Energy islands in Greece: Astypalaia case study

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School of Architecture, Design and Planning
Study board of Planning, Geography and Surveying
Rendsburggade 14, 9000 Aalborg

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Participants:

Nikolaos Proimakis

Supervisors:

Peter Sorknaes

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In present, Greece confronts significant financial challenges which are related with several inefficiencies in the governmental mechanisms and in other sectors.
One sector which is closely related with the economy is the energy sector. Energy influences the economy in the long term by adding value, income and employment which derives from the energy generation, transformation and distribution of energy.
Problems are identified in the Greek energy sector and specifically at the energy provision for the Greek islands.
Greece spends a significant amount of financial resources to secure the energy supply for the island complexes which are not interconnected with the mainland grid.
Greek plans involve the transformation of the energy sector of a Greek island from fossil-fuel based energy system to a Smart Energy System increasing the penetration of RES in the final electricity production to reach 60+%.
This research investigates distinct scenarios for substituting the existing inefficient energy system of the island. It seeks to outline the most advantageous scenarios with positive results in the overall performance of the energy system and achieving the increase in RES share in the final electricity production.

Preface

This is the resulting master thesis from the 4th semester in the Master's programme of Sustainable Energy Planning and Management at Aalborg University. The master thesis has been carried out in the spring semester 2018, with the semester theme: Master's Thesis

Reading guide

Through the report source references in the form of the Harvard method will appear and these are all listed at the back of the report. References from books, homepages or the like will appear with the last name of the author and the year of publication in the form of [Author, Year].

Figures and tables in the report are numbered according to the respective chapter. In this way the first figure in chapter 1 has number 1.1, the second number 2.1 and so on. Explanatory text is found under the given figures and tables. Figures without references are composed by the author.

Nikolaos Proimakis

Nomenclature

AVC Average Variable Cost
CEEP Critical excess electricity production
CO2 Carbon Dioxide
EU European Union
GDP Gross Domestic Product
GHG Greenhouse Gas Emissions
GPA Greek Adjustment Programs
GWP Gross World Product
HEDNO Hellenic Electricity Distribution Network Operator
IMF International Monetary Fund
LPG Liquefied petroleum gas
MoU Memorandum of Understanding
MS Member States
NIIs Non-Interconnected Islands
NREAP National Renewable Energy Action Plan
PPPs Purchasing Power Parties
PPC Public Power Corporation
PSO Public Service Obligation
PV Photovoltaics
RAE Greek Regulatory Authority of Energy
RES Renewable Energy Sources
SES Smart Energy System
TPES Total Primary Energy Supply

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Introduction 1

1.1 From global economic crisis to European economic crisis and vulnerable nations

A principal characteristic of the last 10-year period (2008-2018) is the multitude of economic crises that has erupted and influenced distinct geopolitical levels, transferring from a global scale at a national scale. During the last semester of the year 2007, an economic crisis emerged in the United States of America (mortgage crisis) with consequences for the global economy and extended in the other continents, affecting in a different degree each nation and hindering the growth of gross world product (GWP).

According to United Nations [2018], a fact of the last decennial has been a frail growth of the GWP, highlighted by elevated levels of investor ambiguity and volatile international financial markets. As stated by the European Court of Auditors [2017] and Serdar Ozturk, Ali Sozdemir [2015], the economic crisis developed in the USA is linked with the sovereign debt crisis in the European Union (EU), which has affected all its Member States (MS) and each country to varying degree.

By the end of the year 2016 and entering into year 2017, a notable advancement in the global economy has been observed, as the global economic system marked a balanced boost. A positive trend is estimated for the GWP which has been on the rise since the years 2016 and 2017 with a constant momentum since then [European Court of Auditors, 2017]. The leading economies managed to escape the crisis and go through a harmonized upturn in growth . In detail and breaking down the GWP to the purchasing power parties (PPPs) and the market exchange rates, the curve progress of the GWP is illustrated in figure 1.1.

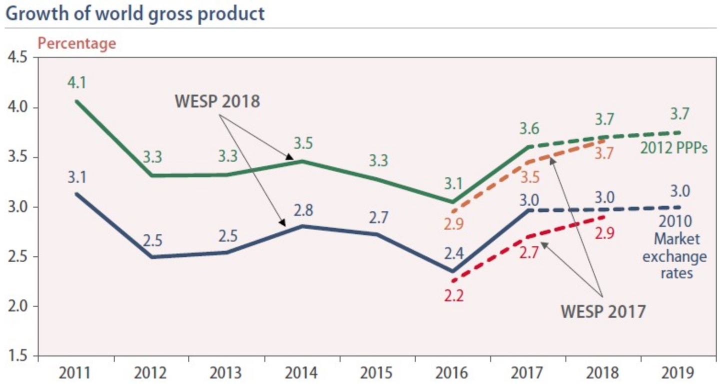

Figure 1.1. Growth of GWP

Nevertheless, the advancement of the economy and the increase in growth rate had not followed the same pattern in every country within the EU [United Nations, 2018; European Court of Auditors, 2017; Serdar Ozturk, Ali Sozdemir, 2015]. On the one hand, the countries with robust economic foundations and adequate governance models (adequate market and policy frameworks) have achieved a progress and to keep on a growth track in an short time frame, showing an instant response to the crisis.

On the other hand, countries with macroeconomic instability and structural deficiencies encountered greatest challenges [European Court of Auditors, 2017], which restrained them to recover from the economic crisis and empowered the existing problems and the weaknesses in the system [United Nations, 2018]. A country with several weaknesses and problematic operational ways is Greece, and as stated by Serdar Ozturk, Ali Sozdemir [2015], with extensive dept level, increased budget loss, insignificant competitive power and feeble political framework.

1.2 Greek economic crisis and Greek Adjustment Programs scheme

According to Serdar Ozturk, Ali Sozdemir [2015], the economic crisis in Greece has been prompted by the global economic crisis, as its roots can be identified in older inappropriate government tactics and inadequate policies, implemented in Greece over the last 30 years. In the opinion of European Court of Auditors [2017] and Serdar Ozturk, Ali Sozdemir [2015], the building-up of macroeconomic imbalances, high shares of public and foreign debt, feeble foreign competitiveness, unsustainable pension system and weak institutions had negatively affected Greece, enlarging the problematic situation.

Over a 5-year period (2010-2015), Greece had requested and received monetary support from the EU Member States and the International Monetary Fund (IMF) under the Greek Adjustment Programs (GAP) scheme. Principal objectives of the GAP scheme are to create a concrete and sustainable national economy and increase competitiveness in the financial market [European Court of Auditors, 2017].

In the last GAP in 2015, a Memorandum of Understanding (MoU) has been signed, designating meticulous financial policy measures to be implemented in Greece and providing a loan to the country. In total, Greece had been part of 3 GAPs. An area of agreement between all 3, is to restore financial stability and re-build the financial markets and the financial institutional system, able to be resistant to economic shocks and to smoothly fulfill its basic functions, decrease the foreign dept of Greece and return to growth [European Court of Auditors, 2017].

An action aiming to reduce the governmental expenditures and contribute to the milestones described in the GPA scheme, is to analyze the national energy sector and the national expenditures spent for the energy procurement and the security of energy supply for the whole nation [Liagou, 2017].

Greece spends a substantial amount of money to cover the national energy demand with the weaknesses of the system to be found on the island energy network. The Greek islands are not powered by the main electricity grid, but they cover their energy needs mostly from fossil-fuel power plants. A more thorough analysis regarding this topic and energy sector in Greece is presented in section 2.2. Prior to analyzing the Greek energy sector and the associated costs and weaknesses in the system, it seems necessary to demonstrate the relevance and close connection of energy with the national economy.

1.3 Energy sector and significance on the national economy

An interesting perspective regarding the energy sector and the influence that projects and investments have on the national economy is addressed by the European Commission [2017b]. As acknowledged by the European Commission [2017b], the energy sector along with the transport sector have a major significance in the economy and are closely related and may impact other sectors of the economy as well.

Energy influences the economy in the long term by adding value, income and employment which derives from the energy generation, transformation and distribution [Anthony Barker et al., 2016]. In addition, the performance of the economy, industries and households is influenced by a stable and cost-efficient energy use and security of supply. Lastly, energy contributes to the macro-economy in terms of innovations on the supply and demand side, which are often linked to societal transformations and economic performance. Furthermore the energy sector and the ways in which a nation fulfills its energy demand demonstrate the levels of energy dependency. In further detail the energy sector has a substantial impact in the economy and may promote economic growth.[Anthony Barker et al., 2016]

In this point the term 'energy dependency' should be described. There is a range of associated elements within the term energy dependency. These elements incorporate i)the potential vulnerability to fluctuating fossil fuel prices, ii) the security of energy supply and iii) the contribution of energy products to trading. The security of energy supply refers to achieving a stable access to tolerable energy and satisfy the economy's requirements. A nation's economy is unquestionably connected and influenced by the import dependency and final energy products to be exported.

A nation's reliance on imports implies its exposure to altering fuel prices, depending on the scale of imports and the divergence of import sources and the transportation routes. As stated by Anthony Barker et al. [2016], 'high energy dependency exposes the EU economy to global energy price fluctuations'. A decrease in imports dependency implies an advancement in the national economies and the ability to fulfill the energy needs by utilizing indigenous resources. Moreover, a transition from fossil-fuels to clean energy provided by renewable energy sources (RES) safeguards the exposure to fossil fuel price fluctuations [Anthony Barker et al., 2016]. After demonstrating the relation between the economy and the energy sector, this research studies the energy sector and energy dependency levels in Greece, described in chapter 2.

Energy sector in Greece 2

2.1 Greece and energy dependency

As acknowledged by Serdar Ozturk, Ali Sozdemir [2015], a significant part of the foreign debt of Greece is utilized for importing products which are intended for consumption. Regarding the energy dependency and the import sector in Greece, a high reliance can be observed in fossil fuels and electricity imports.

According to European Commission [2017b], the trade shortage in energy products has dropped from approximately 3.5% of Gross Domestic Product (GDP) in 2006, to 2.1% in 2015, reaching the levels for the EU. The Greek energy scheme is characterized by elevated percentages of petroleum and solid fuels utilization, with 52.8% and 23.7% respectively and a decreased use of natural gas reaching 11.3% , percentages valid for the year 2015. The average percentage of petroleum and solid fuels use within the EU28 is 34.4% and 16.2% respectively, with the average of natural gas to be 22% . Greece is heavily relying on imports of fossil fuels and this is a fact as the percentages are higher than the EU average [European Commission, 2017b]. A holistic view of the energy mix in Greece and for the year 2015 is illustrated in figure 2.1.

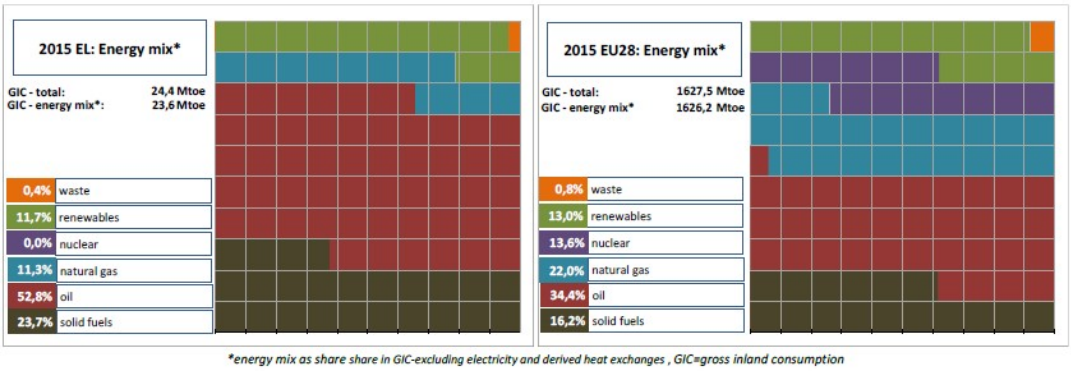

Figure 2.1. The energy mix of Greece and EU28 for the year 2015

Over a 10-year period (2005-2015) the percentage of fossil fuel imports in Greece grew by 3.3%, whereas in EU it has increased by 1.9%. According to European Commission [2017b], Greece imported 61.6% of its gas, 20% of its crude oil and approximately 64% of hard coal from Russia. As also certified by the International Energy Agency [2017], Greece is heavily dependent on imports of oil and gas, which constitute approximately two-thirds of the total primary energy supply (TPES). Hence, the government has as a principal concern to optimize policy framework regarding the national security of energy supply.

At this point it is important to identify where most of the imported products are utilized. The purpose of this is to outline the problematic segments of the energy sector and highlight areas of the sector with potential for improvement.

2.2 Energy sector in Greece and power grid distinction

2.2.1 Energy mix and indigenous sources

According to International Energy Agency [2017], the fuel which prevails in the Greek energy sector is oil, accounting for approximately 50% of the TPES for the year 2016. Greece holds the second place in oil utilization between the IEA member countries and is almost exclusively dependent on oil imports. Coal is the second most dominant fuel with a share of 19% in the TPES in the year 2016 and utilized mostly in electricity production and a small share for industrial purposes [International Energy Agency, 2017]. Natural gas occupies the third place of the most utilized fuel in the total primary energy supply for the year 2016, with a share of 15%. In general, fossil fuels contribute in the Greek total primary energy supply at a significant level, as the percentage reached 84% in the year 2016, fact which led Greece in the seventh position among the IEA countries [International Energy Agency, 2017].

The energy production deriving from RES experienced a double-fold increase over a 10-year period, escalating from 5.9% in 2006 to 12.5% in 2016, with bio-fuels and waste being responsible for approximately half of the RES production in the TPES. It is important to mention that Greece occupies the second position among the IEA countries in the share of solar energy. The above-mentioned data are illustrated in figure 2.2.

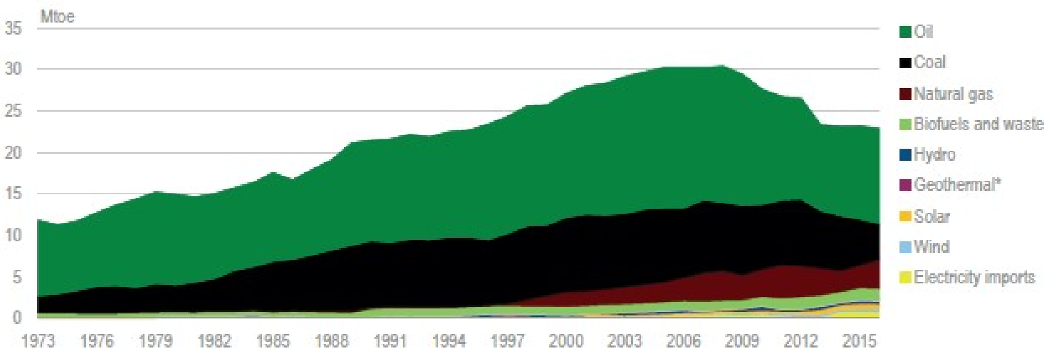

Figure 2.2. Total primary energy supply (TPES) from 1973 to 2016

2.2.2 Mainland Power Grid and Non-Interconnected Islands

Studying the Greek electricity network, it is possible to distinguish and divide the national power grid to the mainland power grid of central Greece and the electrification system of the Greek islands through smaller local grids. Greece can be geographically sub-divided in the mainland region, the Peloponnese peninsula (separated from the mainland) and approximately 6000 islands and islets, of which only 227 are inhabited [International Energy Agency, 2017].

According to the Greek Regulatory Authority of Energy (RAE) and as stated by Greek Regulatory Authority for Energy (RAE) [2018], the islands which are not powered by the mainland power grid, termed as the Non-Interconnected Islands (NIIs) of Greece, have an electricity market which consists of thirty-two autonomous systems and of islands complexes. These thirty-two autonomous systems are categorized according to the peak load demand into three distinct systems. There are 19 small-scale autonomous systems with a peak load up to 10 MW, 11 medium-scale autonomous systems with a peak load ranging from 10 MW to 100 M, and lastly 2 large-scale autonomous systems with a peak load higher than 100 MW (islands of Crete and Rhodes).

As described by the Greek Regulatory Authority for Energy (RAE) [2018] and mentioned in section 1.2, most of the Greek islands are powered by autonomous electrical systems with electricity generated mostly by local thermal power stations and in some cases by RES. The thermal power stations utilize crude oil, heavy oil (mazut) and light oil (diesel). Over the last years, the Greek islands have not yet been connected to the mainland power grid due to technical and economical restrictions which set the investment costs significantly high.

The autonomous island network of Greece is accounted for the significant share of oil utilization in power generation. Greece has a large share of oil use in power production with the oil-fueled power plants to generate approximately 11% of the total electricity production in 2015, fact which places Greece in the first place between the IEA member countries [International Energy Agency, 2017]. This fact is associated with numerous challenges and negative impacts towards the society and the technical performance of the energy system. The existing challenges and the negative socio-economic impacts of the energy system on the Greek islands are examined further in section 2.3.

2.3 Greek islands and existing challenges related to energy

The NIIs are principally situated in the Aegean Sea and as seen in 10.2. Approximately 15% of the Greek population live on the islands and 10% of the total national electricity consumption originates from the islands [Nikos Hatziargyriou and others, 2017]. The current energy pathway demonstrates distinct problems which can be classified to financial, technical and environmental and are presented in the following paragraphs.

Figure 2.3. The interconnected and non-interconnected islands in Greece, source: RAE

From a financial perspective and according to the opinion of Nikos Hatziargyriou and others [2017], overall the NIIs are characterized by an elevated cost in comparison to the mainland power grid. In detail, the Average Variable Cost (AVC) is two to eight times higher than the average system marginal price of the mainland power grid [Nikos Hatziargyriou and others, 2017]. The average variable cost is defined as the total variable cost per unit including material and labor which represents 'the average of all costs on a per unit basis that change with production levels' [My accounting course.com, 2017].

After research, several articles in the Greek press where found which validate the significant difference of the AVC and the average system marginal cost of the mainland power grid [Deligiannis, 2017; Liagou, 2017; Kaitatzidis, 2014; Theodoropoulos, 2017]. The average production cost of autonomous oil-fueled power plants in August 2017, according to official data from the Hellenic Electricity Distribution Network Operator (HEDNO), stood at 336.96 € per megawatt hour, about seven times higher than the mainland limit value, around 50 € megawatt hour [Liagou, 2017; Theodoropoulos, 2017]. These elevated energy costs (generation costs, import costs, operation and maintenance O&M, fuel cost, variable operating cost) resulted in the creation and implementation of a policy measure called Public Service Obligation (PSO). According to this policy measure Greek consumers all over Greece are charged for the energy issues and thus this policy measure adds an economic burden to the Greek consumers [Deligiannis, 2017; Liagou, 2017; Kaitatzidis, 2014].

From a technical point of view, the existing oil-fueled power plants operate at a maximum level particularly during the high season (summer period) to meet the increased electricity demand due to tourism. This is an important difficulty that currently the island energy sector can not efficiently confront. The power plants operation at a maximum extent may present negative impacts such as energy blackouts [Liagou, 2017; Xatzivasiliadis, 2013]. As acknowledged by Nikos Hatziargyriou and others [2017] and Xatzivasiliadis [2013], the challenge of covering the summer loads and peak demand in some islands is by-passed by ad-hoc solutions, such are rental capacity of portable diesel units or transfer of production unit from other networks where surplus capacity is available.

Furthermore, another technical bottleneck which should be considered is the technical lifetime and the low efficiency of the current power plants [Nikos Hatziargyriou and others, 2017]. The electricity supply of the 32 non-interconnected islands in the country is secured by low-capacity (diesel and fuel oil) stations installed since the 1960s and 1970s [Liagou, 2017].

As far as the energy and climate and according to the International Energy Agency [2017], the elevated reliance on coal and diesel in electricity production (especially on the NIIs) results in a high carbon intensity of the economy. As a MS of the EU, Greece has implemented measures until 2020 which foresee the reduction in greenhouse gas emissions (GHG) and the decarbonization of the national economy. Fossil fuels were accounted for 70% of the electricity production in 2015 and the share in the NIIs was even higher [International Energy Agency, 2017].

After the implementation of the EU legislation on pollutant emissions, Public Power Corporation (PPC) is obliged to withdraw the polluting oil-fueled power plants by 2020 and maintain them as an emergency back-up [Liagou, 2017]. Furthermore and according to the criteria of the MoU requirements, Greece should consider and assess alternative ways for fulfilling the energy demand of the Greek islands and assess the cost of interconnection of the islands based on a socio-economic analysis, concluding to proposals for the economically non-viable interconnection of islands [Liagou, 2017].

To achieve that, a national development plan [Ministry of Environment Energy & Climate Change, 2010] for the period 2017-2026 has been published and is examined in section 2.5. In general, it includes plans for interconnections of the islands, where there is such a possibility, and for those that the connection is not viable, the process of replacing existing units with new low-environmental footprint technologies is examined, without having to lead to an increase in the cost of electricity generation by 2020. This energy transition and investigation of alternative scenarios for energy provision on the Greek islands is a requirement of the MoU of the country within the EU [Liagou, 2017].

From the above,it is clear that there is an intensified need for a transition in the energy sector of the Greek islands and identification of more efficient ways for securing the energy supply. From a higher political point of view and within the EU, actions and initiatives have been implemented with the scope to address the issue of the energy provision of all the EU islands and spur up the process for the transition of their energy sector from fossil-fuels to clean energy.

2.4 Political action promoting the energy transition of the EU islands

In the EU, initiatives have been developed with an objective to decarbonize geographical islands and achieve a transition from fossil-fuel based technologies to clean energy systems. A key political priority is to establish the EU as the Energy Union, with a strategy to improve the EU economy, boost job creation, increase growth and attract more investments.

