in the sustainable energy field (as part of the global shift to RES), while the interconnection to the mainland grid can also act as a driver for the transition, since it can solve the problems caused by the intermittency of wind and solar energy. On the other hand, the opposition often expressed by locals to the implementation of renewable energy projects is arguably one of the largest obstacles that will need to be overcome, as is the generally convoluted and bureaucratic legal and political system.

Finally, from the analysis of the potentials, it becomes clear that the RES in the Cyclades could in principle more than cover the energy needs of the islands, with the vast majority of the potential coming from wind and solar. The non-intermittent sources can be used to provide a baseload (especially geothermal) but their potential is unfortunately not on the same level as that of the intermittent ones. Additionally, there is a high potential for energy savings in buildings, with the possibility to decrease the energy consumption even more than 50%. Table 9 includes the potential of the available RES in the Cyclades, as calculated in the previous sections.

Table 9 - Potential of Renewable Energy Sources in the Cyclades

Source	Potential (TJ)
Wind	22,079
Solar PV	30,127
Biomass	389
Geothermal	3,027
Energy Savings	1,011 – 1,992
Total	**55,622**

5 Future Vision & Scenario Development

5.1 Vision

As mentioned in the previous chapter, the Greek government published its latest National Energy & Climate Plan in early 2019, shaped by EU policy. It aims to decrease greenhouse gas emissions, increase RES penetration in the energy mix, and further energy savings (Ministry of Environment & Energy, 2019). Furthermore, the country targets in regards to renewable energy for 2030 are also outlined: 31% share of RES in total primary energy supply (TPES), 55% share of RES in electricity production, 30% share of RES for heating and cooling purposes, and 14% share of RES in the transport sector (Ministry of Environment & Energy, 2019).

While these are valid starting points as targets, especially in the Cyclades much higher percentages for the penetration of RES in the different sectors can be reached, as indicated by the large potential for wind and solar energy in Section 4.5. The region can become a national pioneer in the complete transition to RES, so it is important to develop a more ambitious vision (compared to the national plans and targets), so that the energy system in the Cyclades in 2030 is:

- Self-sufficient
- Efficient
- Reliable

The principal alteration of the present energy system necessary to reach a self-sufficient one in 2030 would undoubtedly be the decrease of the reliance on the fossil-fuel-powered generating units on the islands, as much as possible. As mentioned previously, owing to these units, most islands were – and many still are currently – dependent on fuel being transported by ships from the mainland, which are also raising the cost of electricity generation. Ideally, the energy system in 2030 would be based solely on RES, but as previous studies such as that by Gioutsos have shown, renewable energy penetration of up to 80% would be sensible for non-interconnected islands; beyond that point, a fully RES-based system would lead to large amounts of over-production and require extra capacities and costs. Despite the fundamental nature of such a change, the Cyclades can certainly cope with it, thanks to the great potential for the exploitation of RES. Hence, primarily with the help of solar and wind energy, and possibly also with the expansion of the local inter-island grid, the need for the (expensive) supply of fuel can be curbed, and with it the reliance of the Cyclades for electricity on mainland Greece.

Apart from the electricity sector, the islands are also needful of oil & petroleum products to cover the needs of transport and heating, as well as the requirements of the (admittedly relatively minor) industry and agricultural sectors. This means that moving away from fossil fuels in electricity only to be still dependent on them for other purposes is senseless; a transformation of the other oil-powered sectors is also necessary. Therefore, the energy vision for the Cyclades in 2030 entails the electrification of the aforementioned sectors as much as possible – so that it is feasible to fully take advantage of the use of RES in the electricity sector – and possibly the utilisation of the biomass potential present on the islands.

While the shift to RES for electricity generation and the electrification and use of biomass in the other sectors are significant steps towards self-sufficiency in 2030, they shall also improve the overall efficiency of the energy system. Although solar PV panels and wind turbines were in the past generally less efficient than fossil fuel power plants when compared directly, generating electricity by exploiting locally available free solar or wind energy can certainly be more efficient than importing oil & petroleum products that have already undergone several processing steps from extraction until reaching their end destination, and that is not even taking into account the rapid progress that has been made regarding the efficiency of wind turbines. Moreover, several measures can also be implemented to increase the efficiency of the energy system, of either technical, financial, or behavioural nature.

The creation of a system based on RES and with a large degree of electrification such as the one proposed for the Cyclades in 2030 can bring numerous advantages, not limited to those outlined above, but can also pose several challenges. Being dependent on RES, and especially ones with a strong intermittent and seasonal character, as are solar and wind energy, requires extensive planning and preparing in advance to avoid disruptions in the energy supply in times of low or no availability of solar irradiation and/or wind. Consequently, while envisioning this sustainable Cyclades 2030 energy system, special attention must be paid to ensure that sufficient (short- and long-term) storage capacity is installed on the islands to complement the intermittency of solar and wind energy, in order to keep it reliable.

5.2 Energy Demand Change

Before moving forward with the scenario development, it is crucial to evaluate the development of the energy demand in the future. The consumption of energy is expected to increase in 2030 compared to 2016, with the National Energy and Climate Plan (NECP) including specific growth rates for the different sectors (while also taking into account the improvements in energy efficiency between the starting and end points). Nevertheless, these growth rates do not exactly match the categorization of energy consumption presented in section 4.2, so an adaptation between the two is necessary. Table 10 presents the growth rates for each aspect of the energy consumption as presented in section 4.2, while also including the relevant sector as cited in the NECP (Ministry of Environment & Energy, 2019).

Table 10 - Energy Demand Growth Rates (2016 – 2030)

Sector		Growth Rate	NECP Sector
Electricity	Tertiary buildings	11.1%	Tertiary
	Residential buildings	7.7%	Domestic
	Public lighting	11.1%	Tertiary
	Municipal buildings	11.1%	Tertiary
	Agriculture/forestry/fisheries	16.4%	Agricultural
Heating	Heating	7.7%	Domestic
Transport	Transport	3.5%	Transport

Unfortunately there is currently no data pertaining to the energy demand in the future for the Cyclades explicitly, so the national growth rates will be used to estimate the requirements of the islands in 2030. Table 11 presents the projected energy consumption of each sector in the Cyclades in 2030, using the above rates, along with the relevant consumption in the present. Looking at Table 11, it is worth noting that despite the provisions made in the NECP regarding energy savings and the improvements in energy efficiency, the total energy demand in 2030 is set to increase slightly, with the main reason for this increase being the predicted continuing growth of the economy and of the disposable household income.

Table 11 - Energy Demand in the Cyclades in 2030 per sector (TJ)

Sector		2017	2030
Electricity	Tertiary buildings	1,669.03	1,854.29
	Residential buildings	695.43	748.98
	Public lighting	250.35	278.14
	Municipal buildings	139.09	149.80
	Agriculture/forestry/fisheries	27.82	30.90

Heating	Heating	470.79	507.04
Transport	Transport	1,721.14	1,781.38
	Total	**4,973.65**	**5,350.53**

With the energy demand in 2030 representing less than a tenth of the potential of renewable energy in the Cyclades, it is obvious that the shift to sustainability in the Cyclades is not a matter of availability, but rather one of striking the optimal balance between the sources, locations, and storage solutions, taking into account the practical and economic efficiency, reliability, and environmental impact of the project(s).

5.3 Scenario Development

A desired future can be attained in numerous ways, represented by scenarios. Three such scenarios are presented below, based on the current situation, the potentials of RES and energy savings, and the vision characteristics laid out above. Scenario A is a relatively straightforward one, largely based on the present situation but with the necessary steps to reach a sustainable energy system in 2030, Scenario B is developed on the same basis, but there is special regard for the energy efficiency of the tourism sector, since it is the main income source for most islands, and Scenario C is a more extreme alternative, in which there is no dependence on wind energy, owing to the strong opposition that has been observed towards such projects from some citizens.

5.3.1 Scenario A – A Simple Transition

The first scenario follows the assumption that the energy demand will follow the growth trend predicted by the Ministry of Environment & Energy in the 2019 National Energy and Climate Plan (NECP), but is more ambitious than the NECP, aiming to cover the entirety of the energy needs of the islands using RES.

More specifically, the (inhabited) islands are split into two categories: the group connected with each other (and the national grid), and those that are autonomous: the 13 islands in the first category are (from most to least populous) Syros, Naxos, Paros, Mykonos, Andros, Tinos, Ios, Antiparos, Folegandros, Koufonisi, Sikinos, Schinoussa, and Irakleia, while the 11 islands in the second category are (from most to least populous) Thira (Santorini), Milos, Sifnos, Kea, Amorgos, Kythnos, Serifos, Kimolos, Thirasia, Anafi, and Donousa. It is worth noting that Kea is connected with the mainland grid, but not to any other islands, and is thus placed in the second category, and that Milos and Thira (Santorini) are connected with nearby smaller islands (Kimolos and Thirasia respectively).

This scenario takes advantage of the existing interconnections between the islands of the first category to optimize the location of the RES projects, since it can happen that some of them either do not exhibit renewable energy potential at all or if they do it is not enough. Another benefit of these islands is that they are part of the mainland (and consequently European) electricity grid, which offers the opportunity for grid balancing and storage option. The rest of the islands remain independent, but with RES and storage covering their needs instead of oil-powered units.

The energy sources covering the demand are wind and solar, with Figure 19 and Figure 20 showing the share of wind and solar for electricity generation for each island and the percentage of the utilisation of the maximum potential. These figures are based on the future energy mix of each island as calculated based on their RES potential and predicted energy demand and show how the generation of electricity is shared between wind and solar, as well as what percentage of the maximum RES potential needs to be used for each island. A more detailed view of the islands' energy mix is given in Chapter 6. Furthermore, regarding these figures, it is important to make a few observations: the islands Koufonisi, Schinoussa, and Irakleia do not exhibit wind or solar potential themselves, but are connected to the grid; their needs shall be met by resources on other islands. The same limitation holds true for the autonomous islands Thirasia, Anafi, and Donousa – although Thirasia is connected to the island of Thira. Finally, Thira merits special mention since its maximum potential is not enough to cover the demand of this (extremely touristic) island. Indeed, it would need to exhibit more than three times its maximum potential in order to be able to meet the demand locally. To make matters worse, Thirasia, the small island to which it is connected, cannot carry any wind or solar projects, as mentioned previously. It is therefore clear that there needs to be a distinctive strategy for this group of two islands. When inspecting the percentage of utilisation of the maximum potential for the connected islands, it can be easily seen that apart from some of the largest and most populous islands (such as Syros, Mykonos, and Paros), the majority of them need less than 10% of their locally available energy. Therefore, Thira and Thirasia shall be connected to them and the grid and make use of the large reserve of these islands, as will Anafi and Donousa, which face the same problem.