In 2016, the European Commission introduced the 'Clean Energy for All Europeans' plan with the scope to define a legislative framework able to assist the progress of clean energy transition [European Commission, 2016]. The initiative 'Clean Energy for All Europeans' aims to increase the GDP up to 1% over the next 10-year period and create 900.000 jobs. Additionally, for 2030 it is projected a decrease by approximately 43% of the carbon intensity of the EU's economy comparing to present [European Commission, 2016]. A component of this plan is the 'Clean Energy for EU Islands' which sets a long-term legislative framework for spurring up the clean energy transition in Europe's islands. The islands within the EU confront several problems which this plan aims to address, while also functioning as a knowledge sharing platform of best practices and pilot projects [European Commission, 2016].

According to the European Commission [2017a] and as stated in Eurelectric [2017], the significant current challenges that the EU islands confront are the following. Most of the EU islands suffer from significantly increased energy expenses, weak security of energy supply, dependency on imports, small economies of scale and weak access to the EU energy market [European Commission, 2017a; Eurelectric, 2017]. The energy sector of the EU islands is heavily relied on diesel fuel and oil for electricity production. This poses a threat for the environment and it negatively affects the market competitiveness.

In addition, it is noteworthy that the local consumers are exposed to high electricity prices which is a burden for the economy. This is due to the constant need for implementing administrative measures and financial assistance plans to alleviate these elevated electricity costs [European Commission, 2017a]. Lastly, during the touristic season is observed an increased electricity demand which puts pressure in the local infrastructure and natural reserves [European Commission, 2017a]. Under the light of this evidence and according to Eurelectric [2017], the decarbonization of the island energy sector seems necessary and of immense importance.

On the other hand and based on the opinion of European Commission [2017a] and Eurelectric [2017], there are several arguments which justify the need and adequacy for projects on a smaller scale as in the context of an island. The objective is the transition of the EU islands energy sector to a decarbonised system with less dependence on imports.

According to European Commission [2017a], the populated EU islands constitute an ideal system for implementing modernized energy solutions and engage greater investment capital which consolidates local renewable energy generation, storage resources and efficient response to the energy demand. Furthermore, due to several characteristics within the context of the EU islands, such as the geographic location, the climate potential, the size and population, available indigenous resources, they offer a favorable environment for implementation and testing of innovative energy solutions and business models [European Commission, 2017a; Eurelectric, 2017].

As stated in European Commission [2017a], these characteristics are 'important drivers for sustainable and resilient economic growth and the development of local skills and jobs for the communities on EU islands'. The islands may efficiently strengthen the EU's energy and climate targets and assist in the establishment of the EU as the Energy Union Eurelectric [2017]. In Greece political actions have been taken which aim to support this energy transition and introduce larger amounts of RES in the energy mix.

2.5 National Renewable Energy Action Plan (NREAP) and Development Plan 2017-2026

The Greek islands are on the forefront of the energy transition and climate change mitigation and constitute the most key component able to contribute to national economic growth [Giorgos Patoulis and Nicole Katsioulis, 2016]. It is of major importance to create adequate plans and ensure an efficient sustainable energy planning for the Greek islands able to tackle the existing challenges as mentioned in section 2.3.

Shedding light on the NREAP and the 10-year Development Plan of Greece, the solutions for the existing problems related with energy in the Greek islands are explained [Ministry of Environment Energy & Climate Change, 2010; Independent Power Transmission Operator S.A (ADMIE), 2016]. The proposed solutions and the fundamental concerns as stated by the Ministry of Environment Energy & Climate Change [2010] are the following:

i) The gradual interconnection of the Greek islands with the power grid on the mainland and thus reducing the use of fossil-fuel power plants

ii) In cases where this is not feasible due to restrictions (financial, technical etc.), solutions are based on the development of self-sufficient energy systems and pilot implementation on small islands.

The 10-year development plan 2017-2026 is a strategy which includes the total number of all projects to be done within the pre-established time frame. It also describes the basic mentality and philosophy followed for the planning, configuration and management of these plans. Specifically, the 10-year development plan i) defines the required infrastructure works over this period, including ways to increase RES penetration, ii) includes all the investments from previous development plans and iii) provides techno-economic assessment for the important works and all the interconnection projects at a national level, but also for the Greek island network [Independent Power Transmission Operator S.A (ADMIE), 2016].

According to Independent Power Transmission Operator S.A (ADMIE) [2016], an important and urgent action for the Greek government is to connect the Aegean islands with the mainland grid and thus increase the efficiency in security of supply, decrease the energy costs and generation costs, protect the environment and harness the high RES potential of the NIIs.

Distinct phases have been established which incorporate plans about interconnecting different island complexes with the mainland power grid [Independent Power Transmission Operator S.A (ADMIE), 2016]. However, for smaller islands where the connection is not feasible due to lack of economies of scale and other difficulties, it is a requirement and as discussed in the MoU, to assess the availability of alternative solutions and increase the penetration and development of RES in the energy system. As also presented in the Greek press and stated by Liagou [2017], for the islands that there are no plans for interconnections, techno-economic assessments and studies for alternative energy scenarios should be conducted and in relation to the environmental goals and aiming for reduction in carbon dioxide (CO2) emissions and decarbonizing the energy sector of the Greek islands.

These remaining island complexes refer to 11 small islands: Agathonisi, Agios Eustratios, Anafi, Antikythera, Astupalaia, Arkoi, Donousa, Ereikousa, Megisti, Otthonoi and Gaudos. The electrification of these islands is already a subject for investors and researchers, operating in the domestic energy market.

As officially stated by AthensNewsAgency [2018] and Worldenergynews.gr [2018], there are two islands that are planned to meet their electrification needs by utilizing approximately 60 to 70% of RES to fulfill their electrification needs. These interventions aim to increase the penetration of RES in the energy system and at a rate of 60 up to 70% of the existing demand. This will lead to a reduction of the PSO, which today covers the extra costs of electricity.

As stated by the Minister of Environment Energy & Climate, Giorgos Stathakis, 'the goals of applying smart technologies to the islands is to ensure their energy autonomy, the electrification of the transport sector, cost savings for consumers and achieve CO2 emissions'. This energy transition of the Greek islands has been planned to include the creation of hybrid power stations with RES units, which will be combined with the appropriate storage system and the corresponding energy management system[AthensNewsAgency, 2018; Worldenergynews.gr, 2018].

Problem statement and research design 3

According to Kush, Max [2015] the problem statement refers to an on point description of a subject to be addressed or a condition to be studied upon. It describes the gap between the prevailing problem state and the expected outcome of a process. In this chapter the problem statement for this research is presented, followed by the research question and sub-questions shaped, and the research design aiming to answer these questions.

3.1 Problem statement

As a synopsis of the chapters 1 and 2, this research focuses on the Greek island of Astypalaia and outlines the necessity for conducting plans aiming to decarbonize its energy sector and achieve an increased penetration of RES in the energy system. Furthermore, the percentage of the RES share for fulfilling the current demand is set to 60 up to 70% and according to the development plans for Greece, as described in section 2.5. The plan and the theory behind the project of energy transition on the island of Astypalaia involves the development of a Smart Energy System (SES), described in detail in section 4.2, which combines RES with storage facilities and interconnections between distinct sectors, such as the transportation sector.

The principal objective of these plans is to outline feasible alternative scenarios of SES which are able to improve the technical, economic and environmental performance of the system, decarbonizing the energy sector of the island and substituting the existing energy system. After reviewing the above information, several questions can be shaped which form the gaps between the prevailing problem state and the expected results for this research.

Firstly, the need is presented to define and analyze the current energy system in Astypalaia island. It is necessary to obtain data and information regarding the energy demand and supply profiles, as well as the available energy infrastructure on the island. This is essential for gaining knowledge which is subsequently used for the development of the alternative scenarios and their 'tailored' design to the existing energy needs of the island.

Secondly, since the current energy system in Astypalaia and its operation ways are acknowledged, a relevant question for the alternative scenarios development would be how the different combinations of RES capacities and other modifications in the energy system and the demand and supply side may affect the technical, economical and environmental performance of the SES scenarios. Under which technology combination and energy infrastructure, the preferable RES share percentage (mentioned in the first paragraph) can be achieved?

Lastly, questions are raised regarding SES and the influential parameters which may impact the technical, economical and environmental performance of the energy system. What are the factors which have a significant impact on the output values of a SES and may alter the results in each alternative scenario? What are the interrelations between these factors and what should be considered when designing alternative scenarios?

3.2 Research question

This research seeks to investigate the issues mentioned in the problem statement section 3.1 by integrating these under the concept of one principal research question which will drive this research case.

At a next stage, the formulated research question is divided further in sub-questions. The purpose is to reduce the complexity of the principal research question and highlight the ways in which this research should go into. For each sub-question a relevant analysis process is chosen to be implemented able to contribute to their answer.

The principal research question and the sub-questions established for this research, and according to the already described problem statement are the following:

• *'Which are the most competent alternative scenarios for decarbonizing the energy sector in Astypalaia, and for achieving the 60+% share of RES in the final electricity production?'*

1. *'What are the characteristics of the current energy system in Astypalaia and what is the energy utilization profile on the island?' (supply,demand,fuel utilization,end-use types)*

2. *'Which factors may affect the technical, economical and environmental performance of the Smart Energy System scenarios and which are the most advantageous technology combinations implemented in each alternative scenario for reaching the 60+% of RES share in the final electricity production?'*

3. *'Which are the factors that add uncertainty in the results of this research and what are the inter-connections between them?'*

In the first stage and for the first sub-question, it is relevant and necessary to examine in detail the current energy system in Astypalaia. The purpose is to obtain a concrete idea about its characteristics and gather relevant data regarding the energy demand and supply, the available energy infrastructure and in general the information needed to sufficiently model and represent the energy sector of the Greek island as it is in present. This information is essential for developing relevant SES scenarios able to substitute the existing energy system of the Greek island.

The characteristics refer to the existing infrastructure for energy provision, the power production technologies and the supply and demand profiles of the island. Moreover, the energy balance refers to the fuel utilization and the shares according to each fuel type and end use in the final energy consumption of the island. This research seeks to answer this sub-question as it is necessary to obtain this knowledge for developing relevant SES scenarios which are able to respond to the already existing energy demands.

In the second stage and for the second sub-question, to identify the SES scenarios which are able to substitute the existing energy system and also certify the optimal technical, economical and environmental performance, a comparison of alternative scenarios is required. The feasibility is examined and certified regarding the technical, economical and environmental performance and in relation to the established development goals.

In order to answer the second sub-question, this research starts an investigation of various RES capacity combinations and types, alternative regulation strategies for the excess electricity produced and potential for utilization in other sectors, incorporating storage facilities in the system, and modifying the demand side of the island. The purpose of these actions is to assess a large range of numerous technology combinations in relation with distinct regulation strategies which concern the management of the power production units with the aim to control the excess electricity produced without wasting energy.

Lastly and regarding the third sub-question, in this research and in the assessment and development of the SES scenarios there might be factors which may significantly influence the results if they have been applied differently. It is important in this research to outline all the factors of uncertainty or else stated sensitive factors. The purpose of this is to outline the relations between them and how they might affect the performance of the energy system in each of the developed scenarios. In this way the results for each SES scenario are tested for their robustness, connection between the inputs and outputs can be found and there is the potential for developing optimized alternative scenarios in future projects.

Each of the described sub-questions is connected with an appropriate analysis procedure able to result in their answer. This analysis procedure incorporates the most relevant theories and methods. The analysis procedures followed in this research and the research objectives which this thesis seeks to achieve are thoroughly described in chapter 4 and in relation with the established sub-questions in section 4.1.

In the following section the research design which is developed and tailored to the needs of this research is presented.

3.3 Research design

This section introduces the research design, or else stated the detailed strategy applied in this research. This strategy involves the integration of the distinct components of the study in a coherent and logical way so that the research problem is sufficiently addressed. The distinct components of the study refer to the research methods, theoretical hypotheses, research tools and the analytical framework applied with the scope to answer the sub-questions and hence the principal research question. [De Vaus, D.A., 2001; Trochim, William M.K., 2006]

The length and complexity of describing research designs may vary considerably. According to De Vaus, D.A. [2001]; Gorard, Stephen [2013]; Leedy, Paul D. and Jeanne Ellis Ormrod [2013]; Vogt, W. Paul, Dianna C. Gardner, and Lynne M. Haeffele [2012], any well-developed design seeks to achieve the following tasks:

- Identify the research problem clearly and justify its selection

• Clearly and explicitly specify hypotheses central to the problem
• Review and synthesize previously published literature associated with the research problem
• Effectively describe the data which will be necessary for an adequate testing of the hypotheses and explain how such data will be obtained
• Describe the methods of analysis to be applied to the data in determining whether or not the hypotheses are true or false.

This research design and as illustrated in figure 3.1 forms the core investigation strategy followed in this research for answering the sub-questions and answering the principal research question.

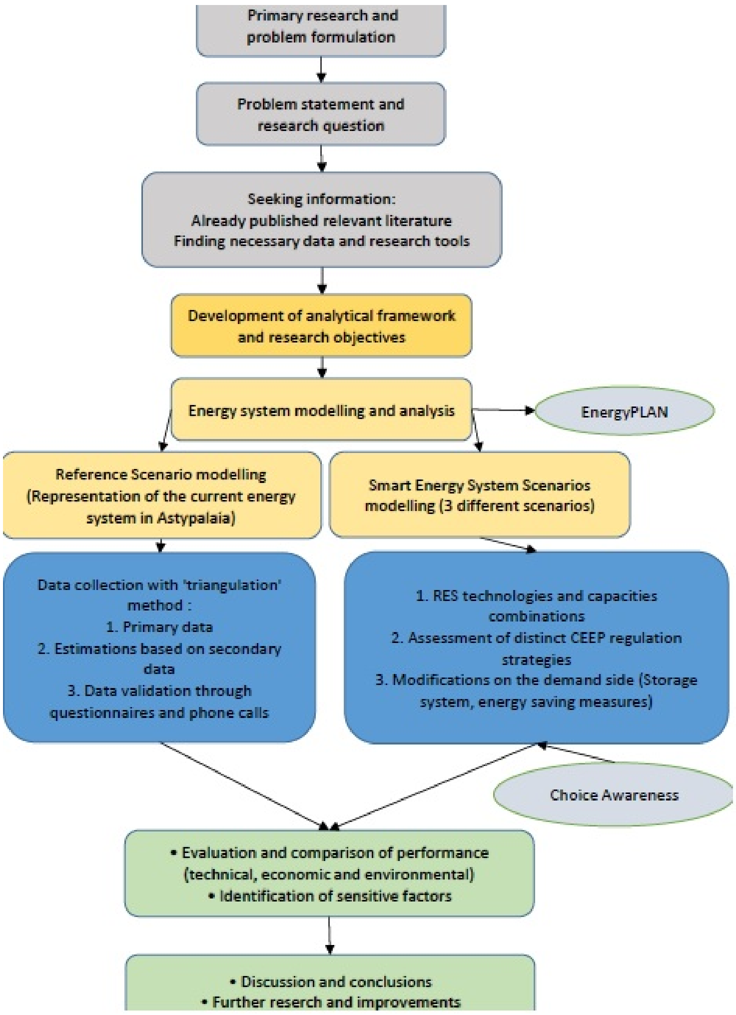

Figure 3.1. Research design

The research design illustrated in figure 3.1 is divided into distinct stages. The first stage shown in grey color includes the initial tasks of the research which are the primary research and problem formulation process. This process includes the chapters 1 and 2 and a broad investigation which eventually narrows down to a concrete problem statement and the development of the research question and sub-questions.

The second stage of the research design as illustrated in orange color includes the process of developing an analytical framework and establishing concrete research objectives which are closely linked with the principal research question and the sub-questions.

The third stage of the research design which is shown in blue color, involves the processes followed according to the established research objectives and analysis tasks. These include the data collection processes for the reference scenario modelling and the procedures implemented for the modelling, analysis and comparison of the alternative scenarios. These are developed according to the SES concept which is described in chapter 4, section 4.2.

The final stage of the research as illustrated in light green color includes the assessment of the developed alternative scenarios and in relation with the technical, economical and environmental performance of the energy system. This results in the identification of the alternative scenarios able to respond to this research needs and answering the sub-question number 2, already mentioned in section 3.2. Lastly the analysis and identification of sensitive factors included in the calculations is done with the scope to provide a deeper understanding of the results, demonstrating the relation of inputs and outputs and how the results are affected by any potential changes. A thorough description of the sensitive factors and the need for conducting a sensitivity analysis are achieved in chapter 9 ,section 9.1.

3.4 Delimitations

The delimitations are decisions implemented in this research which describe the boundaries that are constructed for this research case. The purpose for establishing delimitations is to clarify the viewpoint of this research and how it considers the system which is examined.

The first delimitation answers to the question for whom this research is being done and from what perspective the analyses are accomplished. This research has the form of an academic study report which could be done for a governmental institution, consulting company but in this case is being conducted as a master thesis. Thus, it has a more general form and focuses on socio-economic analysis of the examined case. The term 'socio-economic analysis' and according to European Chemicals Agency [2018] is a method for calculating the advantages and disadvantages of an action towards the society as a whole. The socio-economic analysis in comparison with the business-economic analysis does not take into consideration the taxes. In this research all the calculations and the total annual costs of all the scenarios do not include taxes.

The second delimitation involves the analysis and modelling of the reference scenario and the already existing energy system in Astypalaia. It is chosen for this research to take under consideration the residential and commercial sector in Astypalaia and exclude the industrial, transportation and water sectors. That is due to the fact that it is challenging to obtain information and necessary data for the modelling of the reference scenario.

It could be argued that as realized for the development of the reference scenario, data for these sectors could be estimated and following the same procedure as for the other sectors and their data handling. Nevertheless, in this research this is decided not to be done as it would increase the uncertainty and deviation of data and the final results from the actual, realistic data. Thus, to not enhance the uncertainties in this report, the transportation, industrial, water sector are excluded from the analysis process.

Lastly, in the commercial sector, data could not be found for a number of infrastructure facilities in Astypalaia such as the airport and the 2 ports. Thus this research also excludes these from the modelling and analysis of the energy system. The commercial sector in this research viewpoint consists of the hotels and other accommodation types, dining businesses and food catering services and the school buildings in Astypalaia. These along with the residential sector form the system under examination for this research.

Applied research methods and theoretical notions 4

In order to answer the sub-questions and hence the principal research question, an arrangement of methods and research tools are selected which shape the methodological framework applied in this research. In this section, the research methods and tools are presented, described and affiliated to the research objectives and the analysis structure. This methodological framework is linked with the theoretical notions applied in this research. Both of them are accumulated with the stages of the analysis structure. The result of this synthesis of theories and methods is the analytical framework applied in this research.

This chapter includes a description of the analysis structure and the research objectives as set for this research. It continues with a description of the methods and research tools utilized in each stage of the analysis along with the necessary associated theoretical notions. In continuation, the data required along with the data accumulation and management plan are described. A detailed description of all the data utilized as inputs in this research can be found in the Appendix section.

4.1 Analysis structure and research objectives

The initial stage of this research involves the formulation of a concrete problem and the establishment of the overall research objectives and tasks able to provide solutions to the main problem . The research objectives are expressed in the principal research question and the developed sub-questions. The tasks and the process followed with the scope to answer the research question and the sub-questions are described in this section and form the analysis structure of this research.

The analysis structure of this research and relating to the established sub-questions consists of i) the modelling and analysis of the current energy system in Astypalaia and the design of the reference scenario, ii) the investigation and assessment of diverse RES capacities combinations, energy infrastructures and technologies integration for 3 different Smart Energy System scenarios, and the examination and analysis of how each technology combination affects the technical, economical and environmental performance of the Smart Energy System and for each scenario, and iii) the analysis and discussion regarding the uncertainty factors and inter-relations which may affect the results of this research and distort the resulting outputs and hence the conclusions made for this research.

The first task of the analysis process is to analyze and model the current energy system of Astypalaia island in Greece and examine its technical, economic and environmental performance. The purpose of this analysis task is to obtain all the necessary information regarding the characteristics of the existing energy system in Astypalaia and the energy balances of the island. to clarify, the energy balances refer to energy sources and fuels used in the current energy system in Astypalaia. These are required for the modelling of a reference scenario. This reference scenario will provide all the necessary data, according to which the development of alternative scenarios is based. The reference scenario is planned to be compared with the alternative scenarios in this research and examine significant differences in their performance.

The second task of the analysis is to develop alternative energy scenarios incorporating RES and storage system, which is then compared with the reference scenario and its technical, economic and environmental performance. In order to identify which technologies combination is the one presenting the most advantageous results regarding the technical, economical and environmental performance, this analysis task seeks to assess and simulate the operation of distinct RES capacities combinations and include different measures on the demand side. The purpose of these actions is to create a wide range of potential combinations of technologies, regulation strategies and modifications in the energy system with the scope to outline the best suited solutions for this case. The results of the second analysis task concern 3 different Smart Energy System scenarios and their comparison, narrowing down to the most advantageous and well matched solutions for this research case.

For the developed scenarios numerous technology combinations are assessed and compared regarding the outputs and impacts on the technical, economical and environmental performance of the Smart Energy System. The aim of this process is to outline feasible alternative Smart Energy System scenarios with the most advantageous results which are able to decarbonize the energy sector of the Greek island and contribute to the energy transition. The alternative energy scenarios include the development and modelling of Smart Energy Systems, providing a cost-efficient and sustainable way for energy provision and security of supply under the cooperation of RES, storage system facilities and power utilization and connection with other sectors. A more thorough description of the definition 'Smart Energy System' follows in the next section 4.2.