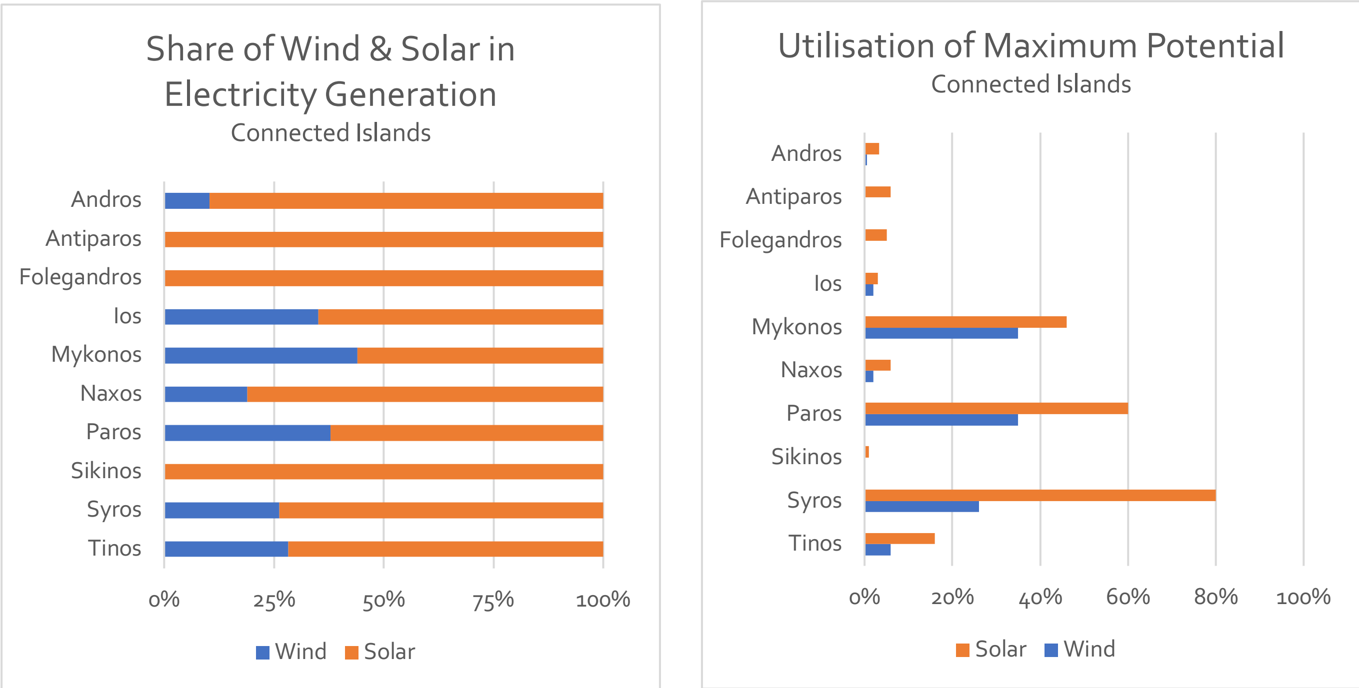


Figure 19 – Share of wind and solar in electricity generation and utilisation of maximum potential for the connected islands in Scenario A

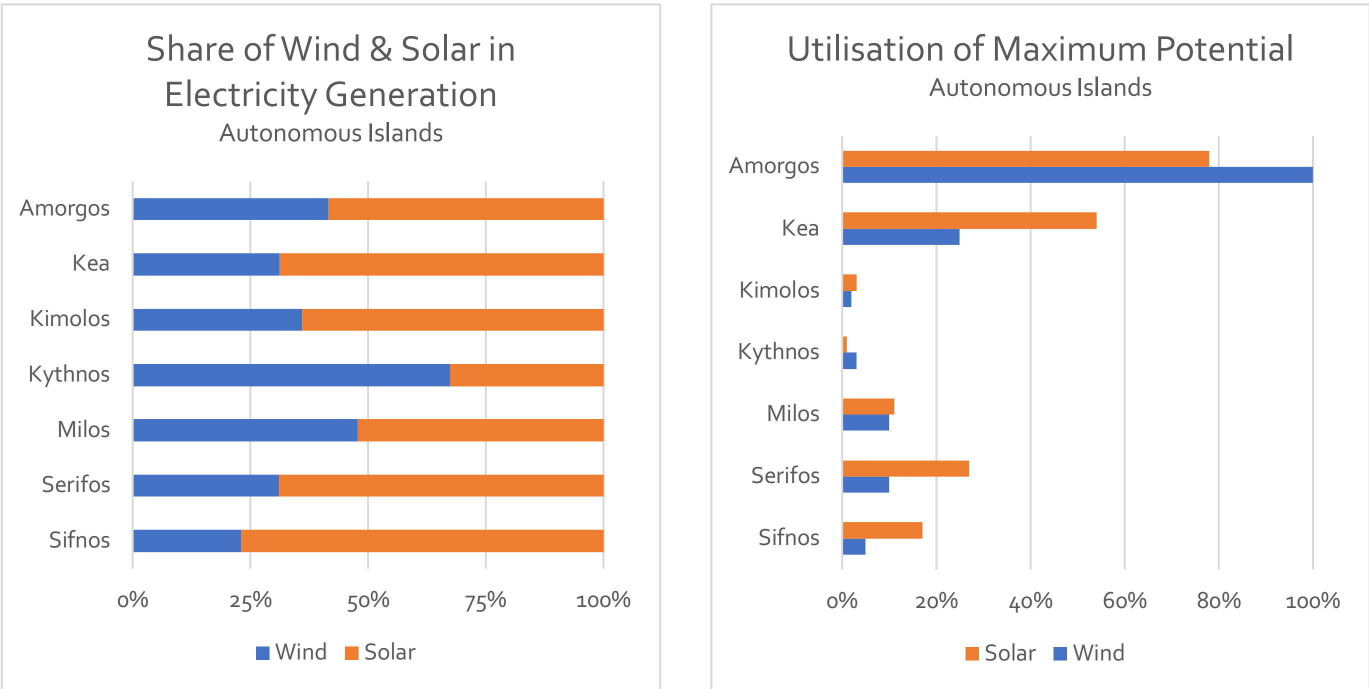


Figure 20 – Share of wind and solar in electricity generation and utilisation of maximum potential for the autonomous islands in Scenario A

Short-term energy storage is provided by batteries (for needs up to the order of a few days),while hydrogen will be produced when excess energy is available and be used to store energy for longer periods of time and biofuels, albeit limited, can also act as a balancing mechanism or energy storage option. In fact, for most of the islands, the interconnection offers the opportunity of covering the electricity needs during moments of peak demand or in times of insufficient generation by the wind turbines and solar PV panels, so in reality only the islands of Amorgos, Kythnos, Sifnos, Serifos, and the duo of Milos and Kimolos (which are already connected together) will require the extensive energy storage and baseload options mentioned before. It is assumed that the national trend of growing energy demand in the years up to and including 2030 explained in the NECP will also be valid for the Cyclades, taking into account (also following the NECP), that energy efficiency and savings are increased as well (Ministry of Environment & Energy, 2019). As far as the substitution of energy sources is concerned, electricity shall replace fossil fuels to cover the heating needs of the islands, and oil & petroleum products in the transport sector. The complete electrification of transport is propelled by the introduction of electric vehicles (EVs) to take advantage of the small distances within the islands and hence the diminished importance of the (relatively) low range of such vehicles.

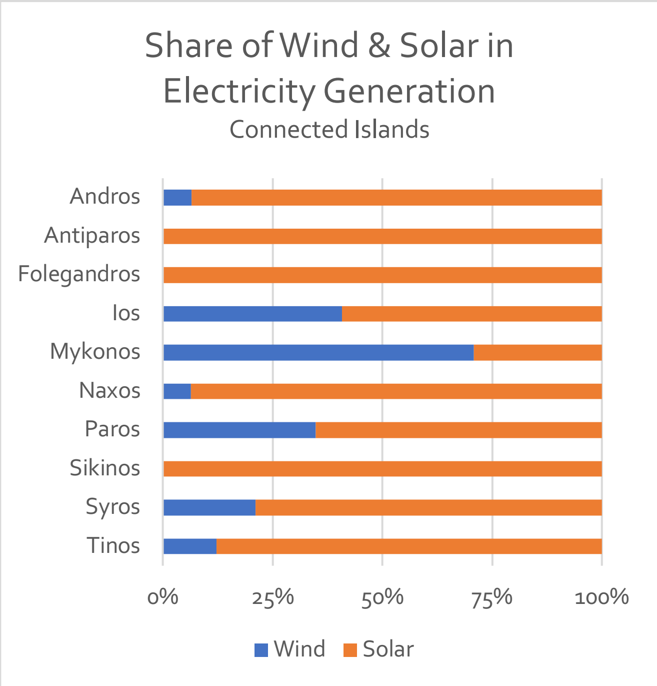
Following the above, it is easily understood that electricity will take over as the energy carrier in 2030, which will account for a large increase in the amount that will need to be generated. More specifically, 2,781 TJ of electricity was consumed in 2017, while with the shift proposed in this scenario and the increase in demand in the future, the requirements for electricity generation in 2030 will reach 5,350 TJ. Comparing this figure with the RES-produced electricity in 2017 (216.13 TJ), since the target is to provide this electricity sustainably, underlines the scale of the effort that will need to be carried out.

5.3.2 Scenario B – Turning the Tourism Sector Green

While following the premise of the first scenario, the second scenario can be thought as building upon the latter by focusing to a greater extent on the tertiary (non-municipal) buildings sector, since it represents a quite substantial majority of the electricity consumption on the islands (which is itself the main element of the energy consumption), as shown in section 2.1 of Chapter 4.

As a result of the nature of the islands as tourist destinations – especially in the summer months – there is a large number of buildings catering to these needs, with hotels exhibiting the largest needs for electricity due to systems such as air conditioning cooling and lighting (Clean Energy for EU Islands Secretariat, 2019). However, and as presented in section 4.5.6, most buildings in the hospitality sector in the Cyclades are considered as having an energy class of C or below, an indication of both inefficient energy use and potential for improvement. For instance, measures such as upgrading the insulation alone can lead to a decrease of up to 20% of the cooling needs of a hotel, while the combination of several energy-saving solutions can reduce the annual energy consumption by 60% on average (Kresteniti, 2016); it is important to note that these values regarding the consumption decrease and efficiency increase are additional to and not included in the energy demand growth data provided in the National Energy & Climate Plan discussed in section 5.2. Moreover, the tourist season (and hence energy demand peak) coinciding with the period in which the solar irradiation is highest in the year can prove a great driver for the shift to solar thermal and solar power technologies; examples include solar collectors for hot water production and solar cooling (Dascalaki & Balaras, 2004). Furthermore, hotels can be equipped with smart energy management systems, as well as EV-charging facilities to also aid with the transition, as mentioned in the previous scenario.

Taking these values into account, together with those presented in section 4.5.6, it appears that the total decrease in the energy demands of the buildings in the Cyclades can reach 60%. Such a reduction would be slightly ideal though, since not all buildings exhibit the same potential for alterations. Nevertheless, even when using 40% as the percentage by which energy consumption will decrease can lead to encouraging signs. With the electricity demand of tertiary & residential buildings in 2030 projected to be 2,603 TJ, a 40% reduction lowers the demand to 1,591 TJ, for a total electricity requirement to the scale of 3,788 TJ, i.e. 70% of the comparable value in Scenario A. Similarly to Scenario A above, Figure 21 and Figure 22 show the share of wind and solar for the generation of electricity and the percentage of utilisation of the maximum potential for each island applicable for this scenario, while Figure 23 and Figure 24 compare the percentages of utilisation of the maximum wind and solar potential between the two scenarios and illustrate the positive effect of the decrease in energy consumption of tertiary and residential buildings.