The last analysis task is to investigate and analyze the uncertainty factors in this research and how they may influence the results. Discussion is made regarding all the influential factors and their inter-relations and in which ways they may influence the final conclusions. The purposes of this sensitivity analysis are described in further detail in chapter 9 and in section 9.1.

4.2 Smart energy system

In this section it is crucial to describe and define the term 'Smart Energy System'. Starting from the necessity to examine these systems, this research answer to the question why to to investigate and develop alternative scenarios based on this theory.

As already described in section 2.5 the development plans for the Greek islands and in particular for the island of Astypalaia argue for an energy system which includes the integration and cooperation of RES in combination with storage facilities and the cooperation of other sectors with the energy sector. This cooperation could be the utilization of electricity produced by RES for the electrification of the transportation sector on the island and the introduction of electric vehicles. Furthermore, and as described in section 2.5, the development plans for the Greek islands seek solutions for a more fuel-efficient energy system, with low energy costs for the consumers and a significant reduction of CO2 emissions.

According to academic literature and as stated by B.V Mathiesen, H. Lund, D.Connolly, H. Wenzel, P.A. Østergaard, B. Möller, S. Nielsen, I. Ridjan, P. Karnøe, K. Sperling, F.K Hvelplund [2015], using a SES approach includes a significant merging of distinct energy sectors and cooperation of sectors which allow the increased penetration of RES in the energy system. The theory of SES is able to result in fuel-efficient and cost-effective solutions while in parallel protecting the environment by reducing the CO2 emissions. For the increased penetration of RES in the final electricity production of an energy system, the SES concept is essential to utilize the storage synergies and exploit all the available resources [B.V Mathiesen, H. Lund, D.Connolly, H. Wenzel, P.A. Østergaard, B. Möller, S. Nielsen, I. Ridjan, P. Karnøe, K. Sperling, F.K Hvelplund, 2015]. As also described in H. Lund, P.A. Østergaard, D. Connolly, Brian Vad Mathiesen [2017], a SES refers to the combination and synergies of electricity, thermal and gas grids with storage facilities with the scope to achieve the most advantageous solution for the energy system and for each sector separately.

4.3 Tools for the Smart Energy System modelling

According to H. Lund, P.A. Østergaard, D. Connolly, Brian Vad Mathiesen [2017], for the development, modelling and simulation of smart energy systems requires adequate tools which expand across all the sectors of the energy system and which focusing on electricity, heating, cooling and transportation and hence across infrastructures connected by electric, thermal and gas grids. Furthermore, since fluctuating sources of energy are integrated in the system, the tools utilized for the simulation and modelling of SES should include and take into account the seasonal variations and the demand and supply in an hourly basis.

As stated by H. Lund, P.A. Østergaard, D. Connolly, Brian Vad Mathiesen [2017], an extensive research has been done by Connolly et al. regarding various energy modelling tools with the ability to analyze and simulate large-scale integration of renewable energy. From the assessment of all the tools in this investigation, the modelling tool EnergyPLAN is identified as an adequate tool providing the option to analyze in an hourly basis the energy system and achieve the above mentioned requirements for analyzing SES.

As also described by Kristine Askeland, Kristina Bozhkova [2017], the EnergyPLAN is a tool which is capable of analyzing the electricity, heat and transport sectors, would be able to perform an analysis on an hourly basis, and it can be downloaded and used free of charge. For these reasons, it is chosen as a suitable simulation tool able to respond to the needs of this research.

A description of the EnergyPLAN tool follows in the next section.

4.4 EnergyPLAN and purpose

As far as its operation way, EnergyPLAN model is considered as a simulation tool which is used to simulate the operation of energy systems on an hourly basis, including the electricity, heating, cooling, industry and transport sectors. The EnergyPLAN model is a deterministic input/output model and the main inputs are energy demands in distinct sectors, energy plants capacities and technical data (fuel type, consumption etc.) , energy storage capacities, associated costs (investment costs, fuel costs, O&M costs etc.) and a range of optional diverse regulation strategies focusing on import/export and excess electricity production. It is appropriate for analyzing intermittent RES and the fluctuations in energy demand on an hourly, daily or seasonal basis.

The outputs are energy production profiles, balancing of energy imports and exports, calculation of the excess electricity production, primary energy consumption and fuel demand, total system operating costs and CO2 emissions from the whole system. The outputs of simulations in EnergyPLAN are relevant for the objectives of this research.

Furthermore, for examining the various RES combinations, addition of energy saving measures, the values of critical excess electricity production (CEEP) and the different regulation strategies for CEEP, the EnergyPLAN tool provides the options to simulate all these parameters. For these reasons, the EnergyPLAN model is chosen as the modelling tool in this research and utilized fro the modelling of the reference scenario and alternative SES scenarios for the Greek island of Astypalaia.

Moreover, there are several existing case studies available in the official website of EnergyPLAN tool including several national, regional, and small island applications. These studies are published in journals and reports for academic research purposes. Since the EnergyPLAN tool is widely acknowledged and applied in scientific research and also corresponds sufficiently to the needs and objectives of this research, it is chosen to be used for the modelling and simulation of the examined scenarios.

4.5 Modelling of the reference scenario

The energy system modelling and analysis refers to two distinct modelling tasks. Firstly, the modelling and simulation of the current energy system in Astypalaia island which constitutes the reference scenario. Secondly, it refers to the development of alternative scenarios for energy provision incorporating RES technologies combinations, energy storage system and the potential for new end-use types of the surplus of energy produced.

The method followed for the modelling and simulation of the reference scenario in EnergyPLAN includes several steps. In the first stage data collected through correspondence via e-mails and phone-calls with the HEDNO in Greece. The data obtained concerns the technical characteristics of the existing power plant units and the hourly electricity demand for Astypalaia island and for the year 2017.

In the second stage and for providing a more detailed analysis of the energy sector in Astypalaia, this research divides the energy sector and the energy demands to i) the residential sector demands and ii) the commercial sector demands and based on the delimitations already described in section 3.4. The classification is realized as it has been challenging to obtain data for each sector from a primary source. Thus, by the further division of the energy sector into these categories a more accurate and detailed estimation of data can be achieved. This is accomplished by the use of secondary data obtained from literature and regarding the average energy consumption profiles of the infrastructure in the commercial sector. By identifying and choosing the most relevant for this research case data, adjustments are made for the more realistic representation of the energy system in Astypalaia. A thorough description of this approach can be found in the Appendix section.

The applied method for calculating and collecting the missing data is the triangulation method. This method refers to the collection of data by using more than one method and regarding the same topic. The data for planning and modelling the reference scenario are secondary data obtained from relevant reports with the case of the Greek island and in continuation, quantitative methods applied for the validation of the estimated data. These methods include a short and focused questionnaire and phone-calls with residents and local businesses which belong in the commercial sector in Astypalaia. The purpose of these methods are to provide a better and more realistic understanding of the energy system, the energy use, fuel types and energy sources to fulfill the demand in each sector. In addition, the questionnaires and phone calls made on a sample of resident and businesses of the commercial sector works as a validation mechanism. This is because the estimated data which were first obtained, are verified or mismatch with the information obtained from the quantitative research methods.

The combination of the above methods contributed to the -as realistic as possible- modelling and representation of the current energy system in Astypalaia. Thus the reference system modelled in this research is based on primary credible data (obtained from HEDNO) and secondary data and estimated data which are validated and assessed for their validity through the use of the qualitative methods described above. Based on results and input data for the reference scenario, alternative scenarios of SES are developed and modelled. A more detailed description of the method and tha data used as inputs for the reference scenario model is found in the Appendix A section.

In the same approach of dividing the energy sector in Astypalaia island to the residential and commercial energy sector, the background analysis of the Greek island is presented in chapter 5.

4.6 Modelling of Smart Energy System scenarios

In this section, the theories and the methodology applied for the modelling, simulations and the results of the alternative scenarios are described. For the formulation of concrete alternative scenarios and to proceed with the modelling and simulations in EnergyPLAN, firstly adequate RES technologies that are relevant and fit in the context of Astypalaia should be selected. It is important to ensure that the most adequate and feasible production technologies are applied in this research providing as realistic as possible scenario cases. For this reason this research proceeds with the establishment of criteria for choosing the most adequate technologies which fit in the context of the Greek island and the Greek environment.

In this research, the analysis and simulations are realized for both PV and Wind turbines as decided to be implemented in the alternative scenarios. In further detail, a set of 10 x 10 distinct RES capacities combinations are achieved, within a range of 0-1 MW.

In order to realize such a large number of different combinations and cases, an adequate energy tool for accomplishing this is used which is EnergyPLAN. It should be clarified that The RES capacities combined do not necessarily refer to actual and existing types of RES which are available in the market with these exact capacities. For instance, a wind turbine of 100 kW perhaps is not realistic to be implemented in this scale of a project. Nevertheless, for expanding the range of capacities and collecting a larger sample of results, the capacities examined in this research include values such as 0, 100kW, 200kW, 300kW until reaching 1000kW.

Furthermore, it is considered relevant in this research to investigate and include in the calculations these smaller capacities, since this project case concerns a small island in Greece for which smaller-scale installations might be preferable. The larger the variety of capacities in the simulations, the greater understanding will be gained regarding their influence on the SES.

Furthermore, the other factor according to which the scenarios are assessed is the different regulation strategies for the CEEP. The strategies implemented for the CEEP are important and may influence at a significant extent the employment and production both of RES and the existing power plant unit in a SES and for the case of Astypalaia. Each scenario and simulations of the energy system are realized both for the cases of i) reducing/balancing the power plant in combination with RES production and ii) for reducing/balancing power plant in combination with RES and also reduce the RES production in the first two groups (PV and wind turbine). These cases have been identified as the ones for maintaining the lowest fuel demand for diesel and for the existing power plant in Astypalaia. This is one of the principal objectives of this research to significantly decrease the imports of diesel-oil fuel. The CEEP regulation strategies are assessed and adjusted for each scenario in EnergyPLAN software which offers the possibility of such options.

Subsequently, the last factor which is altered in each scenario is the addition of energy saving measures which include the installation of heat pumps. In each scenario measures are implemented which concern i) substituting the individual heating demand covered from biomass boilers (fireplaces and heating stoves) of the reference scenario (0.23 GWh/year), ii) substituting the individual heating demand of the residential sector and the dining businesses and food catering services (1.035 GWh/year), iii) installing heat pumps for all the buildings as analyzed in this report (residential, commercial).

It is also important to mention that several other combinations and changes on the reference scenario could be made. These changes and the purpose that this research does not consider them in the scenarios are described in the discussion section 9.1.

4.6.1 Technology selection criteria

The applied criteria are defined through information gathered from literature research and by examining the characteristics of Astypalaia island and assessing the local resources.

This research is influenced at a significant extent from the theoretical frameworks and methods as discussed by Henrik Lund [2014]. In 'Renewable Energy Systems: The Choice and Modeling of 100% Renewable Solutions' a number of empirical examples and cases of energy investments, which took place in Denmark since 1982, are described. With these case studies as a basis, conclusions and guidelines are drawn regarding the criteria for establishing alternative energy scenarios.

The purpose for reviewing this criteria is to guide the decision-making process in this research. The guidelines for the decision-making process are the following:

• Alternatives should be equally comparable in terms of central parameters, such as capacity and energy production.

• Elements from all three aspects of renewable energy systems should be involved (savings in demand, efficiency improvements in supply and RES integration

• Direct costs correspond to those of the main proposal

These criteria define the foundations which are applied in this research for choosing and deciding the RES types employed in the modelling of the alternative SES scenarios. In parallel with these criteria, the local resources and potential should be examined and contribute to the development of feasible alternative scenarios.

4.7 Data management and categorization

In this research, the methodology in data gathering divides the data into primary data and secondary data. The primary data refers to the data which is obtained specifically to respond to the goals and needs of this research. The primary data can be collected through interviews, phone-calls, experiments etc. The secondary data refers to the data which is managed by other researchers and for other purposes which may differ from the purposes of this research. However, this data could be applied in this research case and provide estimations and approximations of data. Both of these data types are gathered and applied in this research while also validating these by the use of quantitative and qualitative. Phone-calls and e-mail correspondence with the local residents in Astypalaia can guide and improve the suitability of data for the purposes of this research. This method is extensively used for the modelling of the reference scenario and to -as realistic as possible- represent the energy system in Astypalaia.

For the modelling of the reference system and the Smart Energy System scenario the data is classified/distinguished in i) the technical data and ii) the economic data and according to David Connolly [2016]. Firstly, the two data categories are described and afterwards the data management and sources are presented and discussed. As acknowledged by David Connolly [2016], the technical data/parameters required as an input are the following:

• The total annual production/demand (TWh/year)
• The capacity of the unit installed
• The hourly distribution of the total annual production/demand

The economic data required an an input in EnergyPLAN to simulate the associated costs of an energy system can be classified in four basic categories:

• Investment costs: capital required, the lifetime of each unit, the interest rate on payments
• Fuel costs: purchasing, handling, and taxes in relation to each fuel as well as their CO2 costs
• Operation costs: the variable and fixed operation and maintenance costs for each production unit

As mentioned in section 4.5, the data collection and management involves the gathering of primary data and a combination of secondary data used in the research to contribute in the estimation of data required as an input in EnergyPLAN.

In Appendix A, the procedure of estimating data and inputting in EnergyPLAN software is described thoroughly. In the next chapter the analysis and background description of Astypalaia is realized.

The island of Astypalaia 5

This chapter focuses on Astypalaia island and its context description and analysis. The purpose of this is to provide sufficient background information which is to be considered for the next research stages and the modelling of the reference scenario and the alternative energy scenario.

5.1 General description and geographical information

Greece is a peninsular and mountainous country located in Southern-Eastern Europe. A characteristic of Greece is the vast coastline of 13.676 km which is the largest in Europe. This record is because of the abundant Greek islands which reach 2.000 in numbers while only 168 of them are populated. The Greek islands are divided according to their geographical location and the sea water area to : Crete, Cyclades, Dodecanese, Ionian, Sporades, Saronic and Eastern Aegean islands.[Greeka.com, 2018]

The Dodecanese island complex is in south-eastern Aegean Sea between the Cyclades island complex, Crete island and the coastline of Minor Asia (Turkey). It comprises of 18 larger and smaller islands and numerous islets. An island which belongs to the Dodecanese island complex is Astypalaia. The location of Astypalaia island is illustrated in figure 5.1.

Figure 5.1. Geographical location of Astypalaia island, source: Google earth

Astypalaia island is characterized by rough and rocky coastlines and mountains which are not significantly high. The highest peak is Vardia mountain at an altitude of 482m. The soil morphology of Astypalaia, as in the majority of the Dodecanese islands, is sterile and rocky. The are no rivers in the Dodecanese region but only only a number of areas with streams.[Greeka.com, 2018]

The population of the island according to the last census realized in 2011 equals to 1334 residents. The municipality of Astypalaia has an area of 114077 km per square. A small area of land of approximately 126 metres wide almost divides the island in two sections. There are 4 villages on the island which are the villages of 'Astypalaia' or 'Chora', 'Livadi', 'Analipsi' or 'Maltezana' and 'Vathi'. The village of 'Chora' has the largest amount of people and most of the islands life is concentrated there.[Astypalaia.com, 2018]

5.1.1 Indigenous resources and local potential

The indigenous resources and the local potential in the island of Astypalaia include the wind dynamic and the solar irradiance. These two elements are described below and the purpose is to argue about the selection of RES that are implemented in the alternative SES scenarios. Furthermore, the geography and soil morphology (highest elevation point etc.) in of the Greek island of Astypalaia have been already examined in section . This could play an important role in the identification and employment of the most relevant and practically feasible storage solutions (hydro pump storage).

The technologies chosen in relation with the elements mentioned in this section are described in section 7.4. In the following, a description of the strengths, the indigenous resources and the local dynamics in Greece and in Astypalaia are described.

As can be seen from the figure 5.2, in Astypalaia the average annual sum of PV output is in the range of 1600 to 1700 kWh/kWp. It is observed that there is a high potential for implementing PV technologies, as the solar irradiance is significantly high and for most of the Greek islands. Hence, RES technologies which harness the solar irradiance should be considered in the design of the alternative scenarios.

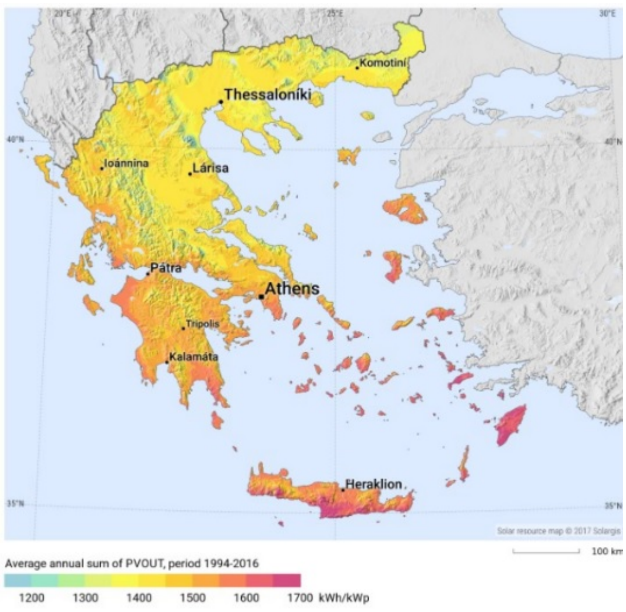

Figure 5.2. Average annual sum of PV output for Greece, source: Solargis

Assessing the wind potential and focusing on the Dodecanese region and the geographical location of Astypalaia as shown in figure 5.1, useful information is obtained from figure 5.3. As illustrated, in general the majority of the Greek island and with specific focus in Astypalaia, there are encountered the highest values of average annual wind speed. Astypalaia is in the range between 8 to 9 m/s. This range is placed between the highest values of average annual wind speed. This is and indicator for this research to also consider this fact in the process of choosing RES technologies for the alternative scenarios.

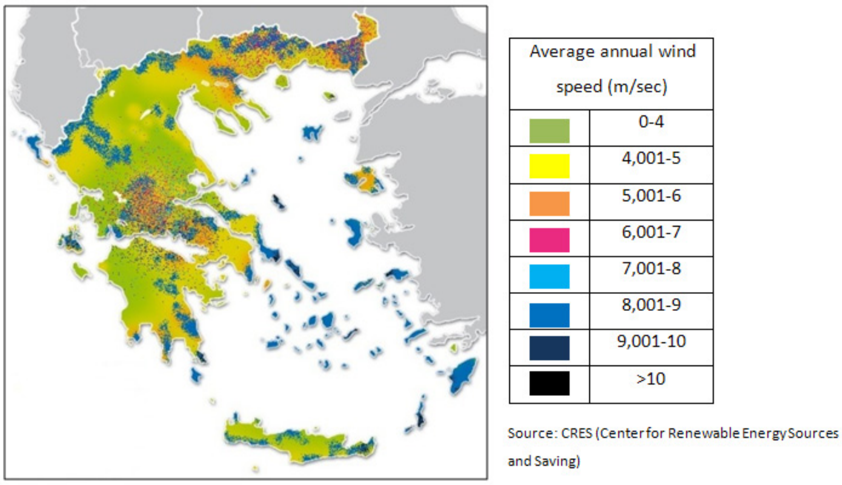

Figure 5.3. Average annual wind speed in Greece

5.2 Energy system analysis

According to Maria Chalakatevaki, Paraskevi Stamoy, Sofia Karali, Vasiliki Daniil, Panayiotis Dimitriadis, Katerina Tzouka, Theano Iliopoulou, Dimitrios Koustoyiannis, Panos Papanicolaou, Nikos mamassis [2017]; Daniel Friedrich, Goerge Lavidas [2015]; General Directorate for Regional Agricultural Economics and Veterinary [2014], the island of Astypalaia is not connected to the mainland electricity grid or to any other neighbouring island grid for security of supply. This means that there are no imports or exports of electricity. The current energy infrastructure involves exclusively electric energy production by oil-fueled power units operating in Astypalaia.

As acknowledged by HEDNO and by information concerning the year 2017, the energy system of Astypalaia island consists of 3 oil-fueled power generation units of licensed power 1.1 MW and nominal power of 1.275 MW each. According to General Directorate for Regional Agricultural Economics and Veterinary [2014],the energy infrastructure consists almost exclusively of the electricity network and the oil-fueled power generation units which are constructed by the PPC, the biggest electric power company in Greece. The input fuel is diesel and the technical information of the power units is presented in figure 5.2.

Unit Number	Unit Type	Licenced Power (MW)	Nominal Power (MW)	Mixed (MW)	Technical Minimum / Power (MW)	Fuel	Specific Consumption (kg/MWh)		
							50%	75%	100%
1	MITSUBISHI S16R-PTA	1.1	1.275	1.1	0.637	Diesel	229.41	220.82	219.85
2	MITSUBISHI S16R-PTA	1.1	1.275	1.1	0.637	Diesel	229.41	220.82	219.85
3	MITSUBISHI S16R-PTA	1.1	1.275	1.1	0.637	Diesel	229.41	220.82	219.85
	ΣΥΝΟΛΟ	3.30	3.83	3.30					

Figure 5.4. Technical characteristics of power generation units in Astypalaia for the year 2017

5.2.1 Heating and cooling sector

An examination of the heating and cooling sector provides useful information which is to be taken under consideration when modelling the reference system. Apart from outlining the heating and cooling demand of Astypalaia island, it reveals useful information about the energy infrastructure of the island and may influence the development of the alternative solutions.

Currently in Astypalaia there is no district heating network and the heating demands are exclusively covered by individual heating sources. The heating demands of Astypalaia island in relation with the end-use type can be classified to the i) space heating demand, ii) domestic hot water demand and iii) heating demands for cooking purposes.