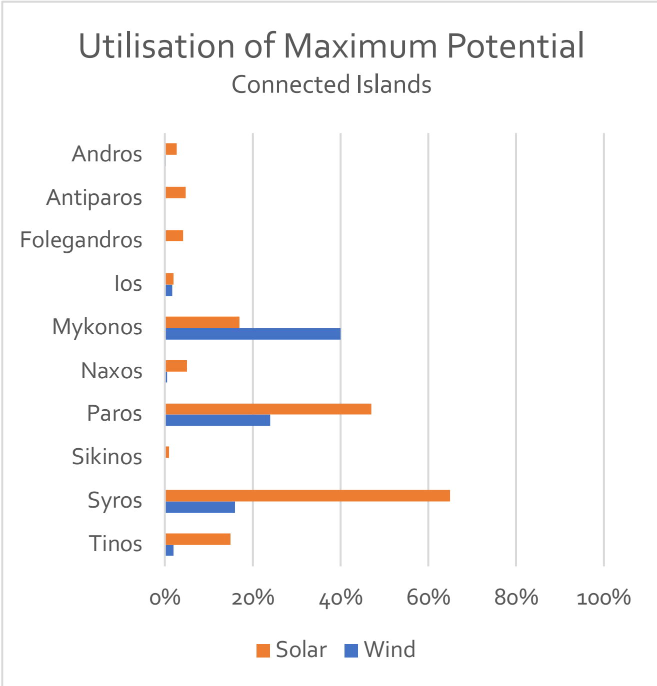
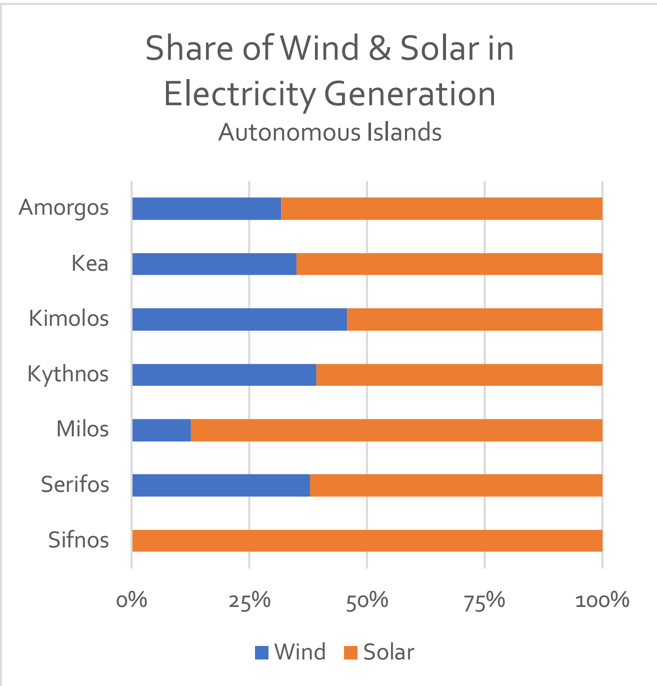


Figure 21 – Share of wind and solar in electricity generation and utilisation of maximum potential for the connected islands in Scenario B



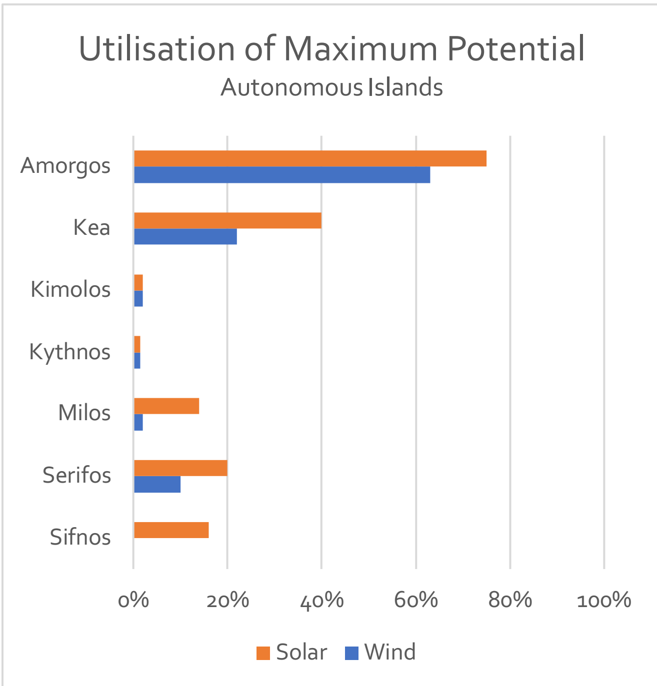
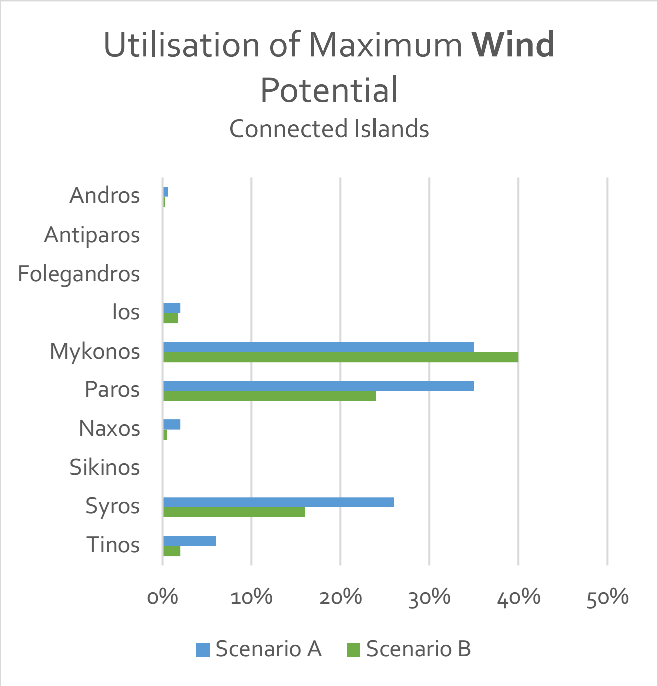


Figure 22 – Share of wind and solar in electricity generation and utilisation of maximum potential for the autonomous islands in Scenario B



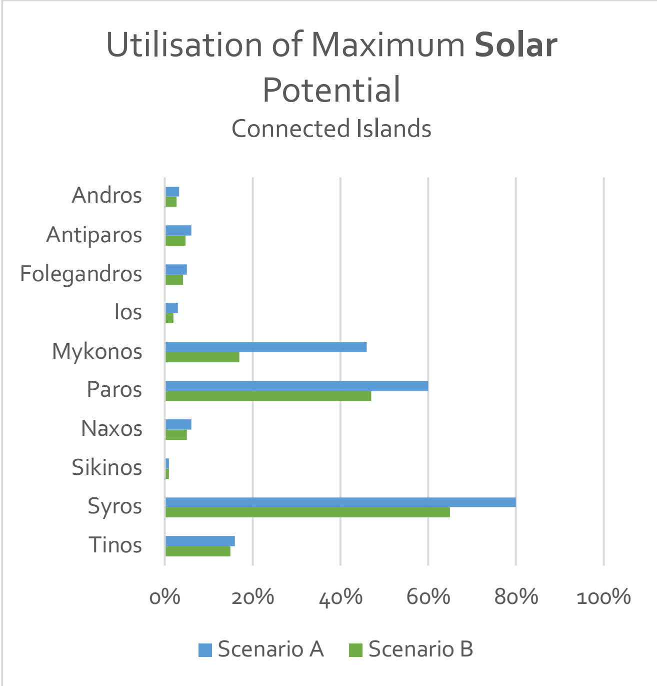
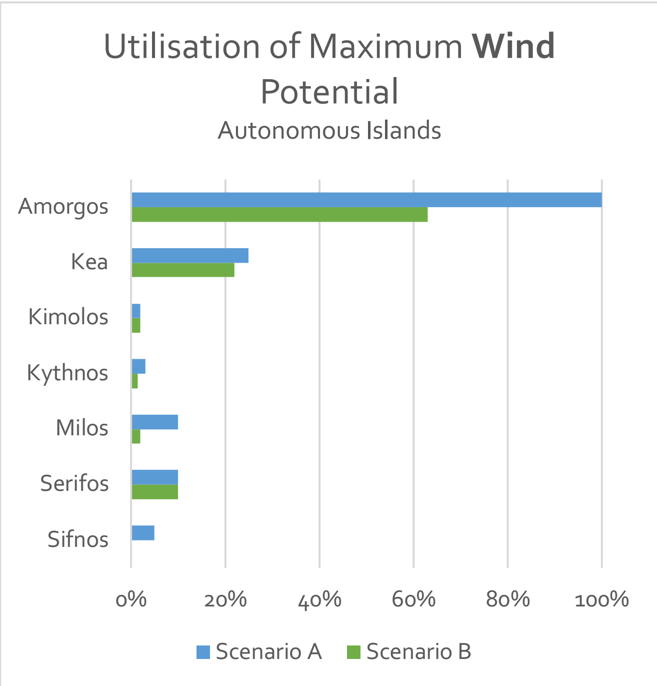


Figure 23 - Comparison of the utilisation of the maximum potential in the connected islands between Scenario A and Scenario B



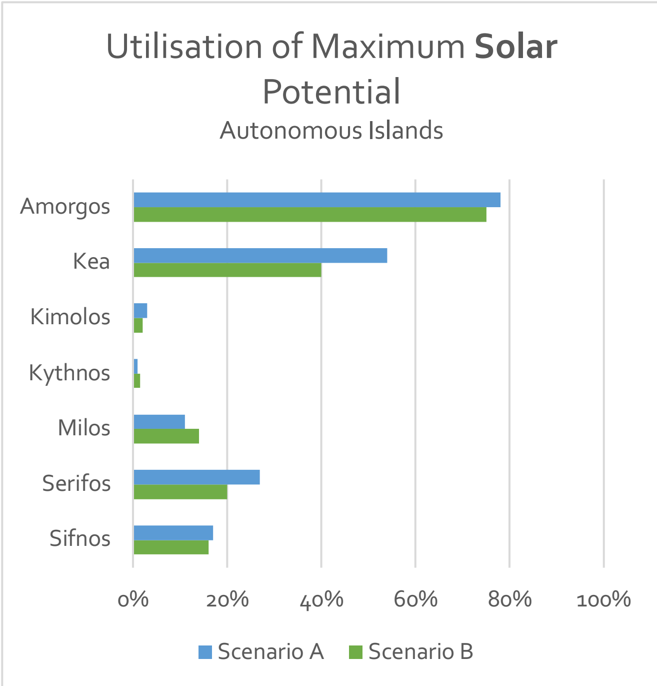


Figure 24 - Comparison of the utilisation of the maximum potential in the autonomous islands between Scenario A and Scenario B

It is clear that conserving energy by reducing the demand through the use of more energy-efficient devices and systems as well as the improvement of the insulation and windows of buildings represents a challenge but also an excellent opportunity to make a large part of the energy system in the Cyclades sustainable with less resources by further decreasing the consumption compared to a less rigorous plan such as that of Scenario A.

5.3.3 Scenario C – The Power of the Sun

The third and final scenario deviates slightly from the first two and could be described as a more extreme option. Owing to the resistance that is typically noticed against the installation of RES projects, and especially wind turbines on (touristic areas of) the islands, as explained in previous chapters, this scenario ignores wind energy and instead relies solely on solar energy to cover the needs of the islands.

Despite this extreme measure, however, it follows the rest of the basic principles of Scenario A, i.e. the islands are divided into the two categories depending on whether they are interconnected or autonomous, electricity shall be the predominant energy carrier, and solar, hydrogen, and biofuels will be the RES upon which the whole energy system will be based. Taking into account the potentials of the different available energy sources as calculated in Chapter 4, even with the absence of wind energy projects, this scenario can in principle be successful, since the annual energy demand in 2030 in the Cyclades is projected to be 5,350 TJ, while solar PV alone could provide more than 30,000 TJ per year for the whole group of islands. Still, this does not guarantee that every island is able to meet its needs using exclusively solar energy; on some islands there is no realistic potential for the exploitation of solar energy (as already mentioned in Scenario A), while on others the available potential is not enough to cover the demand. More specifically, there has already been presented in the previous two scenarios an island that has no option but to use solar energy: Antiparos, from the connected islands. In the previous scenarios solar energy could be used exclusively also for the islands of Folegandros (connected) and Sikinos (autonomous). In these cases, however, this is done by design: since the islands and their needs are small, a few MW of solar can provide enough energy. The third category includes the islands with no RES potential: Anafi, Donousa, and Thirasia are autonomous (Thirasia as a part of a group with Thira, the complication of which has already been discussed), while Irakleia, Koufonisi, and Schinoussa are connected to the grid. Another specific sort of islands is that including Amorgos (autonomous) and Syros (connected), for which the available solar potential is unfortunately not enough, and shall need to rely on other islands (in the case of Amorgos that can only be possible after interconnection). Finally, the rest of the islands – i.e. Andros, Tinos, Mykonos, Paros, Naxos, and Ios (connected), and Kea, Kythnos, Serifos, Sifnos, Milos, and Kimolos (autonomous) – can cover their needs using entirely solar energy, albeit with differing utilisation percentages of their maximum solar potential varying from 3% (Kythnos) to 98% (Paros), as shown in Figure 25.

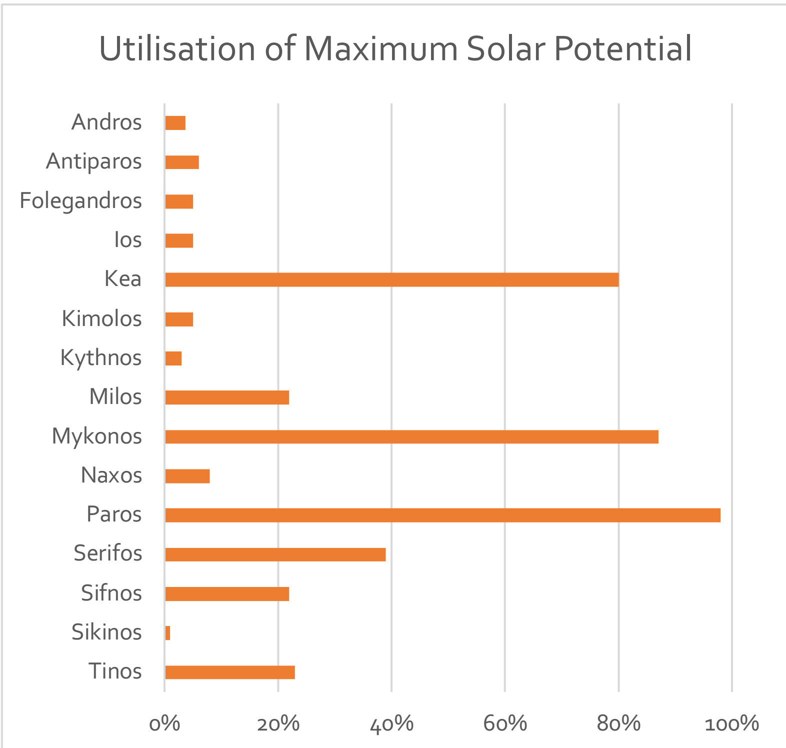


Figure 25 - Utilisation of maximum solar potential in Scenario C

Furthermore, there are two other unique features of Scenario C that need to be discussed. Firstly, removing wind from the energy mix adds a large burden to the other energy sources available, which in the case of the Cyclades are unfortunately not ample. While both wind and solar are intermittent sources that also follow a seasonal pattern, their seasonality matches up quite nicely in the islands, as wind speeds are generally higher in the winter months, while naturally solar irradiation peaks in the summer months. This means that in the other two scenarios for instance there can be a balanced mix of more wind energy in the winter and more solar energy in the summer, while in this scenario the system will be based only on solar energy, creating thus the need for a larger and more robust configuration of generation and storage and removing an important degree of reliability, since it would be more prone to periods of low solar irradiation, especially in the winter months. The second attention point of this scenario has to do with its realistic application. More specifically, as explained above, its basis is the fact that in the past there has been quite strong opposition to the installation of RES projects by the locals, or at least a part of them, especially in instances where they would be located in areas with a high touristic value. The consequence of this is that in the cases where Scenario C is applicable and the necessary intervention would be extensive, such as for islands that require the utilisation of a very large percentage of the maximum potential, for example in Paros (98%), Mykonos (87%), and Kea (80%), there could be considerable resistance that would negate the benefit of designing a non-wind scenario. All in all, even though this scenario could theoretically be put into practice, that would be in a very limited scale, and as such does not seem as a realistic option, especially compared to the other two.

6 Backcasting Analysis

With the vision and scenarios developed in the previous chapter as a basis, as well as the projection of the change of energy demand by 2030, the backcasting analysis which forms the core of this project and corresponds to *Step 3* of the methodological framework can be carried out. The following sections first present the energy mix for each island or group of islands and then the changes and interventions that are necessary to reach a sustainable energy system in the Cyclades, divided into the following categories: technological, institutional, and cultural-behavioral. To complete the so-called WHAT-WHO-HOW analysis explained in *Chapter 3*, the manner of their carrying out and the stakeholders responsible will also be examined. It is worth noting that in this section, and for the rest of this thesis, only the first two scenarios are considered, since as explained in the previous section, Scenario C can only find use in very few circumstances and does not present itself as a realistic option, at least for this moment in time and the end-point of 2030.

6.1 Scenario A Analysis

6.1.1 Energy Mix

As mentioned in Section 5.3.1, the islands are split into two categories, depending on whether they are connected with each other and the mainland grid or not. Based on that, it is relatively straightforward to design an energy mix especially for the autonomous islands, since they shall only cover their own needs with the potential that they exhibit. For most islands of that category this is indeed possible, but there are also some that will need to rely on other islands, which of course means that there will need to be extra interconnections carried out. The simplest cases are that of Anafi and Donousa, two of the smallest islands; Donousa for instance only has a few inhabitants and consequently low demands for energy: its annual consumption for 2030 is projected to be 11.57 TJ, a value that can easily be covered by for instance its neighbouring island of Naxos, which is projected to need only 2% and 6% of its maximum potential of wind and solar respectively to meet its 593.33-TJ-demand in 2030. However, the case of Thira and Thirasia is not so straightforward: these two islands are currently connected with each other but will need to be carefully managed in order to guarantee sustainable energy generation in the future for all islands. Thira is not only one of the most populous and consequently most energy-intensive islands (its demand for 2030 will reach 892.46 TJ), but also exhibits very low potential relative to its needs. Thirasia, on the other hand, is small and has proportionate demands (20.97 TJ) but cannot support any wind or solar projects. The above mean that there are 934.78 TJ that will need to be shared amongst the connected islands on behalf of the islands of Anafi (9.78 TJ), Donousa, Thira, and Thirasia. Nevertheless, this energy is not the only extra burden that the energy-generating islands will have to shoulder: Koufonisi, Schinoussa, and Irakleia are very similar islands characteristically to Donousa, and will also need to get their energy from somewhere else since they do not have the option to generate it themselves, which will bring the total to 976.42 TJ of energy to be shared by the connected islands. The silver lining, however, with these three islands is that they are already connected to the others (since they were part of the Paros NIIPS), and will not require further connections. As far as the specific islands that will have to provide the energy for the seven aforementioned ones, it makes sense to select those that have the lowest percentages for the utilisation of the maximum potential normally, since they are the ones that would be able to generate extra energy more easily. A quick glance at Figure 21 shows that Sikinos, Andros, Ios, Folegandros, and Naxos all require relatively small shares of their maximum potential for their own needs, so by roughly doubling their production, they can provide the additional energy necessary for the islands of Anafi, Donousa, Thira, Thirasia, Koufonisi, Schinoussa, and Irakleia. Table 12 presents the energy demand of each island in 2030, the energy generated from wind and solar, and the capacity for wind and solar.

Table 12 - Energy Mix for Scenario A

Island	Energy Demand (TJ)	Wind Energy (TJ)	Solar Energy (TJ)	Wind Capacity (MW)	Solar Capacity (MW)	Total Energy Generated (TJ)	Total Capacity (MW)
Amorgos	84.87	35.31	49.67	2.40	8.42	84.98	10.82
Anafi	9.78						
Andros	316.50	112.32	532.59	7.65	92.35	644.91	100.00
Antiparos	53.27		56.78		9.69	56.78	9.69
Donousa	11.57						
Folegandros	34.33	28.90	40.60	1.98	6.87	69.50	8.85
Ios	85.73	51.04	121.86	3.47	20.60	172.90	24.07
Irakleia	10.39						
Kea	94.59	30.58	67.32	2.20	11.61	97.90	13.81
Kimolos	44.53	16.01	28.39	1.13	5.17	44.40	6.29
Koufonisi	17.63						
Kythnos	63.37	45.41	21.92	3.19	3.77	67.33	6.95
Milos	222.92	108.70	118.55	7.49	20.13	227.25	27.62
Mykonos	633.27	270.90	345.50	18.06	59.43	616.39	77.49
Naxos	593.33	120.66	1,095.54	8.11	187.29	1,216.20	195.39
Paros	416.76	161.13	264.34	10.85	45.18	425.47	56.03
Schinoussa	13.62						
Serifos	66.41	21.54	47.62	1.53	8.72	69.15	10.25
Sifnos	122.14	30.16	100.25	2.12	18.30	130.41	20.41
Sikinos	14.09		29.28		4.95	29.28	4.95
Syros	488.79	141.98	400.25	9.62	68.88	542.24	78.50
Thira	892.46						
Thirasia	20.97						
Tinos	284.00	82.75	209.67	5.50	36.16	292.42	41.66

6.1.2 Locations of Proposed RES Projects

After having designed the energy mix of each island (shown in Table 12), it also makes sense to investigate where the proposed wind turbines and solar PV panels could be installed on the islands, following the relevant methodology outlined in Chapter 3.

Amorgos (2 wind turbines – 2.40 MW, 16.84 ha of solar PV panels)
Amorgos is characterized by a mountainous backbone that traverses the island and as a result presents many opportunities especially for the installation of wind turbines. Since the main two settlements are on the central and northern parts of the island on its east coast, the wind and solar projects can be carried out at the same location on the side of a mountain with a relatively gentle slope.

Andros (1 wind turbine – 2.29 MW, 184.70 ha of solar PV panels)
Andros is one of the largest islands but rather sparsely populated for its size, and with the largest towns being found on the coasts, there are enough areas in the interior of the island for the RES projects. The necessary wind turbine shall be installed on a mountaintop in the central part of the island, while the solar PV panels are split between seven plots: three near the wind turbine site and four in the northern part of the island.

Antiparos (19.38 ha of solar PV panels)
Antiparos is flat and inhabited largely on its northern half, while the rest of the island is dominated by a cluster of small hills. With only solar PV panels necessary to cover the demand, it is rather easy to select two appropriate locations for the installation.

Folegandros (1 wind turbine – 1.98 MW, 13.74 ha of solar PV panels)
Folegandros is another sparsely populated island, albeit a lot smaller than e.g. Andros, and with the southern part of the island essentially empty and dry, a wind turbine and the solar PV panels can be installed at nearby locations.

Ios (2 wind turbines – 3.47 MW, 41.20 ha of solar PV panels)
Ios' main town and other settlements are predominantly found on the coasts, so it is also here rather straightforward to install the required wind turbines and solar PV panels in areas inland.