The space heating demand appears mostly in the winter months from early November to March. Electric heating, heating stoves and fireplaces are mostly utilized for fulfilling the space heating demand in the residential and commercial sector. Mostly wood and to wood chips are used in the residential sector for fulfilling the space heating demand.

In the commercial sector the space heating demand is almost exclusively covered by electric heating through air-conditioning units. In order to obtain a more detailed illustration of the heating demands and types of fuels and end-uses, a description of a typical residence in Astypalaia and of the services in the commercial sector are realized in sections 5.3 and 5.4 respectively.

According to General Directorate for Regional Agricultural Economics and Veterinary [2014] and as validated from the data obtained through questionnaires and phone-calls with local residents, for fulfilling the domestic hot water demand two different energy options are utilized. The one concerns the use of solar energy and solar water heaters (solar thermal collectors) which is commonly encountered in both the residential and the commercial sector. The other energy option for fulfilling the domestic hot water demand is the use of electric heating. In figure 5.3 the solar thermal collectors are illustrated in red circle.

Figure 5.5. In red circles are shown a number of solar collector installations in Astypalaia

As far as the heating demand for cooking, electric kitchen is mostly used in the residential sector and in the majority of the hotels and studios of the island. In the commercial sector and in the restaurants, according to the investigation of a small sample of restaurant managers in Astypalaia, the use of LPG propane is common and intended for the kitchen stoves and the grills.

A typical restaurant in Astypalaia presents a demand of 30 to 40 LPG propane tanks per year and each tank capacity in most cases is 25kg. From information acquired from the hotel and studios managers and local residents, all the respondents outlined that electric kitchen is mostly used. Thus, this report assumes that the use of LPG fuel is exclusively for the restaurants operating in Astypalaia and the rest of the demand for cooking purposes is covered through electricity.

The cooling demand on the island is needed during the summer months from June to September. It is exclusively covered through the use of electric air-conditioning units and in some cases the use of electric fans for individual use. The use of electricity for cooling but also in general the higher energy consumption is noticed during the summer season and it can be related to tourism and the high numbers of visitors.

In the following sub-sections a more detailed description of the two sectors (residential, commercial) in which this research focuses on, is achieved.

5.3 Residential sector analysis

Analyzing the residential sector and a typical residence building of Astypalaia island is necessary and significantly contributes in this research and for the data estimations for the modelling of the reference scenario. A thorough analysis of a typical residence building provides greater understanding of the indoor and outdoor space, the total floor area, the energy sources in the final energy consumption and common types of end-uses of energy. By comprehending and obtaining a concrete and realistic image of a typical residence, this research can proceed in a -as realistic as possible- development of a reference scenario which closely represents the island context in present.

5.3.1 Typical residence in Astypalaia island

A typical residence in Astypalaia is considered as a two-floor building of a total area ranging from 50-60 square meters. A typical traditional house can be divided in 2 communication levels. Level 1 includes a kitchen with a refrigerator and a cooking stove, a living room/dining room and a bathroom. Level 2 includes a large double bedroom in an elevated area, and a single bed in the living room, storage space and access to the balcony [homeaway.gr, 2018]. In figure 5.4 a typical residence is presented.

Figure 5.6. Typical residence in Astypalaia. In red circle is shown the electric kitchen and the heating stove

5.3.2 Fuel utilization and end-uses of energy

From documentary evidence obtained from the distributed questionnaires to the local residents, it is observed that electricity fulfills the largest part of the annual energy demand. The residential electricity consumption can be classified in different end-uses. Commonly encountered end-uses include the lighting, electric kitchen stove, refrigerator, electric boiler or solar thermal heating (solar water heaters) for domestic hot water, electric heating and cooling (air-conditioning) and other appliances. In many cases there is a fireplace or heating stoves burning wood or wood-chips.

5.3.3 Number of residential customers in final energy consumption

The total number of inhabitants in Astypalaia island is 1334, according to the most recent population census realized in 2011 by the Hellenic Statistical Authority. Since there is no concrete information about the number of persons per household, this research assumes that 3 persons live on average per household. This assumption is done based on the description of a typical residence in Astypalaia and the rooms available (one double bedroom, one singe bed). Thus, the total number of residential customers of electricity is approximately 445 residences. This is taken into consideration for the calculations and modelling of the reference scenario.

In the following sub-section data regarding the energy consumption in the residential sector are presented and the methodology for the data estimations is thoroughly described in the Appendix.

Data for the energy consumption in the residential sector

Residential sector		
Total number of inhabitants in Astypalaia island	1334	
Annual electricity consumption per capita in Greece (Eurostat source)	1.6	MWh
Total annual electricity demand	2.13	GWh
Total annual electricity demand for heating	0.26	GWh
Total annual electricity demand for cooling	0.09	GWh

Figure 5.7. Data for the residential sector in Astypalaia

The data presented in table 1 is considered for the year 2017 while the estimations for the electric heating and cooling demand are based on statistics for Greece and for the year 2016. Since the data for the final energy consumption in relation with the type of end-uses for Astypalaia or any other island of a similar context could not be found, the statistics for Greece average residential consumption obtained from Euro-stat are applied for the purposes of this research.

5.4 Commercial sector analysis

In this section an analysis of the commercial sector of Astypalaia and its consisting components is performed. An investigation of the commercial sector in Astypalaia and its energy system is necessary particularly for i) outlining the total number of the consisting components of the sector in Astypalaia, ii) identifying primary sources of energy used and fuel utilization in each of the consisting components of the sector, energy demands, common types of end-uses, iii) proceed to realistic estimations of energy demand and input fuel which realistically represent the commercial sector of the Greek island, iv) input the collected secondary data or estimated data in EnergyPLAN calculations and summing it up with the residential sector data to calculate the total energy demand of the island. The calculations for the modelling of the reference scenario are described in the Appendix.

5.4.1 Consisting components and existing infrastructure in Astypalaia

For identifying the consisting components of the commercial sector in Astypalaia island, firstly the definition of the term 'commercial sector' is described. A detailed definition is given from the Nuclear Regulatory Commission of the United States, which defines the commercial sector as all the non-manufacturing enterprises, including hotels, motels, restaurant, wholesalers and retail stores, health, social and educational institutions.

This research adopts this definition and seeks to identify information about these components of the commercial sector in Astypalaia. Hotels and other types of accommodation, dining businesses and food catering services, cafe bars and the schools in Astypalaia island are considered in the modelling of the reference scenario. Under the light of the above mentioned evidence and based on these definitions, this research initially seeks to investigate the commercial sector of Astypalaia island and outline the total number of enterprises.

According to General Directorate for Regional Agricultural Economics and Veterinary [2014], the tourist infrastructure is developed in all the 4 villages of Astypalaia. 'Maltezana' or 'Analipsi' is characterized as the resort with the largest tourist action. In this village the largest number of accommodation services for tourists and visitors are situated (such as hotels, hostels, rooms to let, etc.) and also food and catering services such as restaurants or smaller typical restaurants and taverns, and other shops that serve tourists.

From data obtained from General Directorate for Regional Agricultural Economics and Veterinary [2014], the existing infrastructure in Astypalaia for visitors and tourists accommodation is shown in figure 5.4.1.

Accommodation type	Units	Rooms	Beds
Hotels	16	235	459
Other accommodation	87	440	990
Total number of services	103	675	1449

Figure 5.8. Existing accommodation infrastructure for tourists and visitors in Astypalaia, source: Hellenic Chamber of Hotels

As also mentioned by General Directorate for Regional Agricultural Economics and Veterinary [2014], the visitors and tourists of Astypalaia island usually dine at the hotels or other accommodation types of the area or to the restaurants and taverns of the island. According to the Hellenic Statistical Authority (ELSTAT), on the island of Astypalaia are active 64 businesses for dining and food catering services.

Conclusively the total number of hotels and other accommodation types, restaurants and taverns, and school building is known. The purpose of this approach is to describe separately the background regarding the energy consumption and energy sources utilized in each of these components of the commercial sector on the island. Thus, the data inputs in EnergyPLAN for the modelling of the reference scenario are more accurate, representing the current situation.

In the next sub-sections the context in each of the consisting components of the commercial sector is described. This information is taken into account during the calculations and data assumption methods for estimating the total energy demand of the commercial sector. Eventually, the sum of total energy demand of the residential and the commercial sector shows the total energy demand of Astypalaia island.

5.4.2 Typical hotels and other accommodation services

It is noticed that the hotels and other accommodation services in Astypalaia island use electricity as the principal source of energy. From the online research and as validated by the 5 hotel managers during the phone-call discussions, the majority of hotels and other accommodation types include electric boilers or thermal water heaters to fulfill the domestic hot water demand. Electric air-conditioning is utilized for space cooling and heating, while all the examined accommodation services include electric kitchen, TV and other appliances. There is no other fuel used in the final energy consumption of the sector. The operating period for all the services in the accommodation sector is from April to late October.

The average typical profile of a hotel or other accommodation type includes a number of different rooms and studios. Traditional houses which are accumulated to the natural and typical environment prevailing in Astypalaia are commonly encountered. The distinct rooms and their floor areas are ranging from 30 to 70 meters squared. As stated by the manager of a hotel ('Astypalaia Villas'), in traditional buildings the installation of solar collectors or solar thermal water heaters on the roof of the building is prohibited. However, this is the case for an unknown number of hotels or other types of accommodation, or even individual residences. Since, it is not possible to contact separately each manager for every hotel or other accommodation type and summarize the information for the whole sector, the method in which the energy demands and data assumptions are completed, is described in the Appendix.

5.4.3 Typical dining businesses and other food catering services

The majority of dining businesses and food catering services in Astypalaia consists of large open areas. Obtaining documentary evidence through phone-calls with a number of restaurant and cafe bar managers, it is found that on average, a typical restaurant in Astypalaia consists of a total floor area of 120-160 meters squared with indoor and outdoor area to have 40 to 80 and 40 to 100 meters squared respectively.

After phone-calls and short discussions with a number of restaurant managers, it is found that the fuels in the final energy consumption for a restaurant in Astypalaia on average, are electricity and LPG (propane gas). Electricity covers the majority of end-uses and LPG directed for cooking appliances such as the kitchen stoves and grills. As it is acknowledged from the phone-call discussions, the estimated annual consumption of LPG (propane) tanks on average is ranging between 30-40 tanks of 25kg each. According to elgas.com [2018], 1 kg of LPG (Propane) equals to 49 MJ and 1 MJ equals to 0,278 kWh. Thus the calculations for the annual LPG (propane) demand for the restaurants and cafe bars can be estimated and explained in the Appendix.

Concerning the heating and cooling of the space, there is no significant demand as the outdoor area is an "open space" are and the restaurants operate at the maximum extent during the summer season. Since the area is outdoor, the majority of restaurants and taverns do not have significant cooling demand and electric cooling demand via air-conditioning units. Nevertheless in some cases there might be individual fans for ventilation or cool wind flow. For this reason it is assumed that there is no significant cooling demand to be taken under consideration. The same applies for the space heating as during summer there is no demand and during the winter the restaurants are operating at the lowest extent if not closed. The figure 5.7 illustrates the description of a typical restaurant in Astypalaia.

Figure 5.9. Typical outdoor space area in a restaurant in Astypalaia

5.4.4 School buildings in Astypalaia

The school buildings, constructed in stone, consist of four halls, a cabinet manager and teachers and toilets. Nowadays the school, preserved and renovated has six classrooms, IT rooms, integration department, arts room, director's office, teachers' office, multi-purpose room, Infrastructure for people with disabilities. This evidence is capable for providing an overview of the school building floor area, even though the total square meters are unknown.

Regarding the energy sources in the final energy consumption, the schools in Astypalaia are assumed to fulfill their annual energy demands exclusively by the use of electricity. The assumptions and secondary data obtained and applied in the modelling of the reference scenario are described in Appendix section A.1.1.

In the following chapter, the reference scenario is presented and described and the analysis of results is realized.

Reference scenario 6

6.1 Introduction

According to the analysis structure of this report and as described in section 4.1, in order to examine and compare different energy scenarios it is necessary to develop a model of the current energy system of Astypalaia. The development of the reference scenario contributes to this research by providing the data according to which the alternative energy scenarios are to be compared.

The reference scenario objective is to represent -as realistic as possible- the current energy system of Astypalaia island. To achieve this research objective and develop an acceptable reference scenario model, the most recent and accurate primary data are chosen. In some occasions, collecting accurate and reliable primary data has been challenging and therefore secondary data obtained from other reports is applied. The secondary data is chosen according the relevance with the case of the reference scenario modelling for a Greek island. Furthermore, in a number of cases, adjustments in the energy system are made. These adjustments are made in cases where there is no sufficient data of the energy system of Astypalaia and according to the available inputs in EnergyPLAN.

In further detail, these adjustments concern the treatment of electric boilers as electric heat pumps, the biomass boilers considered as heating stoves and fireplaces and the natural gas boilers considered to consume LPG propane fuel as an input. The adjustments are made to ensure a functional operation of the EnergyPLAN tool and to secure comparability in the assessment of the proposed alternative energy scenarios.

This report neglects the industrial and transport sectors due to lack of available data and because the main focus and priority is attributed to the residential and commercial sectors, as described in delimitations section 3.4. The residential and commercial sectors have a significant impact on the energy demand profile of the Greek island compared to the transportation and industry. In the commercial sector are considered specific services for the calculations for the reference scenario which are the hotels and other accommodation types, dining businesses and food catering services and the school buildings of the island.

The inputs considered for the reference scenario, the description of these, the modelling process and the assumptions made are described in the Appendix, sections A.1 to A.4.

As described in section 4.1, the principal research objective is to compare all the examined scenarios according to the technical, economical and environmental performance. Moreover, in order to achieve the decarbonization of the energy system of Astypalaia island, it is necessary to examine the share of RES in the total primary energy supply and assess the economical costs of an energy system principally based on RES. According to the above mentioned parameters, the reference scenario is examined for the following criteria:

- Primary energy supply, demand side and fuel demand (excluding RES)
- Critical excess electricity production (CEEP) • Total annual costs
- Renewable share in the final electricity production
- CO2 emissions

The simulation of the reference scenario is achieved by a technical simulation which balances the heat and electricity demands in EnergyPLAN tool.

6.2 Reference scenario analysis of results

In this section the results from the technical simulation of the reference scenario in EnergyPLAN are presented.

6.2.1 Primary energy supply, demand side and fuel demand

In Astypalaia island and as described in the energy system analysis in section 5.2, the electricity production is exclusively achieved by the thermal power station operating on the island. The fuel input is diesel oil. For the year 2017, the total annual electricity production is 6.56 GWh. The electric heating and electric cooling are accounted for 1.02 GWh and 0.28 GWh respectively. The hourly electricity demand is shown in figure 7.1 for the year 2017 and the data for the electricity demand are presented below.

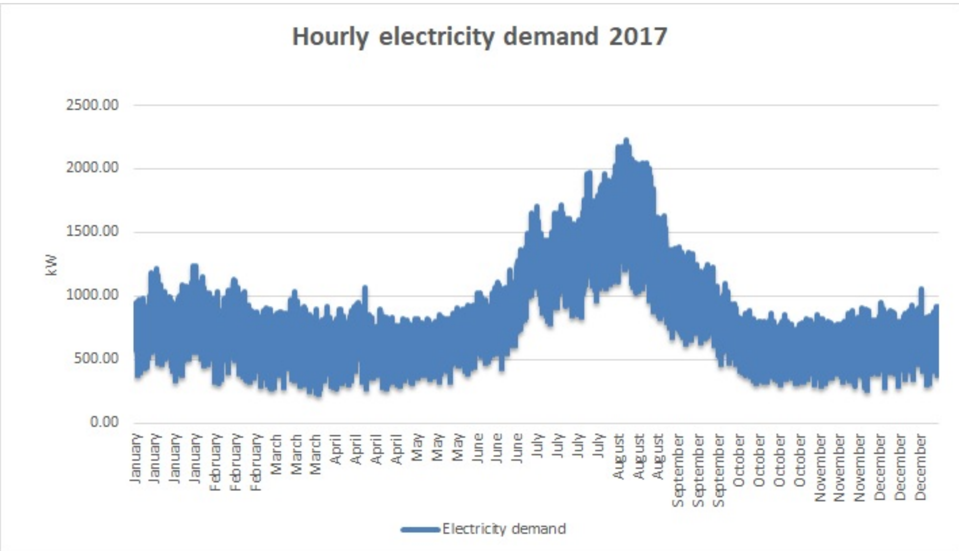

Figure 6.1. Hourly electricity demand in Astypalaia for the year 2017, source: Hellenic Electricity Distribution Network Operator S.A (HEDNO)

As it can be observed from the figure, the electricity demand is significantly higher during the summer months. This fact is related with the touristic season and the increased numbers of visitors in Astypalaia. Moreover, according to calculations in Excel spreadsheets (MAX and MIN formulas), the highest value within the hourly electricity demand of 2017 was 2224 kW and recorded in August, while the lowest value was 241 kW and recorded in March. The average load for the year 2017 was 748.90 kW and calculated using the formula function 'average' in Excel spreadsheet for all the hourly load values.

The heating production in Astypalaia is based exclusively on individual heating solutions. Currently there is no district heating infrastructure in Astypalaia island. Heating stoves and fireplaces are accounted for fulfilling the individual heating demand. An adjustment is made at this point since in EnergyPLAN there is no specific option for fireplace or heating stoves. Therefore, a biomass boiler is assumed to represent the fireplaces and heating stoves.

The total individual heating demand is 1.25 GWh/year and is mostly coming from the residential sector. The services of the commercial sector such as hotels, dining businesses and food catering services operate during the summer season. Thus this report assumes that there is no significant heating demand. Regarding the school buildings in Astypalaia, it is assumed that the heating demand is covered from electric heating units.

The fuel input for fulfilling the individual heating demand is 0.46 GWh/year with an assumed efficiency in biomass boilers of 0,5. This results in a heating demand covered by boilers of 0.23 GWh/year.

Another type of heating demand for the reference scenario comes from the commercial sector and the dining businesses and food catering services. This type of heat demand in the reference scenario is classified as the heating demand for cooking purposes which include the kitchen stoves and grills. These operate based on LPG propane as an input fuel. The estimated annual LPG propane demand equals to 0.87 GWh/year. In EnergyPLAN, this is assumed to be covered from natural gas as there is no option for LPG as an input fuel for this purpose.

The electric heating demand which is both for domestic hot water and to some extent space heating in all sectors is 1.02 GWh/year and is achieved by electric boilers or solar water heaters (solar thermal collectors) and via electric air-conditioning units respectively. Since the data for the solar thermal share is not reliable and accurate, it is chosen to consider only electric boilers for the modelling of the reference scenario.

Based on the total heating demand value and the number of buildings considered under the scope of this report, the heat demand per building is found to be 2035 kWh/year to respond to 614 units of individual households. Breaking down the 614 units, the residential customers are 445, the hotels and other accommodation types buildings are 103, the school buildings are 2, and the dining businesses and food catering services are 64.

The cooling demand is individual and is covered from electric air-conditioning units and in some cases from electric fans for ventilation and cooling. However, since there was a difficulty in collecting the share of electric fans in the total electric cooling demand, it is assumed that electric air-conditioners (AC) cover the total electric cooling demand.

The electricity for cooling is 0.28 GWh/year which gives an estimated cooling production of 0.56 GWh/year. In addition, in EnergyPLAN and in the individual cooling section, the coefficient of performance (COP) of the system should be defined. According to Power Knot LLC [2010], typical COP values for air conditioning systems are in the range 2 to

4. In this report and as also already set in EnergyPLAN tool, the COP of the electric air-conditioning units is assumed to be 2.

The total annual fuel demand which includes the power plant fuel demand, the biomass boilers fuel demand and the LPG fuel demand, is calculated to be 15.91 GWh/year. Breaking down the demand according to the utilization unit, the power plant fuel demand is 14.58 GWh/year, the individual households fuel demand for biomass boilers is (as already mentioned) 0.46 GWh/year and the LPG demand is 0.87 GWh/year.

6.2.2 RES share

In present, there are no RES operating in Astypalaia island and thus the share of RES in the primary energy supply is 0%. Nevertheless, in EnergyPLAN and as the adjustment of considering biomass boilers to represent the fireplaces and heating stoves, the RES share in the primary energy supply holds 2.9% for heating demand and 0 GWh of electricity produced out of RES.

6.2.3 CO2 emissions

The power plant and its fuel consumption (diesel oil) are accounted for 3.86 kt of CO2 emissions, while the natural gas boilers, which represent the LPG propane consumption in restaurants, are accounted for 0.18 kt of CO2 emissions per year. The total value of CO2 emissions per year of the reference scenario is 4.04 kt of CO2.

6.2.4 Total annual costs

For the reference scenario and according to the scope of this research, the socio-economic cost analysis is realized. These socio-economic cost calculations include the investment, the fixed and variable O&M for the total number of technologies used, the fuel costs and the CO2 costs.

All of the costs are annualized based on the lifetime of the technology, assumed to be 15 years in this report and this assumption is based on David Connolly [2015]. It should be mentioned that this number might refer to the power plant technologies as operating in the Danish context and thus the lifetime of power plant for the Greek context might deviate from this number.

The interest rate considered for the calculations is 4,27% and it is chosen as it represents the long term interest rate in Greece and according to ycharts.com [2018]. It should be clarified that this interest rate included in the calculations is valid for the month of March 2018.

The annual investment costs and the fixed operation costs are mostly accounted for the total annual costs. The total annual costs are 2033000 EURO and the annual investment costs and the fixed operation and maintenance costs are 1007000 EURO and 431000 EURO respectively.