Kea (2 wind turbines – 2.20 MW, 23.20 ha of solar PV panels)
Kea has several villages scattered throughout the island, but the main restrictions are the relatively low wind speeds generally, and the available, non-protected areas; this means that it is somewhat imposed to focus on areas in the north of the island.

Kimolos (1 wind turbine – 1.13 MW, 10.34 ha of solar PV panels)
Kimolos has its northwestern part protected, while its settlements are found on the opposite side of the island, creating a sort of gridlock; nevertheless, the area around the mine on the northeastern tip of the island is used, as it is already disturbed.

Kythnos (2 wind turbines – 3.19 MW, 7.54 ha of solar PV panels)
Kythnos, similar to Kea, also possesses settlements on all parts of the island and a small range of available, non-protected locations, so a location on the northeastern part is able to carry both the wind turbines and the solar PV panels.

Milos (4 wind turbines – 7.49 MW, 40.26 ha of solar PV panels)
Milos is another island with large parts protected, in this case the western half; with the majority of the eastern half already utilized, one of the few still available locations is found on the top of a short hill near the coast.

Mykonos (8 wind turbines – 18.06 MW, 118.86 ha of solar PV panels)
Mykonos is one of the two most visited (and thus relatively energy-demanding) islands of the Cyclades, and as such presents a challenge when it comes to finding enough available locations. It is also the case here that the north and northeast is still fairly free, so that is where the RES projects for the island shall be located.

Naxos (4 wind turbines – 8.11 MW, 374.58 ha of solar PV panels)
Naxos is the largest island of the Cyclades, so despite its high energy requirements and some protected areas, it is not extremely hard to find suitable locations for the wind turbines and solar PV panels in the hilly, sparsely-populated southern part.

Paros (5 wind turbines – 10.85 MW, 90.36 ha of solar PV panels)
Paros is quite large and has towns and villages almost exclusively on the coasts, so there are a few opportunities in the interior for the installation of the necessary projects.

Serifos (1 wind turbine – 1.53 MW, 17.44 ha of solar PV panels)
Serifos is almost in its entirety made up of protected areas, so it is a good coincidence that one of the non-protected locations is also available to be used for a wind turbine and solar PV panels.

Sifnos (1 wind turbine – 2.12 MW, 36.60 ha of solar PV panels)

Sifnos is inhabited mostly on the northern and eastern areas, while a large share of the central-western part is protected, but in the southern tip there exists the prospect to install RES projects.

Sikinos (9.90 ha of solar PV panels)

Sikinos, similar to Antiparos, shall rely only on solar PV panels to cover its needs, making the location selection process easier. Nevertheless, since approximately its two thirds coincide with protected areas, it is not completely straightforward, but a plot of land on the slope of a gentle hill is enough for this small and sparse island.

Syros (5 wind turbines – 9.62 MW, 137.76 ha of solar PV panels)
Syros is arguably the island with the fewest available areas; the northern half is protected, while its villages are relatively evenly distributed across the south. This leaves only a small number of opportunities, and its projects are split between a lot of small plots, instead of a few larger ones as is the case for many of the other islands.

Tinos (3 wind turbines – 5.50 MW, 72.32 ha of solar PV panels)
Tinos is a large island, and while its settlements are quite scattered, it is quite easy to find a suitable location for its wind turbines and solar PV panels on top of a plateau between two of them.

6.1.3 Changes & Interventions

Technological changes

WHAT: As described in the previous chapter, the vast majority of the future energy system of the islands will be based on electricity instead of fossil fuels as it has been until now. For this new system to be used there is a large number of technological changes necessary, some relatively easily implemented, but most of them quite disruptive. The most important and large-scale of them is the installation of solar photovoltaic panels and wind turbines, both as stand-alone projects and as parts of hybrid power stations comprising of generation and storage solutions, while conversely the use of the currently active power stations will need to be curtailed. Energy storage will indeed be a key pillar of the energy system as explained previously, which also means that battery packs and hydrogen production and storage sites and infrastructure will need to be developed. Moreover, as explained in the previous section, some of the islands will need to rely on others in order to cover their energy demands, thus another large intervention that is necessary is the connection of these islands to others.

HOW: The first step towards the implementation of the above changes is the phasing out of the oil-powered stations of the islands; depending on their lifetime and location, this means either dismantling or keeping them in a reserve capacity. The stations on the interconnected islands are already inactive since the connection to the national grid, but those on the rest of the islands are still used for the generation of electricity. Keeping them only as a reserve instead of as the primary electricity source leaves a large gap in the system, which will of course be filled by the installation of the wind and/or solar capacity as calculated for each island and presented in Table 12, along with the necessary storage options. Furthermore, since the energy needs will be covered by renewable sources used to generate electricity, it is essential that forecasting systems be developed to ensure a smooth function and management of the system irrespective of fluctuations in demand and, most importantly, generation. A fourth necessary intervention is the upgrading or installation of systems capable of handling bidirectional power flow, specifically in the islands connected to the mainland grid. As explained in the previous chapter, the Cyclades are able and envision to generate electricity not only for local needs but also for export; this can also act as a driver for the speedier transition to renewable energy. Finally, with the use of electric vehicles (EVs) playing a significant role in the future energy system, infrastructure for the charging of these vehicles needs to be provided. This includes charging stations in residential buildings, on the streets, in dedicated locations, and municipal buildings and depots.

Table 13 - Overview of necessary changes for Scenario A

WHAT	HOW	WHO
Technological Changes		
Phasing out of oil-powered stations	Dismantling or keeping them as reserve	Ministry of Environment and Energy
Development of RES projects & systems – wind turbines, solar PV panels, etc.	Installation of wind and solar capacity & storage options	Public Power Corporation
	Development of energy forecasting systems	Independent Power Transmission Operator (TSO)
	Implementation of systems capable of handling bidirectional flow	Hellenic Electricity Distribution Network Operator (DNO)
	EV infrastructure	Private companies
Development of storage options	Installation of battery packs & hydrogen production and storage facilities	
Generation of energy for islands that cannot carry RES projects	Interconnections between energy-generating & energy-demanding islands	
Institutional Changes		
Development of a robust, all-encompassing framework of policies and regulations	Re-evaluation & improvement of already present policies and regulations	Ministry of Environment and Energy
	Establishment of the available locations for the installation of RES projects	Regulatory Authority for Energy
Providing and presenting clearly incentives, benefits, and programs	Subsidies, especially for storage projects and large EVs	Ministry of Finance
	Incentives for the adoption of small islands as pilot locations	
Cultural – Behavioral Changes		

Energizing and involving the general public in the transition	Improvement of communication by active stakeholders (especially the government)	Ministry of Environment and Energy
	Encourage the uptake of sustainable practices and measures	NGOs, citizen groups, educational institutes
	Stimulating the consumers to take advantage of incentives & benefits	

WHO: Depending on the nature of the changes and interventions named above there are a host of different stakeholders responsible for their implementation. In general, the Ministry of Environment and Energy will be tasked with putting forward and overseeing a large number of changes. Together with the Public Power Corporation, they will need to plan the phasing out and future of the oil-powered stations, for instance. In collaboration with the TSO and DNO (Independent Power Transmission Operator and Hellenic Electricity Distribution Network Operator, respectively), the Ministry will be required to design and oversee the necessary interconnections, develop the forecasting systems, as well as manage the implementation of systems for the bidirectional power flow. These stakeholders will also be involved in the introduction of the EV charging infrastructure, possibly also with the support of other, more relevant stakeholders, such as the Ministry of Transport. Companies from the private sector will also need to be part of the implementation of every change presented above, each in their capacity, as well as for the installation of wind, solar, and storage projects.

Institutional changes

WHAT: It can easily become apparent that without changes in the institutional level, carrying out the aforementioned technological interventions will surely prove to be extremely challenging, if not impossible. Therefore, it is clear that a robust framework of supporting policies and regulations needs to be proposed for the new, sustainable energy system. While there have already been several incentives, benefits, and programs developed relating to sustainable energy and the energy transition, these are often either not coherent, not integrated with each other, or not communicated well. They need to be coordinated and presented clearly to every interested party, as well as the public, in order to accelerate and reinforce the involvement of stakeholders, from large multinational corporations to single households and families.

HOW: Apart from the re-evaluation and publication of the already present policies, regulations and incentives, an important policy that needs to be introduced is one establishing and clarifying the available locations for the installation of renewable energy projects, especially owing to the touristic character of the Cyclades and the strong opinions of some locals on the matter of the nature and the aesthetic identity of the islands. The manner of communicating this policy bares added importance as far as the interconnected islands are considered, since inattentive statements can lead to inter-island animosity, souring public opinion, and damage the transition efforts. As far as financial incentives are concerned, feed-in tariffs, tax exemptions, and subsidies are measures that are generally beneficial in supporting sustainable energy systems; subsidies in particular can be effective in encouraging the installation of storage solutions, since they are at an earlier stage in their development compared to solar PV panels and wind turbines and thus more expensive. Subsidies and tax exemptions can also promote the adoption of EVs, especially as far as large vehicles such as trucks and buses are concerned. Moreover, in the case of the smaller, non-interconnected islands, it can prove beneficial to provide incentives for companies so that they can be used as testbeds and locations for complete RES pilot projects in the early phases of the transition, owing to their small size and population.

WHO: As it was the case with the technological changes, the Ministry of Environment and Energy will also play a large role in supporting the implementation of institutional changes. The Regulatory Authority for Energy is another stakeholder that needs to be involved with these changes, as they are dealing with the matters of the energy market and the applications for renewable energy projects in Greece. The Ministry of Finance will also need to collaborate in the planning and implementation of these changes, specifically in regards with the financial incentives, as are banks and other financial institutions.

Cultural - behavioral changes

WHAT: As far as the cultural and behavioral changes necessary are concerned, the key issue currently is that the citizens (which are the consumers by extent) in their large majority are not involved with the energy system and are largely passive to all changes and developments that can arguably affect them quite a lot, apart from instances when they feel threatened, such as those explained in the PESTEL analysis in section 4.4. This is partly their own fault, but probably more due to the lack of transparency and clear communication by the relevant ministries, agencies, and authorities. Spurring their interest and involving them in the processes that influence them is crucial and can compel them to be more active, thus participating in the sustainable energy system by creating new, sustainable habits and mindsets and following the best practices.

HOW: From the above it is easily understood that a principal change is the reconsideration of the communication methods followed by the relevant stakeholders when addressing and informing the public. Furthermore, as far as the more purely energy-related changes are concerned, it is important that the mostly successful upgrading of lighting mediums and appliances to more efficient ones is extended to the upgrading of the energy efficiency of the buildings as a whole; this means that the large difference such – relatively small – changes make must be explained to the public. In addition, consumers need to become a part of the transition: they need to be stimulated to provide the financial and social investment needed to change or upgrade the conventional practices and encouraged to take advantage of the benefits and incentives provided to do so.

WHO: Cultural and behavioral changes can be the hardest of the three categories to carry out, since they involve changing practically every citizen. Therefore, it is even more important that the relevant entities work together, harder, and more efficiently. The Ministry of Environment and Energy is again a key stakeholder and needs to do a better job when communicating its decisions and especially incentives and programs relating to the transition, but other stakeholders such as NGOs, citizen groups, and educational institutes to a smaller degree can prove possibly even more important in changing the behavior of consumers owing to their often local character, as opposed to the largely anonymous and centralized nature of the Ministry.