Smart energy system and alternative scenarios 7

In the first analysis stage and as described in section 4.1, the objective is to create a reference scenario which represents the current energy system in Astypalaia. The reference system is modelled in EnergyPLAN and analyzed accordingly in section 6. In this chapter this research proceeds to the second analysis stage. The objective is to analyze alternative scenarios for energy provision in Astypalaia which are able to substitute the reference scenario. Therefore in this chapter a SES is developed which is based on the theoretical concept described in section 4.2. In order to decide which are the conditions and technology combinations employed in the SES which are adequate for substituting the reference scenario, it is necessary to analyze and compare distinct alternative SES scenarios. These alternative scenarios incorporate different combinations of RES types and capacities, new end-uses on the demand side and other adjustments in the energy system, such as the storage facilities, energy saving measures and regulation strategies with the scope to minimize the excess electricity produced. Further description of these is provided in section 7.3.

The purpose of this analysis stage is to assess the ways in which these diverse combinations of RES technologies and capacities, storage system facilities and modifications in the demand side may influence the smart energy system performance and in particular the technical, economical and environmental performance. The result of this comparison is to identify the most efficient solutions to be employed in each of the developed SES scenarios with the most advantageous outcomes regarding the overall performance of the system. Conclusively, one combination of technologies is attributed to each of the SES scenarios developed and compared with the reference scenario.

7.1 Analysis focal points

In further detail, the focal points of the analysis are to achieve a decrease in the fuel demand of the power plant in Astypalaia, identify the lowest CO2 emissions scenarios, examine the critical excess electricity production (CEEP) and potential for creating new end-uses and increase the share of RES in the final electricity production and ranging from 60 to 70%.

In order to obtain information and draw conclusions regarding these focal points, this analysis stage proceeds with the simulation of scenarios in EnergyPLAN. The output results from EnergyPLAN are grouped in tables in excel spreadsheets for each SES scenario and for each parameter changed . The simulations provide a range of outputs (fuel demand excluding RES, CEEP, total annual costs, CO2 emissions and RES share in the final electricity production) from which the results are compared between them. The comparison is achieved by the creation of graphs and tables which illustrate these parameters for each RES capacity combination and for the modifications made in each SES scenario. The results are presented in chapter 8 following by the identification of uncertain factors in this research and a discussion for sensitivity analysis in chapter 9. The project summary, the discussion and the conclusions are presented in chapter 10. In section 7.2 a brief analysis of the technologies and their technical characteristics is realized.

7.2 RES technologies and storage system

A brief description of each technology follows. The following technologies are considered possible for implementation in the examined SES scenarios for Astypalaia island. The reason for choosing these technologies is the analysis of local potential and local resources in Astypalaia described in chapter 5.

Wind Turbines

A wind turbine belongs to the group of RES which harness the kinetic energy of the wind and convert it into electrical energy. The design of wind turbines varies regarding their size and type. In this case and for the SES scenarios large wind turbines are considered. Wind turbines are becoming a significant source of energy and are employed in several energy systems with the scope to decrease their dependence on fossil fuels. According to Evans A., Strezov V., Evans T. [2009], the wind turbines present the lowest relative GHG emissions and the most advantageous social outcomes when compared with other RES types.

PV

The photovoltaics (PV) are sources of energy which utilize the solar irradiance in order for energy production. The conversion of the solar irradiance into electricity is achieved through the use of semiconducting materials and the photovoltaic effect. Components of a PV system are the modules or solar panels which are accounted for the energy production. As stated by Lo Piano S., Mayumi K. [2016], PV systems do not emit any GHG emissions and it presents simple scaling of the energy produced.

Hydro pump storage

According to Shafiqur Rehmana, Luai M.Al-Hadhrami, Md. Mahbub Alam [2015], the pumped hydro energy storage is a storage technology in a firm position in the markets and widely used for utility-scale electricity storage. Its storage capacity and the flexibility that characterizes this technology results in the grid stabilization and enhances the implementation of RES like PV and Wind [Shafiqur Rehmana, Luai M.Al-Hadhrami, Md. Mahbub Alam, 2015].

Regarding its operation, the pumped hydro storage pumps water from a reservoir which is situated in lower heights and drives it to a higher level reservoir. When there is the need for electricity production to fulfill the demand, the water is released from the higher reservoir to the lower reservoir. In between the reservoirs is a turbine which utilizing the water flow it produces electricity. As stated by Shafiqur Rehmana, Luai M.Al-Hadhrami, Md. Mahbub Alam [2015], this technique is one of the most cost-effective techniques for electricity storage. This is because the low cost electricity in off-peak times could be used to run the pumps of the system and store the water at the higher reservoir. As precisely acknowledged and stated by Shafiqur Rehmana, Luai M.Al-Hadhrami, Md. Mahbub Alam [2015], a site having sufficient water available is adequate for the installation of such a technology.

According to the description of Astypalaia island in chapter 5, the area is ideal for the installation of such a storage system as it includes both the elevation factor and it is an island surrounded by water.

Individual heat pumps

According to U.S Department of Energy [2018], the heat pump systems are an ideal energy saving solutions especially in climates with mild heating and cooling demands. Heat pumps may offer energy-efficient solutions and substitute air-conditioners but also provide heating load during the winter.

Principals of operation are the use of electricity as an input to transfer and drive the heating or cooling load where it is required. Heat pumps are capable for fulfilling the space conditioning demand and in a more cost-effective price in comparison with other conventional heating or cooling units.

7.3 Modelling and analysis of SES scenarios

The scenarios in this research are developed based on a number of possible functions in EnergyPLAN tool and the allowance of setting differently the inputs in this simulation tool. An explanation of these characteristics is achieved in the following sub-sections. The inputs which are changed in each scenario are the following:

- Regulation strategies for the management of critical excess electricity production (CEEP),
- Electricity grid stabilization share
- Energy saving measures and individual heat pumps
- Combination of distinct RES capacities
- Storage facilities and integration of hydro pump storage

7.3.1 Critical Electricity Excess Production (CEEP)

The power production achieved from the utilization or RES technologies in an energy system does not necessarily match the demand in every hour of the year. The RES as intermittent power production sources and with the output values to fluctuate significantly depending on the weather conditions, present an uncertainty of matching the power produced at every hour with the demand. Often there are cases where the electricity production exceeds the demand, and this results in the production of surplus electricity. This amount of power produced exceeding the demand profile is termed as Critical Excess

Electricity Production (CEEP) and it shows the amount of surplus electricity produced and not utilized in an energy system.

In this research it is chosen to analyze the CEEP in the SES scenarios and assess the potential for its utilization in other sectors and new end-use types. As mentioned in section 2.5, in the development plans regarding the Greek islands and specifically the island of Astypalaia, one future goal is the electrification of the transport sector. This is a potential new type of end-use and in relation with the excess electricity produced from RES which could be utilized for the electrification of the transportation sector. However, since the transport sector is delimited from the scope of this research and the modelling of the reference scenario, the use of CEEP and the potential new end-uses in the transportation sector are only discussed in section 10.1. This research attempts to identify the SES scenarios and the adequate RES capacity combinations leading to the lowest amount of CEEP and in a second stage the potential uses of CEEP are discussed.

The CEEP is possible to be managed according to factors which concern the operation and management of the power production technologies of an energy system. In the case of Astypalaia energy system, the CEEP relates to the power plant and the RES employed in the SES scenarios. There are several regulation strategies which could be implemented with the purpose to control and minimize the CEEP. These regulation strategies and the management of the CEEP include the reduction of power plant operation in combination with RES, the reduction and balancing of RES groups and other strategies concerning the operation and control of power production technologies employed in an energy system and other strategies which function as a 'break' and 'harmonization' tool for the power production technologies of an energy system. These regulation strategies and different operation ways of the power production technologies may have an important influence in the CEEP of the SES scenarios and a consequent impact on the technical, economic and environmental performance of the examined energy systems. For this reason, it is chosen to assess the CEEP regulation strategies and examine their influence on the overall performance of the energy systems designed in each SES scenario. This leads to the identification of a CEEP regulation strategy which responds in the greatest level to the preferable outputs as established for this research and concerning the technical, economic and environmental performance of the energy systems in the SES scenarios.

According to the description and purposes of using the EnergyPLAN tool in section 4,4, it is possible to decide for different CEEP strategies and simulate the performance of the energy systems in each SES scenario, examining the influence on the overall performance of the system. The CEEP strategies are an available function in EnergyPLAN and 4 different cases are firstly examined and in relation with the employed production technologies in the energy system. The wind power capacities of 0-1MW and PV capacities of 0-1MW and for each of the 4 different CEEP regulation strategies are analyzed. The purpose is to assess at a smaller RES capacities combination range the first signs of potential impacts that these strategies have on the technical, economical and environmental performance of the system. The purpose of this analysis and comparison of CEEP regulation strategies is to identify the ones for which the fuel demand and the CO2 emissions are the lowest. The CEEP regulation strategies which present the lowest fuel demand for the power plant and thus the lowest CO2 emissions (which are related to the input fuel for the power plant) are chosen to be implemented in the modelling and simulations of the SES scenarios. This is because from the research objectives in this research, principal goal is the decarbonization of the energy system in Astypalaia and the reduced operation of the power plant.

In EnergyPLAN the implementation of the CEEP regulation strategies is represented by numbers ranging from 0-9. Each of these numbers represent a specific regulation strategy. In this research the CEEP regulation strategies followed concern the following:

- 0: No regulation strategy for CEEP
- 1: Reducing the RES groups of Wind and PV
- 7: Reducing the PP production in combination with RES
- 17: Combination of the regulation strategies 1 and 7

These CEEP regulation strategies chosen for this research case are relevant with the power production technologies employed in the SES scenarios. The rest of the numbers representing the distinct CEEP regulation strategies from 2-9 concern the operation of power production technologies which are not employed in the SES scenarios, and thus are neglected in the calculations.

In order to examine the influence of the CEEP regulation strategies with the technical performance of the system, a simulation is realized of PV and Wind power capacities in relation with the fuel demand and under the implementation of the above mentioned CEEP regulation strategies. The purpose is to identify which strategy is related with the least fuel demand. The strategies presenting the lowest fuel demand are applied in the simulations of the SES scenarios. This is relevant with the decreased operation of the power plant and the reduction of the CO2 emissions which are strictly related with the fuel demand for oil.

In figures 7.1 and 7.2 the fuel demand in GWh/year excluding RES is illustrated in relation with the power capacities for wind and PV, ranging from 0 to 1000 kW, and for each of the CEEP regulation strategies mentioned above.

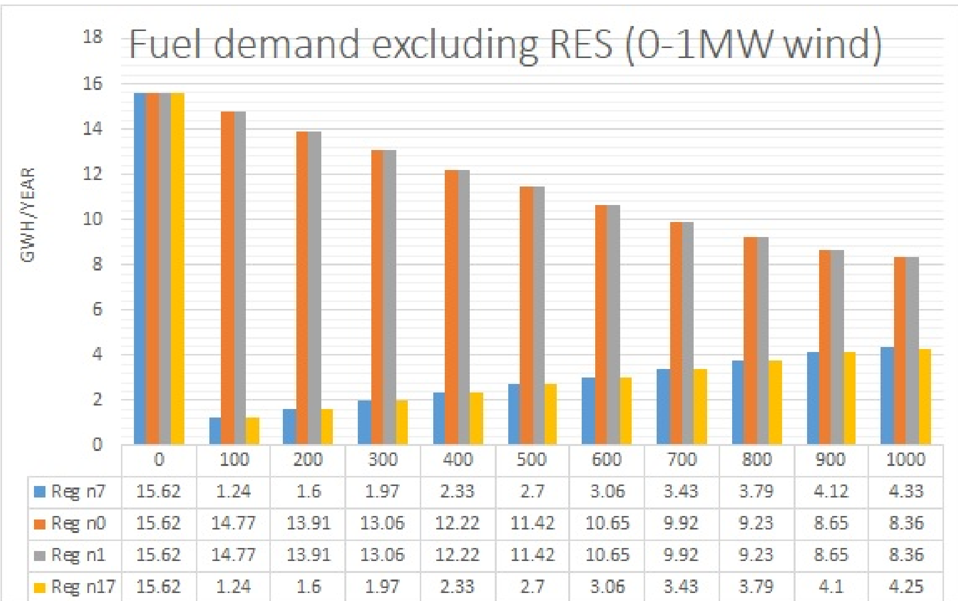

Figure 7.1. Fuel demand excluding RES and for wind power capacities ranging from 0 to 1 MW

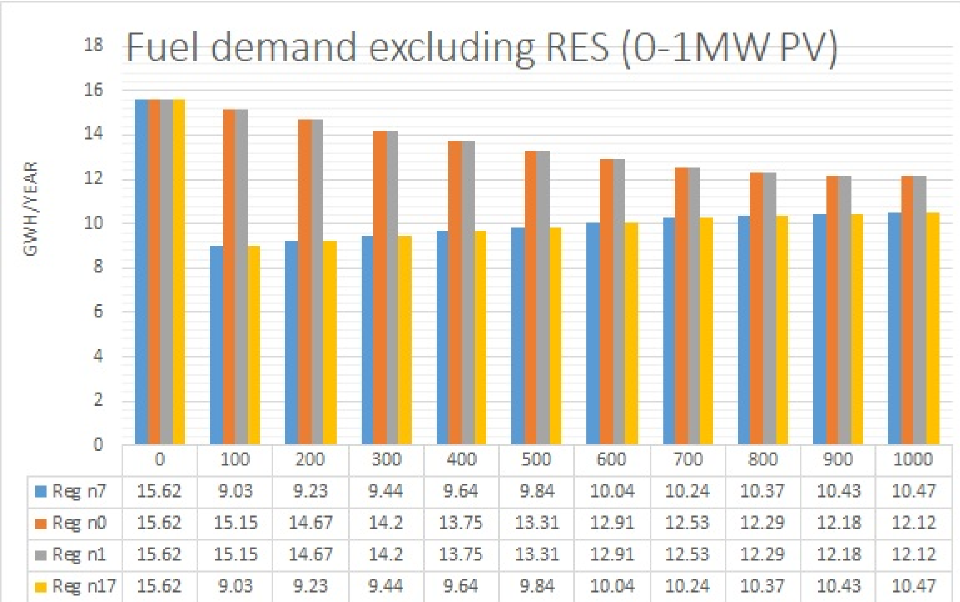

Figure 7.2. Fuel demand excluding RES and for PV power capacities ranging from 0 to 1 MW

As it can be noticed from the graphs, the fuel demand for the regulations number 7 and 1,7 presents the lowest values in comparison with the other regulation strategies number 0 and number 1. This is explained from the fact that in both CEEP regulation strategies number 7 and number 1,7, the operation of the power plant is reduced and balanced in relation to the energy production coming from the RES groups. However, in figure 7.2, the decrease level of the fuel demand and for the same CEEP regulation strategies, is not the same like for the wind case. This is because the power production of PV and for the same capacities as in the examined case of wind, the estimated power production is less than the estimated power production from wind power sources. However, the gradual increase of the fuel demand in each case for the CEEP regulation strategies n7 and n1,7 is closely related with the electricity grid stabilization share, and it should be closely examined.

From the above, it is decided that the simulations and analyses of each incorporated case of the SES scenario are realized for the regulations number 7 and 1,7. Thus, the regulations number 7 and number 1,7 are chosen for the comparison for different cases as they present the largest decrease in the fuel demand excluding RES. It should be noted that this process is realized for all the alternative scenarios analyses. In all the alternative scenarios and the assumed individual heating demand profiles covered by heat pumps, the fuel demand (excluding RES) for diesel oil shows similar pattern. Hence these regulation strategies are selected as similar results are obtained for each scenario. The 3 Smart Energy System scenarios are described and analyzed in the following.

7.3.2 Electricity grid stabilization share

The electric grid stabilization share is set to 30 %. This value represents the % of produced electricity including CEEP in each hour that has to be provided by units which can provide stability. In other words, the power plant can produce energy in a constant and stable rate, while the RES are not able to achieve this as intermittent energy sources with fluctuating energy output, depending on the hourly weather conditions (wind,sun).

This is assumed as in the SES scenario the power plant unit is expected to still operating but at a significant lower extent and as a back up source of energy. In Astypalaia and in any other case which incorporates intermittent RES and uncertainty of when the production will meet the demand, this risk should be mitigated. That is why this research opts for defining the grid stabilization share mentioned above. The ways in which this action influence the energy system and the output results is discussed in the discussion section 9.2.

7.3.3 Energy saving measures and individual heat pumps

In the demand side, changes are done in each SES scenario and as far as the individual heating methods for energy provision and fulfilling the heating demand as calculated in the reference scenario. Simulations of the SES scenarios are done considering that energy saving measures are implemented at a gradual rate. This means that the individual heating is achieved by the addition of individual heat pumps and scaling up the units in each SES scenario.

The scenario 1 seeks to fulfill the individual heating demand of the reference scenario (0.23 GWh/year) which is covered by heating stoves and fireplaces. In this research these are represented by biomass boilers burning wood fuels which have an annual heating demand corresponding to 0.23 GWh/year. The electric heating in this scenario remains at the same levels as in the reference scenario and is used for domestic hot water and at some extent space heating.

The second case in SES scenario 2 is done for a total heat demand of 1.035 GWh which fulfills the demand both of the residential customers (445 residences) and the dining businesses and food catering services of the island (509 units). The electric heating in this scenario remains at the same levels as in the reference scenario and is used for domestic hot water and at some extent space heating.

The last case in the 3rd SES scenario and the simulations are made for a heating demand of 1.25 GWh which concerns the residential sector, and all the integrated sub-sectors of the commercial sector as described for the purposes of this report (614 units). Various capacities of RES units and the different CEEP regulation strategies are included in the simulations in EnergyPLAN and excel spreadsheets. The electric heating is set to 0 and completely excluded from the energy system of SES scenario 3.

The purpose of modifying and changing the heat pumps is to assess how the changed in the electricity demand side and also at the supply side are affected. Furthermore, the addition of heat pumps is considered relevant and applicable for the SES scenarios in this research, as there is possibility to cover the domestic hot water demand, the space heating during the winter and also could be used in future and with heat exchanger units for space cooling.

7.3.4 RES capacities combination and ranging values

The RES technologies chosen as the most adequate energy production technologies for this scenario and for Astypalaia case are already known. However, the combination of capacities needed and the extent to which these may influence the energy system and the focal parameters established in this report may vary. Different capacities and combinations of RES are added in the analysis process and the simulations in EnergyPLAN.

The RES capacities combination for this research concerns the wind turbines and PV capacities which ranging between 0MW and 1MW. The analysis is done by comparing all the possible additions by adding 100 kW in each case while maintaining an energy output which is able to correspond to the established goals (60-70% of RES in final electricity production). Alterations in the supply side are examined for balancing the CEEP and the results are to be compared according to the needs of this research.

In order to define which combination of capacities presents the preferable according to this research results the analysis takes into account the range of values and inputs as shown in figure 7.3. Even though the capacities included in the calculations might not be existing in a single wind turbine, it is chosen to be included in the calculations as they provide a wide range of values offering a broaden simulation analysis.

PV power penetration in %	PV capacity in kW	PV power in GWh/year	Wind power penetration in %	Wind capacity in kW
	0		0	0
	100		6	100
	100		12	200
	100		18	300
	100		23	400
3	100	0.21	29	500
	100		35	600
	100		41	700
	100		47	800
	100		53	900
	100		58	1000

Figure 7.3. Assessment in Excel spreadsheet of various combinations of wind and PV capacities

As it can be seen from the figure, each capacity of wind power turbines ranging from 0 - 1000 kW is examined in combination with the same range of PV capacities. In this table the PV capacity of 100 kW is presented. This analysis process and the simulations are achieved for all the values increasing adding 100 kW each time and reaching 1 MW.

7.3.5 Storage facilities and hydro pump storage

In all the examined scenarios storage facilities are added in the energy system the sizing of which is done with the purpose to utilize the excess electricity produced and store it for the days when it will be needed. It is considered possible to install a hydro pump storage and develop the required infrastructure, as in Astypalaia the necessary settings for making this feasible are already in place. That it the elevation and height differences and mountain areas which exist on the island and offer the possibility to employ such storage facilities in the system and as described in chapter 5.

A hydro pump storage is added in the SES scenario with a charging and discharging capacity of 1 MW and storage capacity of 500 MWh. The efficiency set is the default value in EnergyPLAN of 0.8 and 0.9 for charge and discharge respectively and it can be adjusted to the actual efficiency at a later point. The main purpose of this research is not to assess the detailed technical characteristics required for this component but only to utilize it as a 'battery' storage and connect it with the excess electricity production.

7.3.6 Wind and PV hourly production profile

In the supply side and for the simulations of estimated hourly production accounted for the Wind and PV units, hourly distribution profiles are needed. These are obtained from the online software tool 'renewablesninja.com'.

This tool allows the user to define the exact location and based on weather data offers an output of the hourly production profiles according to wind data and solar irradiation of the area. In this case, Astypalaia is chosen and the data concern the year 2016.

7.3.7 Costs

Along with all the modifications and adjustments occurred in all the scenarios, the costs of each added unit are considered. It is challenging to obtain actual prices for components which are accurate for the Greek context and especially for future prices. For this reason and with a purpose to ease the calculations in EnergyPLAN and by securing a valid source of data, the EnergyPLAN cost database and the prices described in 'EnergyPLAN cost database January 2015' are considered for the calculations of the scenarios in EnergyPLAN.

It should be clarified that this research acknowledges the fact that the prices and technology lifetimes especially for power plants concern the Danish context, and the technologies and operation cycles of the Danish power plants may differ from the Greek power plants. However, the costs of the power plant in Astypalaia and the technical characteristics are obtained from HEDNO. The EnergyPLAN cost database is utilized only for the costs of the RES and the components of the SES scenarios.

Results of the scenarios 8

In this chapter the results of the analysis are presented. The analysis completed in this report has examined various combinations of RES types and capacities. Modifications are made in the demand and the supply side of the reference scenario and the infrastructure (storage facilities).The results demonstrate the influence that each scenario has on the technical, economic and environmental performance of the energy system.

8.1 SES scenario 1

In the first scenario, the combinations resulting in the highest RES shares and above 60% in the final electricity production are the ones as illustrated in figure 8.1. On the left graph are illustrated 11 distinct RES capacity combinations out of 100 in total and following the regulation strategy 1 for CEEP. On the right graph 9 distinct RES capacity combinations are shown out of 100 in total and for the regulation strategy 2 for CEEP. The RES share of the presented combinations is illustrated on the vertical axis and as described in the graphs. The range of RES share of the presented combinations ranges from 60 to 63% in the final electricity production which also includes the critical excess electricity production (CEEP). Out of 100 combinations and simulation results for each, the RES capacity combinations chosen for the results demonstrated below concern exclusively the combinations which reach the preferable share of RES in the final electricity production as established in this research.

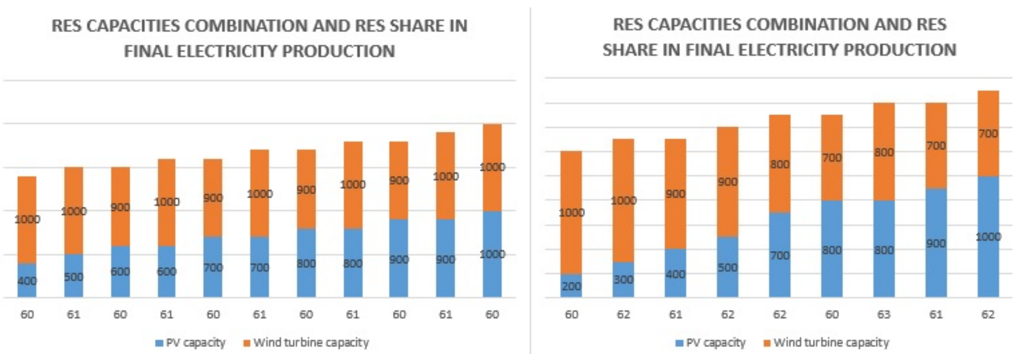

Figure 8.1. Regulation strategy cases 1(1,7) and 2(7) on the right and left respectively

As it can be seen from the bar charts, the wind power penetration is higher than the PV power penetration in most of the RES capacity combinations. This can be noticed from the 'orange' bars which represent the wind turbine capacity.

In the first graph and representing the CEEP regulation case 1, the PV capacities required to achieve the preferable RES share percentage start from 400 kW while the wind turbine capacities remain within the range of 900-1000kW. As noticed from the graph, RES capacity combinations e.g.: 1000 kW of wind with 400 kW of PV and 1000 kW of wind with 1000 kW may have the same share of RES in the final electricity production. That is because of the regulation strategy followed for the CEEP. For the first case this strategy concerns the reduction of production from the RES groups and the reduction and balance of the produced energy by the power plant and in combination with the other RES. After a point and regardless the addition in RES capacities, the electricity production from RES is always balanced to the demand side and thus the percentage of RES in the final electricity production does not change significantly.

In the second graph and representing the CEEP regulation case 2, the PV capacities and the capacities for wind power required for achieving the preferable RES share generally are decreased. The PV capacities commence from 200kW of PV while the range of capacities of wind turbines includes wind turbine capacities of 700kW and 800kW. Under this regulation strategy for the CEEP and as can be seen from the excel spreadsheets in section Appendix C, the effect in the RES share in the final electricity production is apparent. The simulations and results showed that when the power plant is reduced in combination with RES groups, the share of RES in the final electricity production is constantly increasing reaching up to 70% of RES share and for combinations of 1000 kW wind with 1000 kW PV. While in the first regulation strategy the simulation results gave a maximum RES share of 60% with 1000 kW of wind and 1000 kW of PV, in this CEEP regulation strategy case the maximum level of RES share in the final electricity production and for 1000 kW of wind and 1000 kW as can be seen from the Excel tables in Appendix C, is equal to 70%.

These differences relating to the CEEP regulation strategies implemented in each case and the RES capacities ranges have an important impact in the fuel demand and the CEEP, the total annual costs and the CO2 emissions of the energy system. In the next subsections the results for the technical, economical and environmental performance of the energy system are presented and analyzed. Objective is to outline the RES capacity combination and CEEP regulation strategy with the most advantageous results regarding the technical, economical and environmental performance of the SES and for this scenario.

Technical performance

In the reference scenario the total fuel demand is calculated to be 15.91 GWh/year. This number is sub-divided in the total fuel demand for the operating power plant in Astypalaia, the individual households fuel demand for heating (biomass for fireplaces and heating stoves) and the demand and other fuel consumption derived from the industry (LPG propane for the dining businesses and the food catering services).

The fuel demand for the power plant is 14.58 while for the individual households and industrial purposes is accounted for 0.46 GWh/year (biomass) and 0.87 GWh/year (LPG propane) respectively. The graphs below illustrate the fuel demand for each regulation strategy and for the RES capacities combinations for the SES scenario 1 and as shown in section 8.1.

As already mentioned, in this SES scenario the fuel demand for individual households of the reference scenario is substituted by the fuel demand for the individual heat pumps installations and energy saving measures. The 0.46 GWh/year of fuel demand has an output of total heating production of 0.23 GWh/year. This heating demand is fulfilled in this SES scenario 1 by individual heat pumps which have a fuel demand of electricity equal to 0.08 GWh/year.

In figures 8.2 and 8.3 the fuel demand is shown and reflecting the sum of the power plant fuel demand and the industrial purposes (dining businesses and food catering services in this research) fuel demand. The RES fuel demand and the biomass demand (since it is substituted by individual heat pumps and demand for electricity) are excluded. In the vertical axis, the number of RES capacities combination case is shown.

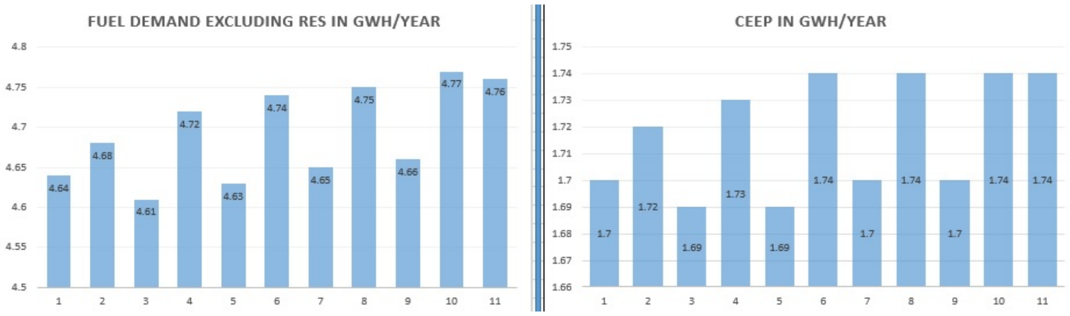

Figure 8.2. Fuel demand and CEEP for the first case regulation strategy

Compared to the reference scenario, in figure 8.2 it can be noticed that the fuel demand in this regulation strategy case 1 marks a significant decrease from 15.91 GWh/year to values ranging from 4.61 to 4.77 GWh/year. This indicates approximately 72% decrease in the fuel use of this scenario and compared to the reference scenario. This is accounted to the reduced use of the power plant in combination with RES increased integration in the energy system. This results in the reduced fuel demand of diesel-oil for the power plant.

The CEEP occurs regardless the regulation strategy implemented, and has values ranging from 1.69 to 1.74 and for the CEEP regulation strategy case number 1. This excess electricity could be utilized for new types of end-uses such as the electrification of the transport sector. The potential use of CEEP and in which sectors is discussed further in the discussion section 9.1.

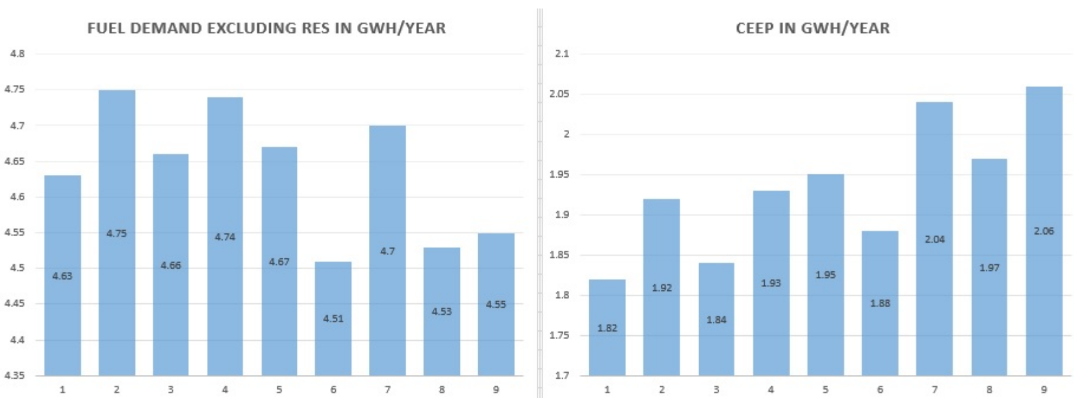

Figure 8.3. Fuel demand and CEEP for the second case regulation strategy

In figure 8.3 and comparing to the figure 8.2, the fuel demand under the second regulation strategy presents a deeper decrease with the lowest value to be 4.51 GWh/year and ranging up to 4.75 GWh/year. This is due to the fact that in this CEEP regulation strategy case, the RES production (Wind, PV) is not reduced as in the first CEEP regulation strategy case. Only the power plant electricity production is decreased in combination with the RES production. The RES production is not balanced between them and thus more energy is produced from RES which covers a larger part of the demand which in different case the power plant would have fulfilled.

The influence of the different CEEP regulation strategies is also apparent in the CEEP values as illustrated in figure 8.3. The CEEP values are slightly higher than the values of CEEP under the first regulation strategy ranging from 1.82 GWh/year to 2.06 GWh/year, comparing to the lowest values as shown in figure 8.2 and ranging from 1.69 GWh/year to 1.74 GWh/year.

Overall, the fuel demand and compared to the reference scenario presents approximately the same decrease of 72% as in the previous case. Nevertheless, it is important to mention the lowest value of fuel demand of 4.51 GWh/year which is to be considered in the conclusions of this report. The fuel demand and the CEEP are important elements which lead to the necessity for examining their influence on the total annual costs and the economic performance of the energy system.

Economic performance

In figure 8.4 the total annual costs are presented for the two different regulation strategies implemented in the simulations for this scenario.

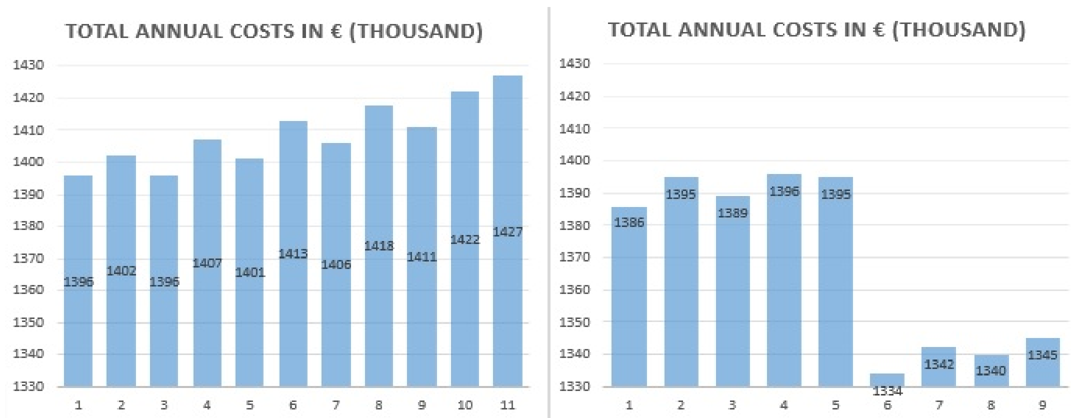

Figure 8.4. Total annual costs for the regulation strategies 1 and 2 on the left and right respectively

A comparison of the graphs outlines that in the second case the total costs are significantly lower with values ranging from 1334 kEURO to 1396 kEURO, while in the first case the values start from 1396 kEURO reaching 1427 kEURO.

The significant decrease in the total annuals costs and for the RES capacity combinations 6 to 9 can be justified to the decrease in fuel demand as well as the decreased capacity of Wind turbines employed in this case. As it can be noticed from figure 8.1, in the combination cases 6 to 9 the wind turbine capacity remains at the levels of 700 to 800 kW. In relation with the first regulation strategy case which have capacity values from 900 to 1000 kW. In figure 8.3 the reduced fuel demand for the combination cases 6-9 is clear and is related to the significant decrease of the total annual costs and for the same combination cases illustrated on the right graph in figure 8.4. Furthermore the lowest fuel demand value is for the 6th RES capacity combination of 800 kW PV with 700 kW of wind, which is also reflected in the total annual costs for this case, which are the lowest.

Environmental performance and CO2 emissions

Regarding the environmental performance of the system and to what extent the different combinations contribute to the decrease of CO2 emissions, the resulting data is illustrated in figure 8.5.

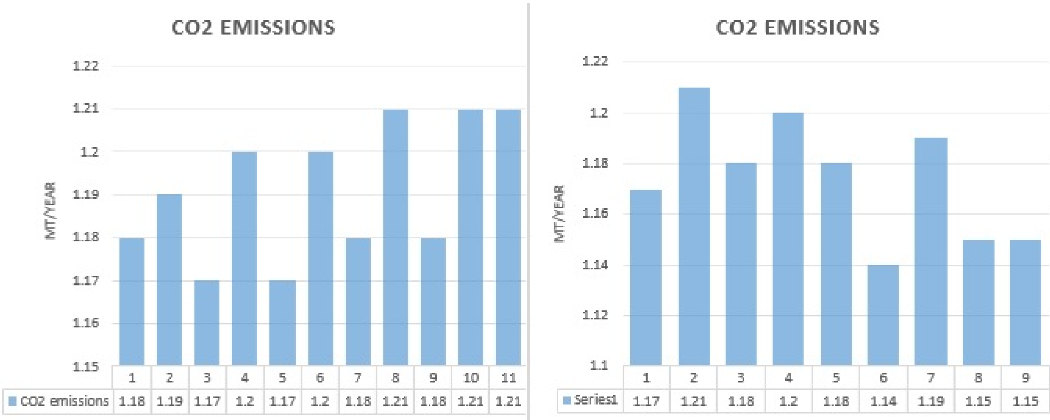

Figure 8.5. CO2 emissions for the regulation strategies 1 and 2 on the left and right respectively

The CO2 emissions in both cases and comparing to the reference scenario are remaining in low levels and marking almost a three-fold decrease of the reference scenario CO2 emission levels which are equal to 4.04 Mt/year. Hence, a drop is marked from 4.04 Mt/year to values ranging from 1.14 to 1.21 Mt/year. The lowest CO2 emissions are 1.14 Mt/year as identified in the second regulation strategy for the CEEP and concerning the RES capacities combination number 6 (800 kW PV with 700 kW of wind) Mt/year).

8.2 SES scenario 2

In this scenario, individual heat pump units are installed in the SES, increasing the heating demand from 0.23 GWh/year to 1.035 GWh/year and thus the electricity consumption for heating from 0.08 GWh/year to 0.35 GWh/year, as described in section 7.5.

For the SES scenario 2, the combinations resulting in the highest RES shares and above 60% in the final electricity production are the presented in figure 8.6. In each case and following the same procedure as in SES scenario 1, 100 different RES capacities combinations are realized and simulated. Out of these 100 different RES capacities combinations and for the two distinct CEEP regulation strategies, 10 combinations for the first case and 9 combinations for the second are resulting to RES shares ranging from 60 to 61% and 60 to 62% respectively. Out of 100 distinct RES capacity combinations only the outputs resulting in a RES share from 60 to 63% are chosen. This is because the deviation of + 3% is assumed to be acceptable in this research. The results giving percentages of RES share from 64% and above are excluded from the results as they are considered to be out of the preferable range for the RES share in the final electricity production.

The illustrated bar charts on the left and right refer to the two different regulation strategies for the CEEP as implemented in this research and the RES share percentage is illustrated in the horizontal axis.

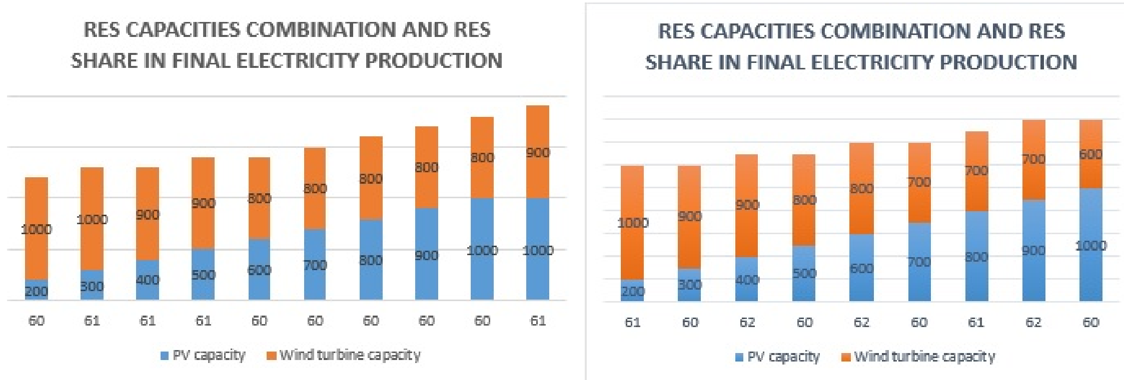

Figure 8.6. Regulation strategy cases 1(1,7) and 2(7) on the right and left respectively

As it can be seen from the bar charts, the wind power penetration is higher than the PV power penetration also in this scenario and for both CEEP regulation cases. This is due to the fact that wind power is used as the primary source of energy and PV modules are consequently added to the system, with the objective to reach the preferable RES share in the final electricity production and as defined for this research. Furthermore the estimated electricity production from wind turbines is higher that the one of PV modules of the same capacity. For instance, 400 kW of installed wind capacity give 1.53 GWh/year while 400 kW of installed PV give 0.85 GWh/year which is almost half of the estimated electricity production of the wind turbines. This explains the fact that in all the examined scenarios the installed wind capacity surpasses the installed PV capacity.

In the first graph and representing the CEEP regulation case 1, the PV capacities required to achieve the preferable RES share percentage start from 200 kW to 1000 kW while the wind turbine capacities are within the range of 800-1000 kW. In all the combination cases the wind turbine capacity does not fall under the capacity of 800 kW.

In the second graph and representing the CEEP regulation case 2, the PV capacities and the capacities for wind power required for achieving the preferable RES share slightly differ from the 1st case. That difference is apparent when observing the PV capacities which commence from 200kW of PV, while the range of capacities of wind turbines includes wind turbine capacities of 600 kW the lowest, 700 kW and 800 kW up to 1000 kW.

The greatest difference in capacity ranges is noticed for the second regulation strategy and the graph illustrated on the right. In detail, in the sixth combination case and as illustrated in the graph, the PV and wind capacities equal to 700 kW each, giving 60% of RES in the final electricity production. Moreover, in the last combination case the installed wind capacity is 600 kW with 1000 kW of PV. The wind capacity of 600 kW is the lowest value for both CEEP regulation strategy cases.

In both cases the impact of alterations in the CEEP regulation strategies are obvious when observing the graphs and the share of RES in the final electricity production. As also mentioned in section 8.1 and concerns all the examined scenarios, when the power plant balances its operation in combination with the RES of the system, higher shares of RES in the final electricity production can be reached by utilizing smaller RES capacities. That is clear according to the figure 8.6, where for instance in the first combination case and in both graphs, 1000 kW of wind with 200 kW of PV are accounted for 60% and 61% for each CEEP regulation strategy respectively. This pattern continues in all the combination cases illustrated in figure 8.6. That is why in general the RES shares illustrated on the right graphs and according to the CEEP regulation strategy case 2 of balancing the power plant production in combination with RES, can achieve greater RES shares even while having the same number of total installed capacity.

It should be clarified again that in the first CEEP regulation strategy case (left graph) the power plant has a reduced operation in combination with the other RES groups and the RES groups production is also reduced and balanced between them and according to the demand. While the second CEEP regulation strategy concerns the balancing and reduced production of the power plant in combination with the other RES.

According to the description and knowledge acquired from the first SES scenario in section 8.1, the RES capacities variations are affecting the rest of the results and the influence of the CEEP regulation strategies affects the technical, economical and environmental performance of the SES.

The results presented in the above have an important impact in the fuel demand and the CEEP, the total annual costs and the CO2 emissions of the energy system. In the next subsections the results for the technical, economical and environmental performance of the energy system are presented and analyzed.

Technical performance

In section 8.1 the total fuel demand of the reference scenario is presented and sub-divided to the several fuel demands which is consisted of. The numbers are important so that they can be compared with each of the scenarios results.

The figures 8.7 and 8.8 illustrate the fuel demand and the CEEP for each of the RES capacities combination resulting to the preferable share of RES in the final electricity production and as shown in figure 8.6. These results are described and explained further in the following.