6.2 Scenario B Analysis

6.2.1 Energy Mix

With Scenario B being in principle an extension of Scenario A, the vast majority of remarks made in Section 6.1.1 are also true here. The energy mix will of course look different since the requirements will decrease owing to the reduction in the energy consumption of the tertiary and residential buildings, but the fact remains that some islands still shall depend on others to cover their energy needs. The energy demand of each island in 2030, the energy generated from wind and solar, and the capacity for wind and solar for this scenario are presented below, in Table 14.

Table 14 - Energy Mix for Scenario B

Island	Energy Demand (TJ)	Wind Energy (TJ)	Solar Energy (TJ)	Wind Capacity (MW)	Solar Capacity (MW)	Total Energy Generated (TJ)	Total Capacity (MW)
Amorgos	69.77	22.25	47.76	1.51	8.10	70.00	9.61
Anafi	7.94						
Andros	241.70	84.24	417.20	5.74	72.34	501.44	78.08
Antiparos	43.45		45.42		7.75	45.42	7.75
Donousa	10.06						
Folegandros	28.12	28.90	28.00	1.98	4.74	56.90	6.71
Ios	69.31	57.84	84.04	3.93	14.21	141.89	18.14
Irakleia	9.25						
Kea	74.68	26.91	49.87	1.94	8.60	76.77	10.54
Kimolos	33.97	16.01	18.93	1.13	3.44	34.93	4.57
Koufonisi	14.39						
Kythnos	50.46	21.19	32.88	1.49	5.65	54.07	7.14
Milos	165.18	21.74	150.88	1.50	25.62	172.62	27.12
Mykonos	439.13	309.59	127.68	20.64	21.96	437.28	42.60
Naxos	440.30	114.62	802.25	7.70	137.15	916.87	144.85
Paros	305.50	110.49	207.07	7.44	35.39	317.56	42.83
Schinoussa	11.54						
Serifos	54.60	21.54	35.27	1.53	6.46	56.81	7.99
Sifnos	90.94		94.35		17.22	94.35	17.22
Sikinos	11.88		24.88		4.21	24.88	4.21
Syros	359.65	87.37	325.21	5.92	55.97	412.58	61.89
Thira	627.01						
Thirasia	16.49						
Tinos	213.94	27.58	195.56	1.83	33.90	224.15	35.73

6.2.2 Changes & Interventions

Again, since Scenario B is not different to but rather building upon Scenario A (as explained in Section 5.3.2), all changes proposed previously are also part of the second scenario, but will not be repeated here; instead the focus below is the hospitality sector, and more specifically accommodation.

Technological changes

WHAT: With the majority of relevant buildings having at most an energy class C (as presented in Section 4.5.6), it is evident that plenty of interventions need to be implemented, and for a large amount of establishments. As with all buildings, lighting is one of the most energy-intense types of consumption in hotels, especially since there are often spaces lighted for the whole day, so it makes sense that lowering the electricity consumption and increasing efficiency where possible can come with large benefits. The other category with large energy demands that can profit by decreasing consumption and increasing efficiency is space cooling, especially relevant due to the hot summer days in the Cyclades.

Table 15 - Overview of necessary changes for Scenario B

WHAT	HOW	WHO
Technological Changes		
Decrease consumption & increase efficiency of lighting, cooling, and other appliances	Replacement of old lamps, air conditioning units, and appliances	Owners and managers
	Improvement of insulation	Architects, engineers, other experts
	Installation of solar thermal collectors and PV panels	
	Installation of automated systems	
Institutional Changes		
Focus on accelerating the adoption of sustainable measures by hotels	Energy certificate for all hospitality buildings	Ministry of Environment and Energy
	Creation of specialized energy agency	Newly created agency
	Financial incentives	Ministry of Finance
Cultural – Behavioral Changes		
Informing and involving owners and managers	Development of policies and incentives in cooperation with hoteliers	Ministry of Environment and Energy
	Informative guides and resources to owners/managers and guests	Federation and organizations of accommodation sector professionals

HOW: For most already existing buildings, upgrading their lighting and cooling systems, as well as other appliances can be one of the most easy means to reduce energy demands. For instance, replacing the (mostly) halogen lamps used currently, with newer and more efficient ones such as LED lamps leads to a large decrease in electricity consumption, as does upgrading air conditioning units and other appliances (such as refrigerators and other household appliances) to ones with a higher energy efficiency class. Especially for cooling (and heating), demand can also be lowered with the help of improved insulation of the buildings, a measure that can be more difficult to carry out but still advantageous. Some more large-scale changes, and perhaps not possible for every existing establishment, are the installation of solar thermal collectors and photovoltaic panels. Solar thermal systems can provide a number of solutions: hot water for sanitary use and for use in the swimming pools and spas, as well as be part of adsorption-based cooling systems. On the other hand, PV panels can generate electricity and power the desalination units in the hotels that are equipped with them. Finally, automated systems can also be installed in almost every building, and perform actions such as turning off the lights, water, and appliances when occupants leave their rooms.

WHO: The major responsibility for the implementation of these changes and upgrades rests undoubtedly with the owners and managers of the hotels, hostels, resorts, etc., with the support of architects, building engineers, and other experts, as well as relevant companies.

Institutional changes

WHAT: As mentioned in the respective section for Scenario A, there are already quite a few policies and programs relating to sustainability, some of them relevant for buildings, and by extent to the accommodation sector. Nevertheless, should the government and other official agencies focus more on this sector to promote the quicker adoption of the technological changes suggested above, the transition itself shall benefit, since reducing the energy requirements of such a large part of the demands will surely reduce the need for (intensive) changes and interventions as a whole.

HOW: While there is already an energy certificate program in place in which is necessary for selling or renting a building, as well as constructing a new one, expanding this to all existing hospitality buildings in use, possibly with the creation of a specialized agency to oversee that and all other relevant policy measures, can be a relatively easy way into making the sector more sustainable. Separately, and to accelerate the implementation of the more technological changes, financial incentives such as subsidies and tax breaks shall also be provided; they can find use in both new and existing buildings in order to upgrade the insulation, install solar thermal collectors, PV panels, and desalination systems, and other larger-scale interventions.

WHO: Due to the nature of the changes, it is obvious that the Ministry of Environment and Energy is the chief responsible stakeholder, as well as possibly and more specifically a new agency to be created to ensure a tighter support and supervision. As far as the financial incentives are concerned, the Ministry of Finance shall also play a supportive role in the planning and implementation.

Cultural - behavioral changes

WHAT: Even though there are a number of further, mainly technological, but also institutional changes necessary for Scenario B compared to Scenario A, one could argue that the cultural and behavioral changes required for A are in principle the same for B. Informing and involving the owners and managers in all phases of the transition is key and can be the difference between success and failure.

HOW: Some of the technological changes mentioned above may be relatively simple and easily made without extra effort from the part of the state institutions, others will surely prove to be more challenging both in their implementation and their acceptance. To solve this, the programs and incentives mentioned above could need to be developed in cooperation with the stakeholders from the accommodation sector. Furthermore, as part of informing the relevant parties, guides and resources can be provided to hotel owners and managers about the measures they can and should take, as well as to the guests regarding how they can make their stay more sustainable.

WHO: The Ministry of Environment and Energy is responsible for the involving and partnering with hospitality professionals, who, on their part, will also bear responsibility through their Federation and other organizations to be part of the changes on behalf of all their members and inform and support them.

6.3 Scenario Analysis Comparison & Discussion

The backcasting analysis of both scenarios presented above has demonstrated the need for great – both in number and significance – changes in any case as far as the energy system in the Cyclades is concerned. That, nevertheless, does not imply that the transition is unfeasible; rather, it comes as a direct consequence of the characteristics of the scenarios chosen in Section 5.3 as part of the future vision for the islands. These scenarios were developed taking into consideration the relatively short endpoint (2030) for the transition, as well as the fact that there are already a few drivers for the energy transition in place, such as the interconnection of many islands with the mainland grid and between them, and the various frameworks and projects promoted (for instance the focus on Sifnos as part of the Clean Energy for EU Islands initiative). Therefore, the decision was made to develop Scenario A, a scenario that is ambitious to the necessary extent but also realistic, without neglecting all relevant current and future factors of the identity of the islands and the energy system. Using that as a basis, and after identifying the potential for large gains with only relatively minor improvements in a specific but important part of the energy system, the tourist accommodation sector, a second scenario was generated. Consequently, and as explained previously, Scenario B shall not be thought of as a different, more/less realistic, or better/worse scenario to Scenario A, but rather as a complementary one. Indeed, in another instance it could have been part of Scenario A, or a follow-up to it, but in the case of the transition plan presented in this thesis project, it offers greater value as a separate item. This is because Scenario B allows Scenario A to have a basic and "bare minimum" character, while the former manifests itself as a more "aggressive" alternative to the transition, further lowering the demand for energy and as a result the need for the larger, more fundamental interventions. Based on the above, a roadmap for both scenarios will be proposed, i.e. the changes and interventions identified in the previous sections for Scenario A will be laid out on a timeline until 2030, as will the extra ones specifically pertaining to Scenario B (since the bulk of the necessary changes and interventions for this scenario coincides with those for Scenario A).

6.4 Transition Roadmap & Implementation Timeline

Following the backcasting analysis and the identification of the required actions regarding each scenario, the next and final step in the development of the transition roadmap is the establishment of the implementation timeline until the endpoint, in 2030. While theoretically and ideally every change or intervention would be arranged to an as much as possible accurate and specific point in time, in practice such precision and certainty is both impossible and impractical. As a result, the transition is split into 3 phases outlined below, starting in 2022 and concluding in 2030. Based on the discussion above, the following parts take Scenario A to be "active", and will mention the extra actions required for Scenario B whenever this is necessary. In principle all additional adjustments needed for Scenario B can be carried out in only one of the 3 phases to a very large extent; however, for the sake of realism, balance, and in order to not overload one of the phases, they will be split between the three. An overview of the implementation timeline is shown in Table 16.

Phase I: 2022 – 2025 – First steps & preparation for the future

During the first phase, the foundations for the whole transition are laid, thus while not the most impressive and visible one, it is definitely the most important one and its success will largely guarantee the success of the whole plan.

Since the aim of the transition is to reach a sustainable energy system, the currently used oil-powered generation stations will need to be phased out, and in Phase I the plans for that will need to be prepared. Furthermore, the operation of the RES generation projects needs to also be prepared, both from a practical (sizing, siting, ordering, etc.) and from an institutional (e.g. establishing the available locations, introducing relevant policies, regulations, and incentives, etc.) point of view. Further technological changes that will need to be carried out in Phase I are the development of energy forecasting systems, and the installation or upgrading of the infrastructure to enable the handling of bi-directional power flow, as explained in Section 6.1.2. With electric vehicles being a key aspect of the transition since they shall cover the transportation needs, provisions need to also be made to support their adoption; in Phase I the charging infrastructure will have to be established, while on the policy side, a first step will be to ban the sale of conventional vehicles, and especially light ones, such as cars and motorbikes. On another note, early on in Phase I, incentives shall be provided to interested parties to promote the adoption of small islands in the Cyclades as locations of integrated sustainable energy pilot projects, that will support the transition both directly and indirectly through the gathering of knowledge and experience to be applied on a larger scale in the latter phases. Finally, one of the most important actions of Phase I will need to be the informing and educating of the public, as its significance has often been highlighted.

The same logic as above, for Scenario A, also applies to the adjustments required in Phase I for Scenario B, i.e. the preparation for the future. This entails the creation of a dedicated energy agency as explained in Section 6.2.2, as well as the development of relevant policies, regulations, and frameworks, and of course further informing and educating the hotel owners, managers, and other pertinent personnel. Besides that, a change that can already easily be executed in Phase I is the replacement of old lamps, air conditioning units, and other appliances in the buildings of the hospitality sector.