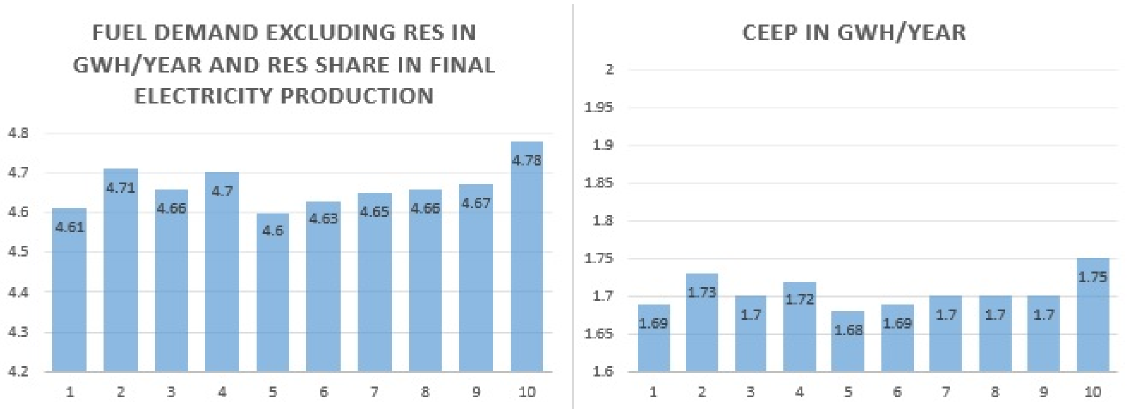

Figure 8.7. Fuel demand and CEEP n the left and right graph respectively and for CEEP regulation strategy 1

The fuel demand comparing to the value of the reference scenario is fluctuating between the same range of levels as in SES scenario 1, presenting approximately a 72% drop. The principal difference is that most of the combinations remain in low levels below 4.7 GWh/year and only 3 RES combinations are above this number. In the SES scenario 1 there are 5 different combinations which are above the value of 4.7 GWh/year. This gives the information that the fuel demand in the SES scenario 2 is a bit decreased but at a quite insignificant amount, since the profile is not changed dramatically from the SES scenario 1.

The decrease pattern is also noticed in the CEEP which has a small difference between a number of combinations with values ranging from 1.68 to 1.7 GWh/year. This overall slight decrease in the CEEP is due to the increased number of installed individual heat pump units and that the excess electricity production is absorbed by these extra units and this modification in the demand side. Also it is attributed to the fact of the CEEP regulation strategy and as already described in the SES scenario 1 in section 8.1.

The two highest values have the combination number 2 and combination number 10 with 1.73 and 1.75 GWh/year respectively. It should be mentioned that these details are important for establishing only one RES capacity combination and under one specific CEEP regulation strategy to represent the SES scenario 2.

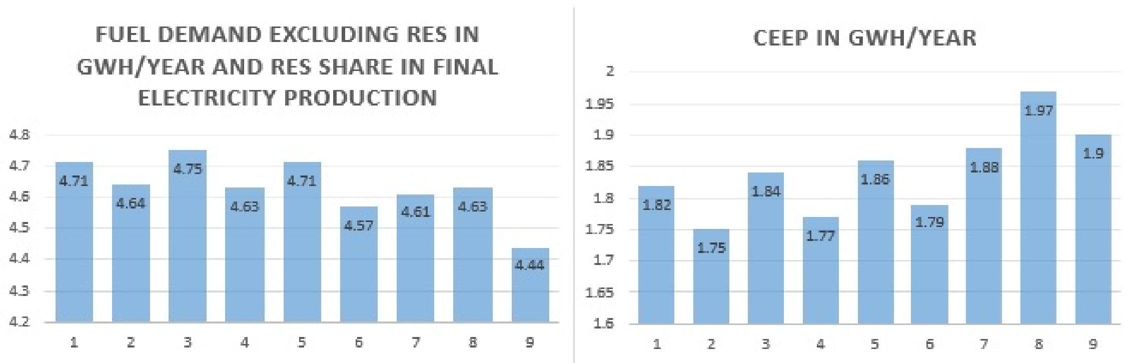

Figure 8.8. Fuel demand and CEEP on the left and right graph respectively and for CEEP regulation strategy 2

In this scenario and as shown in figure 8.8 the fuel demand marks the lowest value recorded in the simulation results. The RES combination number 8 has a 4.44 GWh/year fuel demand which is the lowest in all the scenarios until this point of the research.

The CEEP in this case is increased compared to the regulation strategy number 1 of SES scenario 2 and following the same pattern as in SES scenario 1. However it should be pointed out that overall the CEEP of SES scenario 2 is in lower levels that the CEEP in the SES scenario 1. That is due to the increase of the heating demand fulfilled by individual heat pumps from 0.23 GWh/year to 1.035 GWh/year and the increased electricity consumption.

Economic performance and total annual costs

The economic performances for each CEEP regulation strategy and for the SES scenario 2 are illustrated in figure 8.9.

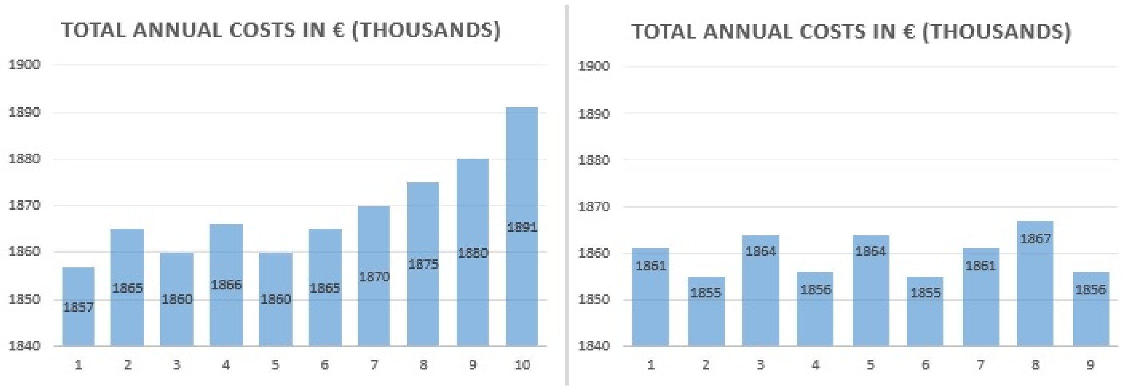

Figure 8.9. Regulation strategy cases 1(1,7) and 2(7) on the right and left respectively

Overall and comparing to the SES scenario 1, a growth in the total annual costs for both CEEP regulation strategies occurs of approximately 20 to 25%, which corresponds to 400 to 450 kEURO. The total annual cost values for the SES scenario 2 are always higher than 1.8 million EURO and ranging between 1855 to 1891 kEURO. These elevated levels in the total annual costs are explained from the fact that an increased number of individual heat pumps matching to a heating demand of 1.035 GWh/year are installed in the SES. The investment difference between the fuel based heaters and heat pumps is accounted for these higher annual total costs. Thus, the total cost for individual heat pumps is increased and hence the total annual costs of the SES are also increased accordingly. Moreover, if figures 8.7 and 8.9 are observed, the increase in fuel demand excluding RES follows the same pattern in the increase of the total annual costs. This is an additional reason of why the total annual costs for CEEP regulation strategy case 1 are also increasing.

In the graph illustrated on the left which concerns the CEEP regulation strategy 1, the range of values is greater that with RES combination cases reaching a total annual cost of 1891 kEURO and increasing from RES capacities combination cases 6 to 10. This increase follows the pattern of the elevated levels in fuel demand and in the RES capacities combinations of PV and wind power which remains to 900 and 1000 kW.

On the contrary, in the second regulation strategy for the CEEP and as presented in the graph on the right, the total annual costs remain at a value lower than 1867 and with insignificant total annual costs changes, ranging from 1855 kEURO to 1867 kEURO. This overall decrease of the total annual costs is due to the decreased fuel demand excluding RES.

To repeat this clarification, the factor which has an influence on these is the CEEP regulation strategy mostly and the grid stabilization share as mentioned **in section 7.7.3 check it after changes** . Both of them are taken into account and are assessed in the sensitivity analysis chapter 9 with the aim to comprehend in what extent and how they may affect the SES.

Environmental performance and CO2 emissions

The environmental performance of the systems in SES scenario 2 and to what extent the different combinations contribute to the decrease of CO2 emissions is shown in figure 8.10.

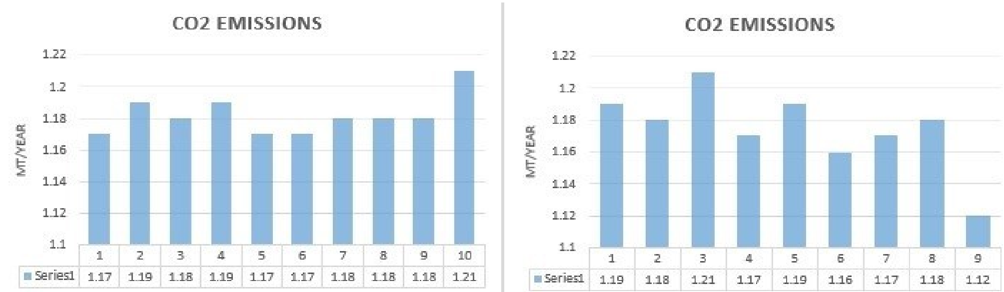

Figure 8.10. Regulation strategy cases 1(1,7) and 2(7) on the right and left respectively

The CO2 emissions values do not defer significantly from the values of the SES scenario 1. It should be mentioned however that in the graph for the CEEP regulation strategy number 2, the CO2 emissions are decreased comparing to the graph for the CEEP regulation strategy number 1 illustrated in the left. In fact, the lowest CO2 emissions value is found for the 9th RES capacity combination as illustrated in the right graph which equals to 1.12 Mt/year of CO2 emissions. The lower levels of CO2 emissions are related to the fuel demand levels of each system. This is clear by noticing that the lowest fuel demand case in figure 8.8 and concerning the CEEP regulation strategy case 2, is the combination case with the lowest levels of CO2 emissions (1.12 Mt/year). To mention again and pointing out the great difference of the SES scenarios comparing to the reference system, the CO2 emissions initially are 4.04 mt/year.

8.3 SES scenario 3

In this section the results for the SES scenario 3 and the various RES combinations and for the different CEEP regulation strategies are described.

It should be clarified that in this scenario the electric heating which is accounted for both domestic hot water purposes and space heating is also substituted by individual heat pumps. Thus, if the SES scenario 2 includes 1.035 GWh/year of heating demand fulfilled by individual heat pumps and 1.02 GWh/year of electric heating, in the SES scenario

3 the heating demand from individual heat pumps is changed to 1.25 GWh/year which corresponds to an estimated electricity consumption of 0.42 GWh/year. That modification in the demand side changes the total individual heating demand which decreases from 2.27 in the SES scenario 2 to 1.25 GWh/year in SES scenario 3. This also means that the electricity demand for heating purposes is decreased from 1.44 GWh/year to 0.42 GWh/year.

It is noteworthy that for this SES scenario and the addition of individual heat pumps for all the examined sectors in this research (heating demand of 1.25 GWh/year corresponding to an electricity consumption of 0.42 GWh/year) , the regulation strategy referring to the reduction of the power plant in combination with RES is the only one which includes RES percentages of 60 % and higher in the final electricity production. The regulation strategy case 1 for the CEEP and after 100 different combinations did not have an output of the preferable RES percentage share in the final electricity production. That is because of the change in the electricity demand for heating purposes and as mentioned in the paragraph above. In other words, the total electricity consumption for heating purposes is decreased and thus by using the CEEP regulation strategy case 1 which also balances the RES production between them, their production profile decreases and is adjusted to the electricity demand. Since the demand is lower, the percentage of RES share in the final electricity production is also decreased. If the demand remained as in previous scenarios (including electric heating), then the production of RES would be higher and thus the RES share in the final electricity production would be higher.

The results for the technical, economical and environmental performance of the SES scenario 3 are presented in the following. In figure 8.11 are shown the RES capacity combinations resulting in the preferable RES share in the final electricity production.

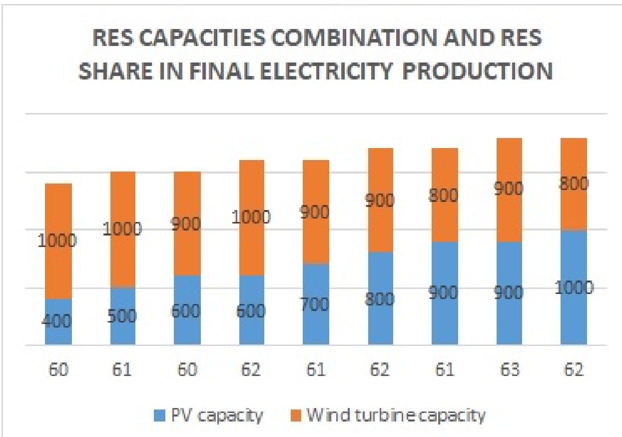

Figure 8.11. RES capacities combinations for the SES scenario 3 and RES share percentage in final electricity consumption

In this scenario and as it can be seen from the graph, the PV capacities are within a range of 400 kW to 1000 kW and the wind capacities range between 800 kW to 1000kW. Due to the CEEP regulation strategy case 2 and according to the explanation described for the previous SES scenarios 1 and 2, the power plant balances its production in combination with the production from RES. The RES are not balancing the production between them and that gives an increased percentage of RES shares in the final electricity production. In

SES scenario 3 and as seen from the figure 8.11, only two combinations of 1000 kW wind with 400 kW PV and 900 kW wind with 600 kW PV give 60% of RES share in the final electricity production. The values in this scenario range from 60 to 63% of RES share in the final electricity production.

Technical performance

The fuel demand excluding RES and the CEEP are illustrated in figure 8.12 and on the left and right graph respectively.

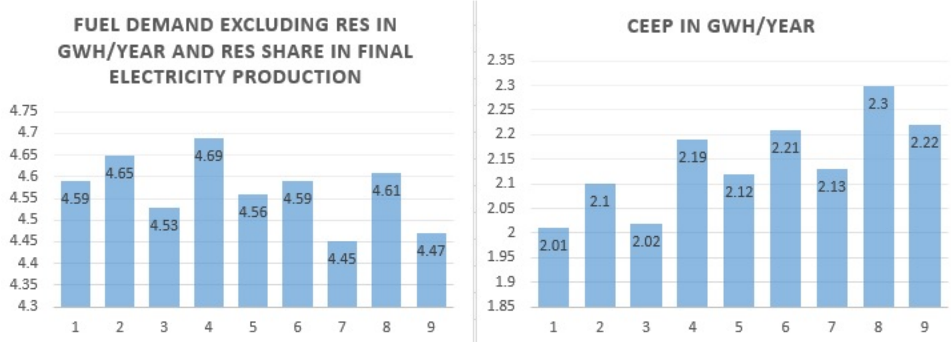

Figure 8.12. Fuel demand and CEEP for SES scenario 3 and for CEEP regulation strategy 2

In this scenario and as noticed from figure 8.12 the fuel demand excluding RES presents low values for combinations number 7 and 9 with 4.45 and 4.47 GWh/year respectively. **why?** The values in total for this scenario ranging from 4.45 to 4.69 GWh/year with only 3 RES capacities combination cases to exceed the 4.60 GWh/year.

The CEEP marks the highest values out of all the examined scenarios with ranges from 2.01 to 2.3 GWh/year of excess electricity. This is due to the reduction of the electricity demand on the demand side of the energy system since the electric heating is removed and substituted by individual heat pumps. A percentage of CEEP in the previous SES scenarios 1 and 2 is 'absorbed' by the demand side utilizing both heat pumps and other units for electric heating (electric boilers and air-conditioning for heating). Since the electric heating is completely removed and as already described before, the estimated total electricity demand specifically for heating purposes is decreased significantly. Thus, the CEEP which used to be driven to fulfill this demand, in the SES scenario 3 is not utilized in any demand side use. That explains the elevated CEEP levels in comparison with the SES scenarios 1 and 2.

In comparison with the CEEP of previous scenarios, these elevated values indicate that apart from the potential electrification of the transportation sector, new end-uses and interconnections of other sectors with the electricity sector could be combined. More detailed discussion about the potential use of CEEP follows in the discussion section 9.1.

Economic performance and total annual costs

As far as the economic performance of SES scenario 3 and the total annual costs these are presented in figure 8.13.

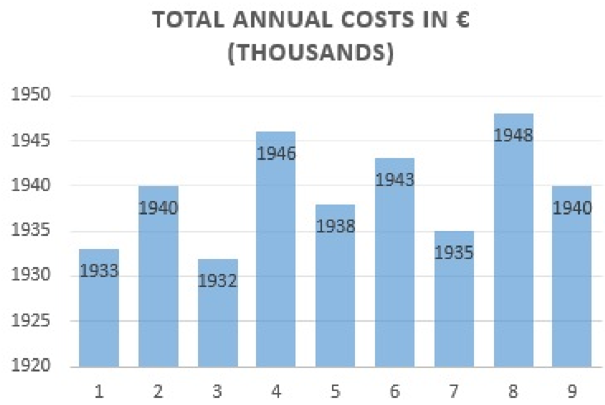

Figure 8.13. Total annuals costs for the SES scenario 3 and CEEP regulation strategy 2

As illustrated in the graph the total annual costs surpass the total annual costs of all the other examined scenarios. That is mainly accounted to the fact of the increased use and installation of individual heat pump units and also the high capacity levels of RES implemented in this scenario. The electric boiler units and biomass boilers (fireplaces and heating stoves) are completely removed from the energy system. The annual costs from the individual heat pump units installed are accounted for the overall increase in the total annual costs for the SES scenario 3. The total annual costs of the SES scenario 3 ranging between 1932 kEURO to 1948 kEURO. It could be stated that approximately the increase is about 500 kEURO per year comparing to the SES scenario 1 and only 100 kEURO per year when compared to the SES scenario 2.

Environmental performance and CO2 emissions

The environmental performance of the systems in SES scenario 3 and to what extent the different combinations contribute to the decrease of CO2 emissions is shown in figure 8.14.

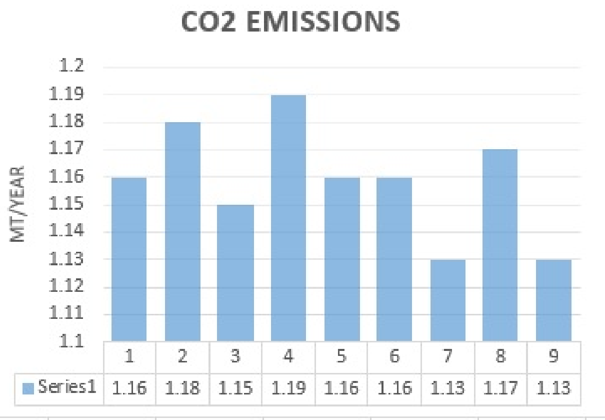

Figure 8.14. CO2 emissions for SES scenario 3 and CEEP regulation strategy 2

From the graph and comparing it to the rest SES scenarios it can be noticed that the CO2 emissions of this energy system do not differ from the other SES scenarios. The RES capacity combination cases number 7 and 9 mark the lowest CO2 emissions values with

1.13 mt/year each. Overall, in this SES scenario the values range between 1.13 to 1.19 mt/year, which are approximately the same levels in all the examined scenarios. Since the fuel demand excluding RES did not change significantly, it is realistic that not significant changes occurred in the CO2 emissions either.

9 Sensitive factors and uncertainties in results

This research categorizes these sensitive factors to i) the uncertainties of estimated data on the demand side and the reference scenario modelling, and ii) the uncertainties on the data applied in the modelling of the SES scenarios.

The first category refers to the insufficient data and the estimations made and applied as an input for the reference scenario. The second category refers to the applied input values for the modelling of the SES scenarios. It is chosen to outline and discuss about the sensitive factors and their potential influence in the results of this research, as they could be included in a sensitivity analysis in further research.

9.1 Definition and purpose

In order to examine the influence of these sensitive factors on the potential SES scenarios for Astypalaia island, a sensitivity analysis should be conducted. The sensitivity analysis is the assessment of how the uncertainty in the output of a mathematical model or system can be divided into distinct factors of uncertainty in its inputs [Saltelli, A., 2002].

The purpose for conducting a sensitivity analysis and the contribution to this research is to i) test the robustness of the analysis results of a model, ii) enhance the understanding of the relationships between input and output values in a system of model, iii) decrease the uncertainty through the identification of inputs which may cause this uncertainty in the output, iv) examine the model for errors by identifying unexpected relations between the inputs and the outputs and v) to outline significant connections between model inputs and forecasts which lead to important conclusions about the model and possible ways for optimizing it [Hill, M.; Kavetski, D.; Clark, M.; Ye, M.; Arabi, M.; Lu, D.; Foglia, L.; Mehl, S, 2015].

9.2 Factors for sensitivity analysis

A sensitive factor which add uncertainty in the results is the CEEP regulation strategies. From the analysis of results it is outlined that this factor may influence significantly the outputs of the model. This is observed after analyzing the two different regulation strategies for the CEEP and for each of the SES scenarios in results chapter 8. The decisions made regarding the operation of the power production technologies of a system and how to deal with the CEEP may affect significantly the technical, economical and environmental performance of the examined SES scenarios. Therefore, this research outlines the CEEP regulation strategies as a sensitive factor which should be included in a sensitivity analysis.

In addition the electricity grid stabilization share is undeniably a factor which may impact the output values of the SES scenarios regarding the technical, economical and the environmental performance of the system in each case. This is due to the fact that the percentage of the electricity grid stabilization share defines the operating hours of the power plant. Thus, since the results concern only one value of the electricity grid stabilization share (30%), it is uncertain how this factor would affect the results and what is the connection with the overall performance parameters of the energy system.