Phase II: 2025 – 2028 – Generation from RES

Assuming everything mentioned above has been successfully accomplished, the transition can move to its second phase, the highlight of which is the operation of the RES generating units.

After having devised a plan for the phasing out of the oil-powered stations in the previous phase, now is the time to actually start the process: these units cease to be the primary provider of electricity on the islands and are downsized and kept only for use in peak demand times and whenever solar and wind energy are not able to fully cover the electricity needs. In order for this to work, the RES units installed in Phase I will have to be brought to action concurrently. This will allow for the focus to now be more rigorously on the planning and development of short- and long-term storage solutions, so as for them to be operational in Phase III. Apart from that, Phase II also entails the continuation of the penetration of electric vehicles and at this point in time EVs will start to become the norm: their sale is driven by the widespread availability of charging locations (installed in the previous phase) and by more incentives, such as the beneficial retiring of old vehicles or swapping for new ones. Finally, the pilot projects developed in Phase I are now mostly mature or in their latter stages, and the first results can be seen, analyzed, and exploited for the future.

In the second scenario, another important but relatively simple measure is carried out in Phase II, namely the improvement of insulation of the buildings. Additionally, modern automated systems are installed that help manage and reduce the energy consumption, and the energy certificate becomes mandatory for all in-use establishments.

Phase III: 2028 – 2030 – Storage of renewable energy & complete transition

The transition concludes, and by the end of 2030, the overwhelming majority of needs of the islands are covered by renewable energy, with the final pieces of the puzzle being added in the last phase, most importantly the availability for storage of energy for later use.

With the energy storage solutions becoming more mature and plans for their use having been developed in the previous phase, Phase III sees the storage projects become active and the need for oil-powered stations become obsolete. In their majority, the latter are taken out of use and dismantled, since excess energy is now being generated at times of large availability and stored in batteries or in the form of hydrogen for use whenever necessary. The penetration of electric vehicles is also finalized with the introduction of large vehicles such as trucks and buses as well, supported also in this case by the mature technology. The pilot projects on small islands are now complete so a total review is made and conclusions are drawn.

The final intervention for Scenario B is also implemented in Phase III, namely the installation of solar thermal collectors and photovoltaic panels on all buildings, as well as possibly desalination systems for the larger ones.

Table 16 - Overview of the implementation timeline of the transition

	Scenario A	Scenario B
Phase I: 2022 – 2025 First steps & preparation for the future	• Planning of phasing-out of oil-powered stations • Preparation & development of RES generating units • Development of energy forecasting systems • Installation or upgrading infrastructure to enable bi-directional power flow • EVs: charging infrastructure & ban on sale of conventional vehicles • Incentives for the adoption of small islands as pilot project locations • Informing – educating the public	• Creation of dedicated agency • Development of policies • Informing – educating relevant parties • Replacement of old lamps, air conditioning units, appliances
Phase II: 2025 – 2028 Generation from RES	• Phasing-out of oil-powered stations • Operating RES generation units • Development & planning of RES storage units • EVs: incentives for sale & retirement/swap of old vehicles • First analysis of pilot projects	• Improvement of insulation • Installation of automated systems • Mandatory energy certificate
Phase III: 2028 – 2030 Storage of renewable energy & complete transition	• Implementation of storage projects • Dismantling of oil-powered stations • EVs: introduction of large vehicles (trucks, buses) • Review & conclusions of pilot projects	• Installation of solar thermal collectors, PV panels, desalination systems

7 Discussion

7.1 Scientific Relevance

As mentioned in the introduction of this thesis report, the Cyclades islands despite exhibiting great potential for the exploitation of RES, and especially wind and solar, they are or were relying on polluting and expensive oil-powered stations to cover their electricity needs, with RES only covering a very small percentage of the demand. They can therefore provide a very inviting location to start the transition to sustainable energy that is so much discussed nowadays, in a large scale. As indicated by the literature review carried out and presented in Chapter 2, however, there has been no plan for the transition of the islands as a whole to renewable energy sources, despite the publication of several academic works either confirming the available potentials and, consequently, opportunities, or presenting a case-study about the transition for a specific island. This thesis therefore has covered this gap by examining the current situation regarding the energy system and broader landscape, developing a vision for the future energy system in 2030, analyzing using the backcasting approach how this vision shall be attained, and finally arriving at a roadmap for the transition to sustainable energy for the Cyclades islands.

7.2 Limitations

In this thesis project, the transition to sustainable energy in the Cyclades islands has been examined and as a result a roadmap and implementation timeline has been proposed. To reach this end goal, first a literature review was carried out and a knowledge gap was found, and then, after a short (historical) review of the relevant frameworks, a methodology was developed to be followed. The Strategic Problem Orientation revealed all necessary characteristics of the energy system of the islands as well as the potential for the exploitation of renewable energy sources, information that was used to create a vision and scenarios for the future energy system. A backcasting analysis for these scenarios was then carried out, and the changes and interventions that make up the roadmap were determined. As it can be easily understood, such a long and multi-stage process does not always go smoothly or as expected and can have several limitations; this was the case also in this thesis project.

While it was a choice made consciously at the start of working on this thesis, the fact that the Quist framework was only used as a basis for the methodology and its participatory characteristics were omitted can be regarded as a shortcoming of this project. The input of and collaboration with stakeholders in energy transition projects can prove to be a very useful tool in the development of the pathways to the new energy system, owing to their expertise, knowledge, and experience with the problem at hand. It is worth noting that during the course of the project, after the stakeholder analysis, there were some attempts made to conduct interviews with a small number of stakeholders but unfortunately the interest and response was absent. Had these interviews been carried out, the project would have been undoubtedly more robust and accurate in each of its phases and chapters, and the end result of the roadmap more relevant and realistic.

Surely the toughest obstacle faced in this thesis project was the lack or difficulty of access to data and resources, a complication that affected a large part of the work. For instance, monthly data for the consumption of electricity of each island was not found; that was replaced by the monthly data for the generation of electricity on the level of each NIIPS (Non-Interconnected Island Power System). In some cases the NIIPS corresponds to one island only, but there are instances where one NIIPS includes several islands, and in those cases the population of each island was used to arrive at the electricity consumption at the level of the island, with the added assumption of course that generation equals consumption. Among others, data was also missing for the energy consumption for heating and transport on the islands. Thankfully, at some point in time during this thesis project, the Clean Energy Transition Agenda of the island of Sifnos was published (as mentioned in the Literature Review), and Sifnos was often used as a proxy for the Cyclades islands, with the data for that island being extrapolated for the rest of them, after making a large number of assumptions. Another part of the project that could improve with the right data is that of the RES potentials;

unfortunately the values presented could be described as fairly vague and also relying on assumptions. In short, due to the lack of accurate and reliable data, the results of this thesis are largely based on assumptions, estimates, and educated guesses, a fact that definitely diminishes their value.

A third limitation of this piece of work, especially vis-à-vis similar projects on energy transitions, is the absence of a rigorous computer model for the determination of the optimal energy system and the mix of energy sources at the endpoint. Owing to the lack of experience with such models, and in order to simplify the work, a rather simple spreadsheet was used to figure out the necessary capacities for wind and solar, but optimization with such a model is extremely difficult, as is the addition of several parameters that would make the result more vigorous.

8 Conclusion

8.1 Conclusions

The completion of the research and the conclusions it has brought forward are presented in this chapter in the form of answers to the research questions.

- **How is the energy system in the Cyclades organised currently?**

The Cyclades, being an island group, have a distinctive energy system with some unique characteristics not found in the main energy system of the country. To start with, until a few years ago, most of the islands were served by local power stations, but were not autonomous, since they were relying on the transport of fuel oil from the mainland. The dependence on these power stations was problematic, since on the one hand the environmental burden was doubled because the necessary fuels needed to be transported with ships and also were used for the generation of electricity, and on the other hand there was also considerable economic burden, as the use of oil products was expensive and the costs were being shared among the consumers in the whole country. In order to solve a large part of this problem, an interconnection project with the mainland grid had been planned and was completed in 2018. Currently, only 10 of the inhabited islands are still relying on local generation of electricity, or approximately 24% of the permanent population compared to 83% before 2018. Another characteristic of the Cyclades is the seasonality pattern of the demand, which in the summer months can be even double the average for the rest of the year, and is a result of the touristic nature of the islands. This nature is also visible in the share of electricity consumption per sector, with the tertiary (non-municipal) buildings such as hotels and businesses accounting for 60%. While electricity is the main energy carrier, fuel and oil products are also used extensively, especially to cover the demand for heating and transport.

- **Who are the relevant stakeholders?**

While the Cyclades are generally recognized as an entity in a lot of settings, and were even comprising one single prefecture of Greece until a decade ago, as far as the energy landscape is concerned, they are not at all independent. Therefore, despite its national character, arguably the biggest stakeholder in the field is the Ministry of Environment and Energy, with a broad range of responsibilities and interests regarding the energy system and the transition to sustainability. Another important stakeholder is the Regulatory Authority for Energy, an independent authority with the primary goal the overseeing of the domestic energy market, as well as the evaluating and deciding upon production license applications and monitoring the projects granted a production license. Apart from these, a noteworthy role is played also by the Public Power Corporation, the Independent Power Transmission Operator, and the Hellenic Electricity Distribution Network Operator. A large number of private companies are also present in the energy sector in the Cyclades, either in the form of producers and retailers, or as companies active at the supply chain of wind and solar energy. Finally, some important stakeholders also include interest groups such as institutions or NGOs, with some examples being the DAFNI Network, the Aegean Energy & Environment Agency, and the Sifnos Island Cooperative.

- **Which are the pertinent macro-environmental factors?**

The macro-environmental factors relevant to the transition to sustainable energy in the Cyclades are investigated via a PESTEL analysis, and include political, economic, social, technological, environmental, and legal factors. In the political spectrum, while there are generally policies and measures introduced to promote and support the transition, these are often hindered by bureaucracy and as such rarely have the full impact intended. Economically, in the previous few years there have been attempts to attract capital after especially the very large negative effect the Greek debt crisis of the previous decade has had on investments; the energy sector and specifically that of sustainable energy is seen as one of the most promising opportunities. One of the most important factors influencing the transition to sustainable energy is the public opinion; quite often when there have been attempts to install RES projects such as wind turbines on islands, there is strong opposition from a share of the inhabitants who argue that such projects diminish the aesthetic value of the area, especially vis-à-vis the touristic character of the islands. Such incidents also demonstrate the lack of information regarding the benefits of sustainable energy, and the need for more adequate education around the matter.

- **What RES are available and what is their potential?**

Owing to their location, the Cyclades are fortunate enough to be exhibiting a large potential for the exploitation of mainly wind and solar energy. At the maximum, more than 22,000 TJ of energy can be generated annually from wind, while for solar this value rises to more than 30,000 TJ. Although there is some potential also from biomass and geothermal energy, unfortunately that is not enough to be a viable part of the energy mix in the Cyclades, while other RES that could be exploited especially in the islands taking into account their geography, such as wave energy or ocean thermal energy conversion, are also either not attractive or unfeasible. Nevertheless, there is quite some potential for energy savings – between 1000 and 2000 TJ, as a large amount of buildings still are in the lower energy classes.

- **What would a suitable energy system in 2030 resemble?**

With such large amounts of renewable energy potential, the Cyclades can aim to become a national pioneer in the transition to RES, and can develop a vision for a self-sufficient, efficient, and reliable energy system in 2030. The energy system of the future will move away from the fossil-fuel-powered generating stations and the dependency they create, and shall instead harvest the locally available wind and solar energy potential, albeit complemented with energy storage options to ensure reliability. Moreover, its efficiency shall also be increased, as one of the pillars of the transition is the electrification of as many sectors as possible, also in order to be able to enjoy the benefits of clean electricity from wind turbines and solar PV panels. An essential step in that direction is the adoption of electric vehicles, in order to take advantage of the small distances within the islands and hence the diminished importance of the (relatively) low range of such vehicles.

- **Which is the proper process to achieve this vision?**

In order to move from the current situation and reach the envisioned energy system in the Cyclades by 2030, there are undoubtedly a large number of changes and interventions necessary. Apart from the obvious installation of wind turbines, solar PV panels, and storage facilities, one of the main changes will also be the phasing-out of the oil-powered stations; they will either be dismantled (in the case of the interconnected islands), or kept in a reserve capacity (in the independent islands). Furthermore, there will need to be energy forecasting systems developed, as well as systems capable of handling a bidirectional flow of electricity, since it can be the case that the Cyclades will offer the opportunity of exporting energy, instead of only producing it for local use. In order for these changes to be successful however, it is imperative that there is a solid framework to base the transition on, as is the offering of incentives and stimuli, either of financial or behavioural nature. Finally, the citizens shall play an important role in the transition and could greatly support and accelerate it, but they need to be made a part of it and not kept on the fringes, irrespective of that happening of their own volition or by design.

- **How can a sustainable energy system in the Cyclades islands be realised by 2030?**

Starting from the present day, the transition to a sustainable energy system in the Cyclades shall be split into three stages, each of which will cover a different phase. Phase I, from 2022 to 2025, includes the first steps and the preparation for the future. This is arguably the most critical of the three, since the foundations of the whole transition shall be laid, and if that does not happen successfully then the whole plan could fail. Among the tasks that will need to be carried out during these first years is the planning of the future of the oil-powered stations, as well as the preparation of the RES generation projects and systems, practically and institutionally. As far as the transport sector is concerned, in Phase I it is necessary that the charging infrastructure for the electric vehicles is established, while a relevant policy measure that will have to be enacted is the ban on the sale of conventional light vehicles, such as cars and motorbikes. Also, with the importance of the public regarding the success of the transition, in the first phase attempts to inform and educate the local citizens (on what does the transition entail and how it benefits them) will have to be made. In the second phase, from 2025 to 2028, the generation of energy from RES will start, as the already installed in Phase I RES projects will be brought to action, while the fossil-fuel-powered stations will cease to be the chief providers of electricity. Moreover, the planning for the implementation of (large-scale) storage options will start in Phase II, while electric vehicles will by now be the norm. Finally, in Phase III, between 2028 and 2030, the transition shall conclude. The overwhelming majority of needs of the islands will be covered by renewable energy, supported by the availability to store energy for longer periods, and thus the power stations on the islands will be able to be taken out of ordinary action and kept only as reserves.

8.2 Recommendations

With the end of this thesis research project and based on the process and results of it, there have also been some concrete recommendations to stakeholders raised regarding the transition, apart from the actions and interventions identified in the backcasting analysis.

Firstly, as also mentioned in the PESTEL factors, bureaucracy can be a very common theme in Greece – and for projects concerning the Cyclades as a result – so it would be of great value if this obstacle could be overcome. The transition would be greatly accelerated and supported by simplifying and expediting the different processes regarding the development of RES projects, such as obtaining licenses and permits.

Moreover, it can be understood from the backcasting analysis and the implementation timeline that a very large effort is required in a rather small amount of time for the transition to be complete by 2030. If all the necessary projects have to be carried out concurrently, a practical concern is that a large number of companies shall be required for their implementation – companies that might not still be active in the Cyclades. It is therefore essential that attempts are made to attract more of these companies in order for the burden to be shared in a more effective way and for the transition to be able to meet its target of 2030.

A third recommendation would be to focus on the accommodation sector and its path to sustainability. As the analysis of Scenario B showed, the results of paying special attention to this energy-intensive sector are very encouraging compared to those of Scenario A. There can and shall be larger interventions carried out, but even making some relatively simple changes can greatly decrease energy consumption levels and thus ease the transition.

Finally, and while it has also been alluded to several times throughout this report, it is highly recommended to work with the general public at every possible stage of the transition. Citizen support could make or break the plans, and communicating with and including them in the process shall be of great help in ensuring the Cyclades islands reach a sustainable energy system by 2030.

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Appendix A: Energy Balance

In order to identify the flows of energy in its different forms on the islands, a simple energy balance was composed for the Cyclades. It is worth pointing out that due to the (un)availability of data as also mentioned previously, the balance is quite basic and based on rudimentary calculations and several assumptions. It also overlooks aspects such as losses, etc., but it nevertheless gives a decent view of the energy system of the islands. All values are in TJ.

Supply & Consumption	Oil & Petroleum Products	Renewables	Electricity	Total
Production	0.00	216.13	0.00	216.13
Imports	8,330.40	0.00	0.00	8,330.40
Exports	0.00	0.00	0.00	0.00
Primary Energy	8,330.40	216.13	0.00	8,546.53
Transformation input	6,138.40	216.13	0.00	6,354.53
Transformation output	0.00	0.00	3,221.90	3,221.90
Final Energy	987.17	0.00	3,221.90	4,209.07
Tertiary (non-municipal buildings)	0.00	0.00	1,933.14	1,933.14
Residential buildings	0.00	0.00	805.47	805.47
Public lighting	0.00	0.00	289.97	289.97
Municipal buildings	0.00	0.00	161.09	161.09
Agriculture/forestry/fisheries	0.00	0.00	32.22	32.22
Heating	470.81	0.00	0.00	470.81
Transport	516.36	0.00	0.00	516.36

Appendix B: RES Potentials

For the calculation of the potential of the different renewable energy sources on the islands, first a brief literature review was carried out in order to establish whether they have already been investigated, and if so, at which scale. Depending on the results, calculations were made in order to identify with as much accuracy as possible the values for each island. While for some RES the potentials were straightforward, those of wind and solar merit an extra explanation.

Wind

As mentioned in Section 4.5.1, the practical exploitable area for the purposes of installing wind turbines has been calculated and presented in a technical report by the University of Thessaly, commissioned by the Regulatory Authority of Energy. After accounting for several (mainly regulatory) restrictions in the islands, the authors make a distinction between three cases (1 MW wind turbine, 55 m rotor diameter; 2 MW wind turbine, 85 m rotor diameter; 3 MW turbine, 112 m rotor diameter) and report the maximum number of wind turbines to be installed, the maximum capacity based on the number of wind turbines, and the capacity factor for each island. With these known values, the energy that can be generated annually can be calculated by multiplying the maximum capacity with the capacity factor and 8760 for the hours in a year.

Solar

For the potential of solar energy there were unfortunately no useful estimates available, thus as mentioned in Section 4.5.2, the available area for the installation of wind turbines was used as stated in the above technical report, to approximate the available area for the installation of solar PV panels. After choosing the type of panels – and consequently their nominal power – and an estimate for the area required per 1 kW of installed capacity, the tools of the Photovoltaic Geographical Information System of the European Commission were used to calculate the total solar potential per island.

Appendix C: Energy Demand

In order to find the energy demand both for the present as well as for the end-point of 2030, there have been calculations made based on known data combined with relevant assumptions.

Consumption of electricity per sector

In order to calculate the consumption of electricity per sector for every island, the relevant data known was the annual electricity consumption for Sifnos (both in total and split per sector) from the Clean Energy Transition Agenda, as well as the annual electricity generation for each Non-Interconnected Island Power System (NIIPS). It was assumed that the profile of the electricity consumption of Sifnos is the same for all the islands, i.e. the percentage of consumption of each sector does not change per island, and that the electricity generated by each NIIPS equalled the electricity consumed by each NIIPS. The calculations were then relatively straightforward: the annual electricity consumption for Sifnos was used to find the percentage of consumption by sector, and then this percentage was applied to the electricity consumption of the NIIPS. The results were then multiplied by the relevant growth rate as presented in Section 5.2, in order to obtain the annual electricity consumption per sector for every NIIPS in 2030.

Heating

The calculations of the energy consumption for heating were also quite simple, having as a given the annual energy consumption for heating per capita of Sifnos. The assumption was made that since tourists are visiting the islands in the summer and as such do not make part of the demand for heating, and the islands all exhibit the same climate, the per capita value shall be the same for every island. Then it was a matter of multiplying the annual energy consumption for heating per capita of Sifnos with the population of every island, and in a second step multiplying the results with the growth rate in order to calculate the annual energy consumption for heating for every island in 2030.

Transport

Calculating the energy demand for transport proved to be the most challenging of the three, owing to the lack of data. With the annual demand for primary energy for transport in Sifnos as the only known piece of information, a number of assumptions had to be made. Firstly, the average distance a vehicle would cover was assumed based on each island's size, geography, and location of settlements and places of interest. Subsequently, the annual mileage of a vehicle was calculated by multiplying the average distance by 2 (to account for a road trip) and by 260 (assuming this trip would be made 5 days a week; 5 days multiplied by 52 weeks in a year = 260 days). The next step was to find the ratio of the annual mileage for Sifnos to the annual mileage of the Cyclades in total, so that the annual consumption of primary energy for transport in Sifnos (i.e. the only certain value known) could be divided by it in order to obtain the annual consumption of primary energy for transport in the Cyclades. After that was found, it was multiplied with the proportion of annual mileage for each island to the annual mileage for the Cyclades and thus the annual consumption of primary energy for transport for every island was calculated. Finally, the growth rate was applied to these results in order to find the analogous results in 2030.

Appendix D: Scenarios

In the first steps of *Step 2* of the methodological framework, three scenarios were developed; the first ended up being included in the thesis report (after several modifications) as Scenario A. The other two scenarios (shown below as Scenario I and Scenario II) were judged to be overly optimistic and perhaps non-realistic so the choice was made at the time to focus only on the most sensible of the three – Scenario A, while afterwards two new scenarios were developed (Scenarios B and C). They are presented here in the state they were discarded, as they were part of the evolution of this project and as such also carry some value.

Scenario I

The main focus of this scenario is the push for self-sufficiency for every island (even the interconnected ones) and not the whole region as before. Wind and solar are again chiefly providing electricity, and geothermal is now available only for the island of Milos, due to each island being "separate" from the others. Another distinctive feature of this scenario is the decrease in energy consumption and the further growth of energy efficiency, after the introduction of aggressive policies and measures (such as demand side management) and the efforts to increase the awareness and knowledge of the public about sustainable practices. The electrification of the heat and transport sectors takes place and is also accelerated by the new policy framework.

Scenario II

This scenario regards the Cyclades as a whole, and includes every island and islet of the group, both inhabited and uninhabited. A large-scale interconnection scheme is carried out, with the aim to create a Cyclades sub-grid by connecting every populated island, but also any isle that can prove an attractive option to install RES projects. This is more in line with – but certainly more aspiring than – the plans that have been laid out to connect also the western islands of the Cyclades with the mainland grid (and thus with the other, already connected islands). A further benefit of this scenario compared to the others is the opportunity to use the geothermal potential on the island of Milos as a baseload source for the entire group of islands. Despite the interconnections, the necessary storage solutions remain installed in every island, to ensure a degree of autonomy in case of extended underperformance of the wind and solar resources or other emergency. Moreover, an assertive policy package is implemented, leading to reduced energy demand, increased energy efficiency, and quicker substitution of oil products in heating, cooling, and transport for electricity.