In a final stage the coefficient of performance (COP) is outlined as an important factor which adds uncertainty in the results. This is because the addition of individual heat pumps in each of the SES scenarios and their efficiency may alter at a significant extent the electricity needed for their operation. In other words, the ratio of useful heating provided is reliant on the electricity needed for the heat pumps to operate. Alterations in the COP of the heat pumps change the electricity demand and impact the SES performance. The relations between these should be acknowledged and taken into consideration in the sensitivity analysis to be done.

In many cases there has been lack of data specifically the electricity, heating and cooling demand for each of the sectors examined in this research. The handling of this imperfect data is done by estimations based on secondary data obtained from other reports and used and adjusted according to the purposes of this research. These estimated data is subjected to considerable uncertainties and perhaps deviations from the actual data for the island of Astypalaia. This means that if this kind of data were available, the results and demand profiles and hence the supply profiles and RES capacities may have been different. For this reason a range of different values could be implemented in a sensitivity analysis and examine the influence on the results.

The applied costs of the technologies and energy infrastructures concerning the SES scenarios and their investment costs, operation and maintenance costs and any other relevant costs applied in this research concern the Danish context. For the reference scenario and the power plant unit, the costs have been provided by HEDNO and are considered to be credible. Nevertheless, for the SES scenarios and as it has been challenging to identify the actual costs which are accurate for the Greek context, the cost database for Denmark and with prices projections for the years 2020, 2030 and 2050 has been implemented. This action has an impact on the resulting total annual costs of the equipment in each of the SES scenarios and adds a risk and uncertainty in the results and how realistic these are.

In order to reduce this uncertainty, a sensitivity analysis could be done by utilizing different costs which are accurate for other countries. Especially for counties which present similarities with Greece, it could be argued that the costs would have had a more realistic influence on the results. By analyzing cases of different values for costs, the accuracy in the results and projections about the economic performance of the system could be increased.

Discussion and Conclusions 10

10.1 Discussion

According to Annesley, Thomas M. [2010], the purpose of the discussion section is to clarify and analyze the significance of the research findings in relation with the hypotheses, choices and delimitations made in this research. In this section are described the factors which may affect the research findings and which should be considered in advance of shaping the conclusions for this research. This section purpose is also to critically reflect on the hypothesis, methods and concepts applied in this research and how these may influence the outcome.

In this research the factors that have an important role in the results and conclusions and represent an area of difficulty, adding uncertainty to the results are the following:

- Choice of modelling tool for the simulations
- Sensitive factors and uncertainties in input data for the simulations
- Political context in Greece and potential influence on RES technologies selection

Furthermore it is chosen to discuss about the CEEP of the SES scenarios and potential connection with other sectors such as the transportation sector with future plans for its electrification.

10.1.1 Choice of modelling tool

In this research it is chosen to realize a technical simulation of the energy system in Astypalaia, balancing heat and electricity demands and simulations achieved on an hourly basis. Furthermore, different CEEP regulation strategies are implemented in the SES scenarios, various RES capacity combinations are examined and the resulting outputs concern the technical, economic and environmental performance of the system. An adequate tool for offering these options and also that is available for free is chosen and that is EnergyPLAN.

In case that this research decided to realize a market economic simulation of the energy system in Astypalaia, a different variety of modelling tools could have been investigated. This may have had different results for this research that may deviate from the results presented for this case.

The choice of the modelling tool in this research is done according to the criteria presented in methodology chapter 4. The advantage of EnergyPLAN is to simulate the system on an hourly basis and the relation between heat and electricity on an hourly basis. If the simulation of the energy system needed to be done in a yearly basis then a different tool may have been used.

10.1.2 Political environment and potential influence on the RES technologies

In order to empower this research and develop optimized and more concrete results which answer the sub-questions and the principal research question, a policy research and assessment of the institutional settings in Greece could have been made. From the technical point of view and for the modelling and technical simulations of an energy systems these factors are not included. Nevertheless, the political environment, the institutional settings and initiatives for energy transition projects play an important role in the feasibility of this kind if projects.

Although not mentioned at any point in the research, the political environment and the institutional frameworks prevailing in a country are closely linked to the design of an energy system. This fact is particularly apparent in the selection of RES types and the energy infrastructure in general. The political strategies, the institutional settings and the available finance schemes and subsidies for promoting RES and the realization of energy transition projects in islands are pivotal for the feasibility of such projects.

The selected RES capacity combinations, the storage facilities and in general the technology equipment chosen for the SES scenarios and the simulations might have been different. That is due to the fact that if the policy research was conducted, then different indicators regarding the employment of RES technologies and storage systems may have been outlined. This means that the SES scenarios would have been different in this research and subsequently the results and conclusions.

10.1.3 CEEP and new end-use types

This research and according to section 2.5 intended to relate the excess electricity production with the transportation sector and achieve and introduce electric cars or buses in Astypalaia. In this research stage the CEEP is examined for each SES scenario and without the introduction of electric vehicles. This is an important subject to discuss and mention as the introduction and modifications on the demand side and addition of electric vehicles and the necessary infrastructure would have an impact on the technical, economic and environmental performance of the system. The total annual costs would have been increased due to the addition of new infrastructure. The results and conclusions of this research do not consider these additional costs which perhaps would have modified differently the decisions for each SES scenario.

10.2 Conclusions

The principal aim of this research and according to the research question described in section 3.1 is to assess distinct SES scenarios which are adequate to substitute the current energy system in Astypalaia and identify the most feasible scenarios contributing to the development plans for the Greek island.

The first stage of the analysis is the creation and modelling of a reference scenario which represents as realistic as possible the current energy system in Astypalaia and the energy balance characteristics. These concern the fuel utilization types, energy sources mostly used and the profiles in the demand and supply side.

The second stage includes the development and modelling of alternative scenarios which are capable to fulfill the existing demands, substituting the reference scenario and respond to the goals set in the research question. These alternative scenarios are created based on the reference scenario data and according to the Smart Energy System concept. The SES scenarios developed are 3 and the main difference between them is the scaling up of energy saving measures by adding heat pump units and increasing the demand in each case.

For each scenario and in order to establish the optimal set of production technologies, energy infrastructure and regulation strategies for the management of the excess electricity production, numerous simulations are made. The parameters changed in each simulation case and for all 3 examined SES scenarios are the following:

- Regulation strategies for the management of critical excess electricity production (CEEP)
- Electricity grid stabilization share
- Energy saving measures and individual heat pumps
- Combinations of distinct RES capacities
- Storage facilities

The simulations in all scenarios are achieved with the use of the EnergyPLAN modelling tool and by using the technical simulation strategy balancing both electricity and heat demands. The assessment of numerous possible combinations of the above mentioned parameters is able to narrow down the decision-making process to a small number of feasible solutions for the purposes of this research.

The results of the simulations for each of the scenarios are presented and analyzed in chapter 8, following by a discussion regarding the uncertainties and the need for sensitivity analysis to test the robustness of the results and identify connections between inputs and outputs. In this way crucial information is obtained regarding the factors which may alter the results in case of being changed even though the sensitivity analysis is not realized. It stands though as a better understanding of the results and conclusions made and how these might change.

Finally, the sensitivity factors and uncertainties in calculations are outlined and discussed regarding possible influences, followed by a general discussion. Eventually conclusions are made which contribute to answering the principal research question. Each sub-question is connected to the conclusions drawn out after the completion of this research and finally conclusions are made addressing the main research topic of this thesis and the main research question.

To answer the first sub-question which purpose was to analyze the characteristics of the current energy system in Astypalaia, the existing energy infrastructure and energy balances, the analysis proceeded with the modelling and simulation of reference scenario in EnergyPLAN. The results for the reference scenario and according to the output data obtained from EnergyPLAN tool, are summarized in the following table 10.1 and concern the technical, economical and environmental performance of the system.

Total Fuel demand (excluding RES) in GWh/year	Fuel demand for the power plant in GWh/year	Fuel demand for the individual households in GWh/year	LPG fuel demand in GWh/year
15.91	14.58	0.46	0.87
Total annual costs	€ 2,033,000.00		
CO2 emissions	4.04 kt/year		
RES share in el. Production	0		

Figure 10.1. Reference scenario output data from EnergyPLAN simulations

The purpose of the second sub-question was to examine the factors that may affect the technical, economical and environmental performance of the SES scenarios and identify the most advantageous technology combinations for reaching 60+% of RES share in the final electricity production. The analysis showed that the following technology combination cases, presented in table 10.2, are feasible for each of the examined SES scenarios.

SES scenarios	Wind power	PV capacity	Fuel demand (excluding RES)	CEEP	Total annual costs	CO2 emissions
SES Scenario 1 and CEEP regulation 7	700 kW	800 kW	4.51 GWh/year	1.88 GWh/year	1,334,000 €	1.14 Mt/year
SES Scenario 2 and CEEP regulation 7	1000 kW	600 kW	4.44 GWh/year	1.9 GWh/year	1,856,000 €	1.12 Mt/year
SES Scenario 3 and CEEP regulation 7	800 kW	900 kW	4.45 GWh/year	2.13 GWh/year	1,935,000 €	1.13 Mt/year

Figure 10.2. Reference scenario output data from EnergyPLAN simulations

The third research question is answered in chapter 9 and the identification of factors which add uncertainty in the results of this research and their inter-connections are described. The conclusions made regarding the factors which may have a significant influence on the results of this report concern i) the electricity grid stabilization share, ii) the COP of the heat pumps for the SES scenarios and the estimated COP for the biomass boilers (fireplaces and heating stoves), iii) the costs of the system for the SES scenarios.

The electricity grid stabilization share in combination with the different CEEP regulation strategies is related and affecting the technical, economic and environmental performance of the system in the SES scenarios. That is because by the requirement of certain amount of energy in every hour to be obtained by units which can offer stability, this means that the power plant will operate more hours (unit with stable energy output). Consequently the fuel demand will increase in comparison with a lower share of electricity grid stabilization which indicates that the power plant will operate less hours. This is going to have snowball' effect on the total annual costs of the system which are connected with the fuel input and its price. Thus, also the carbon dioxide emissions (CO2) are influenced in relation with the ration of the fuel demand for the power plant.

10.3 Further research

The results and conclusions made for this research case are based on an arrangement of primary data from reliable sources and from estimated imperfect data based on secondary data obtained from literature and adjusted for the needs of this research. Three basic tasks can be included in future research work with the purpose to optimize the models described in this research.

One task to be completed in further research is to conduct an extensive and detailed analysis in each sector of Astypalaia island and combine qualitative and quantitative methods which will provide the realistic and pragmatic data. The qualitative and quantitative methods refer to questionnaires in each sector, focused interviews, documentary evidence and observation and correspondence with the responsible authorities in Greece. The purpose of this would be to scrutinize the input data applied in this research and examine their validity and accuracy. Since this task is completed, an optimization of the reference scenario and the energy balances can be achieved. This will influence the creation and development of the alternative scenarios and eventually will provide more realistic, accurate and vigorous results.

The second task to be completed in further research which could also test the robustness of the results and empower the conclusions of this research, is a sensitivity analysis. Due to limited time and due to the fact that the sensitivity analysis in all of the examined scenarios and for each of the technology combinations would be demanding and needs precision and accuracy, this research chooses to include only a discussion regarding the sensitivity factors. Thus, the next stage and to support the first task of further research described above, would be a detailed sensitivity analysis.

The third task in further research and to complete the 'umbrella' of validation and robustness of the conclusions and results made in this research, would be a policy research in Greece considering how the existing political frameworks, institutions, financial schemes and other relevant factors could enable or obstruct to the realization of projects which involve the energy transition on the Greek islands. The contribution of this task in this research would have been to outline a specific set of technologies and infrastructures, financial support and funding schemes which could drive the modelling process of the SES scenarios and the selected RES technologies.

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Appendix A

In this section, a detailed description of the input data required in EnergyPLAN tool for the modelling of the reference scenario is realized. The collected data, their sources and the implementation methods utilized in this research are discussed.

To achieve a detailed and comprehensive description of the required inputs for the EnergyPLAN tool, this chapter is being conducted in accordance with the tabs in the EnergyPLAN tool. Briefly, the principal tabs of the EnergyPLAN tool are the following:

- Demand
- Supply
- Balancing and storage
- Cost

A.1 Demand tab

A.1.1 Electricity

The primary data collected from the Hellenic Electricity Distribution Network Operator S.A (HEDNO) concerns the hourly load consumption profile of Astypalaia island for the year 2017 (01/01/2017-31/12/2017).

According to David Connolly [2016], in the hourly distribution profile of the total annual production there must be 8784 data points, one for each hour. However, the year of 2017 and due to less days in February (28 days) includes 8760 points which are considered in this report. In EnergyPLAN and as mentioned by David Connolly [2016], the required input of the hourly distributions should include 8784 points for the realization of simulations. For this reason an extra day is added by copying the last day of the year 2017 and assuming that a similar demand follows the day after. Thus, the total number of points reaches the 8784 and the simulations in EnergyPLAN are realized.

The sum of the values representing the hourly load consumption results in the total annual electricity demand for the island of Astypalaia in 2017, which was calculated in an Excel spreadsheet . Thus, the total annual electricity demand for Astypalaia in 2017 is equal to 6558355.50 kWh or 6558.35 MWh or 6.56 GWh. The hourly load consumption profile for Astypalaia island in 2017 is presented in figure A.1.

Total annual electricity demand: 6558355.50 kWh or 6558.35 MWh or 6.56 GWh
Hourly maximum value: 2224 kW (at 12/08/17 and 21:00)
Hourly minimum value: 241 kW (at 26/03/17 and 3:00)
Annual average load value: 748.90 kW

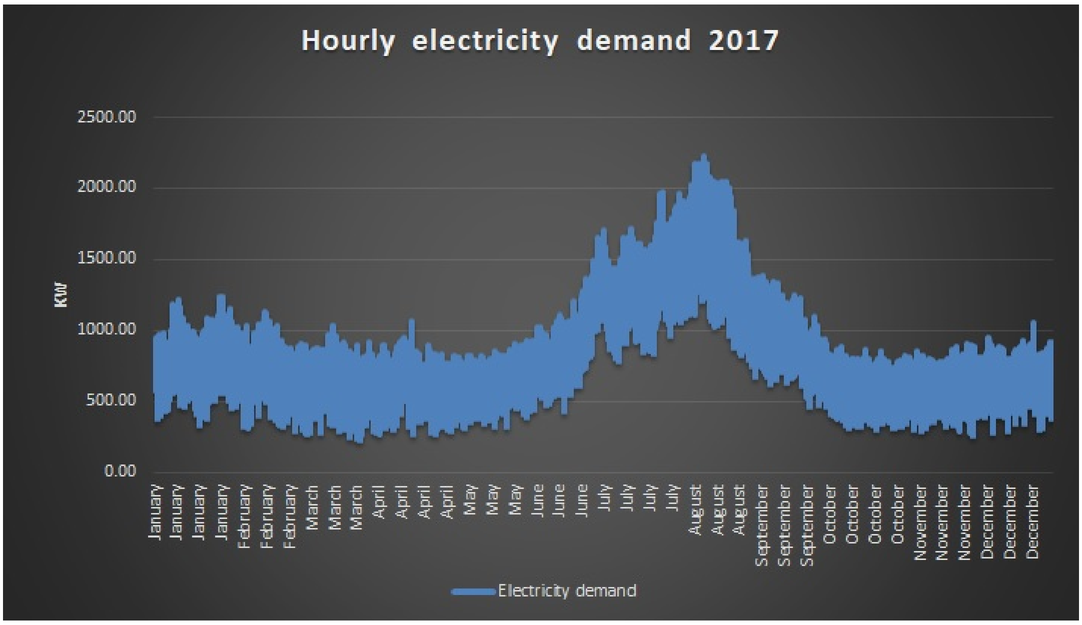

Figure A.1. Hourly electricity demand in Astypalaia for the year 2017, source: Hellenic Electricity Distribution Network Operator S.A (HEDNO)

In order to calculate and fill in the fields of electric heating and electric cooling the approach describe in the following sub-section is followed. The principal concept is to split the annual electricity demand according to the delimitations of this report. Thus, the annual electricity demand is distinguished to the electricity demand of the residential sector and of the commercial sector. The purpose of this approach is to provide a deeper insight in each sector and more realistic estimations and accurate data.

Classification of the total annual electricity demand

In order to investigate each sector separately and obtain more realistic and accurate results, a classification of the total annual electricity demand is realized. This research divides the total annual electricity demand into two main categories, representing two distinct sectors which are:

i) Residential sector electricity demand
ii) Commercial sector electricity demand

The purpose of this classification is to calculate the total annual electricity demand and examine the share of fuels, the sources of energy and the types of end-uses for each of the sectors separately. This provides a more thorough analysis of the energy sector and the annual load demand profile while strengthens the modelling of the reference scenario by providing greater accuracy in the values.

In detail, the reason for breaking down the total annual electricity demand into these distinct sectors, is to estimate for each case the percentage of electricity which is utilized for heating and cooling purposes. Thus electric heating demand is divided into i) residential electric heating demand and ii) commercial electric heating demand. The total annual electric heating demand is a required input in the EnergyPLAN tool and it is calculated for each sector separately and conclusively it is summed up.

The same procedure is followed for the electric cooling demand which initially is estimated separately for each of the categories and eventually it is summed up to calculate the total annual electric cooling demand of Astypalaia island. Conclusively, the sum of the total annual electricity demand for cooling of these two categories is the total annual electricity demand for cooling of Astypalaia island.

Residential sector

To estimate the total annual residential electricity demand, the total number of inhabitants of Astypalaia island is necessary. That is 1334 inhabitants and according to Eurostat, the average electricity consumption per capita in the residential sector in Greece is 1.6 MWh per year. The average electricity consumption per capita for the residential sector in Greece as a whole is selected, as it is the most accurate and relevant value for the purposes of the calculations since it has been challenging to find the average electricity consumption per capita for Astypalaia island.

Hence:

1334 inhabitants x 1.6 MWh per capita consumption = 2134.4 MWh or 2.13 GWh

Based on the typical residence characteristics and the rooms total floor area profile as described in chapter 5, a double bedroom and a single bed are commonly encountered. For this reason, this report assumes that 3 persons live per residence. That gives the number of residential customers, which is approximately 445 residences. The total number of residential customers and residences is useful for calculations which follow and about the heating and cooling demands and the number of installed units in the residential sector.

The next stage of the calculations process involves the estimation of the electric heating demand. For calculating the total annual electric heating demand for the residential sector the following procedure is followed. By knowing the total annual residential electricity consumption and from secondary data obtained from Euro-stat and for the year 2016, about the share of final energy consumption in the residential sector in Greece and according to the type of end-use, the percentages of electricity utilized for heating and cooling purposes are acknowledged.

According to Eurostat, the following percentages describe the share of final energy consumption in Greece for the residential sector and by type of end-use, for the year 2016 :

- Space heating 56.9%
- Space cooling 4.1%
- Domestic hot water 12.4%
- Cooking 6.5%
- Lighting and appliances 20.1%

As described in the analysis of the residential sector in chapter 5, the space heating in the residential sector is achieved via fireplaces and heating stoves with wood-chips or wood as utilized input fuel. In few cases electric heaters might be used which are disregarded in the calculations of this research, as it is impossible to find the precise number of units and hence energy demand data.

The domestic hot water demand is considered to be reached by the use of individual electric boilers and in some cases solar thermal collectors. Since the share of the solar thermal collectors is unknown, this research assumes that electricity exclusively is accounted for the domestic hot water demand. The domestic hot water demand is considered stable throughout the whole year as the basic purpose is for securing hot water for shower. Only in summer months the electricity for domestic hot water might present a slight increase due to the increased numbers of visitors.

Hence:

Electricity for domestic hot water = 12.4% of the total electricity demand in the residential sector or 12.4% of 2.13 GWh = 0.26 GWh

Furthermore, from the secondary data described above and according to Eurostat, it is possible to estimate the electric cooling demand in the residential sector of Astypalaia island. At this point it should be clarified that an assumption of this report is the total cooling demand is satisfied exclusively by electric air-conditioning (A/C) units. That is the only way for cooling load provision on the island and in Greece as a whole, as district cooling is not available.

Thus the following calculations are made:

Electricity for space cooling = Electric cooling demand in the residential sector or 4.1% of 2.13 GWh = 0.0874 GWh or 0.09 GWh

The resulting data for the residential sector is summarized in figure A.2.

Residential sector		
Total number of inhabitants in Astypalaia island	1334	
Annual electricity consumption per capita in Greece (Eurostat source)	1.6	MWh
Total annual electricity demand	2.13	GWh
Total annual electricity demand for heating	0.26	GWh
Total annual electricity demand for cooling	0.09	GWh

Figure A.2. Data for the residential sector in Astypalaia

Commercial sector

In this report and according to the delimitations described in section 3.3, there are two dominant categories accounted for the total annual energy electricity consumption, the residential sector and the commercial sector. It should be clarified that in the commercial sector are considered the services as described in the commercial sector analysis section 5.4. and in the delimitations section 3.3. Thus, by subtracting out of the total annual electricity demand the total annual electricity demand of the residential sector, the total annual electricity demand of the commercial sector is calculated.

Hence:

Total annual electricity demand - total annual residential electricity demand = Total annual commercial sector electricity demand or 6558.35 MWh - 2134.4 MWh = 4423.95 MWh or 4.42 GWh.

According to the analysis of the commercial sector as mentioned in section 5.4 and to the classification of sub-sectors according to the type of services provided, the following assumptions and calculations are made.

Hotels and other accommodation services

In order to estimate the average energy consumption, share of fuels and the type of end-use consumption (e.g.: cooling, space heating, domestic hot water, lighting etc.) different scientific papers are reviewed [A. Moiá-Pol, Michalis Karagiorgas, V. Martínez-Moll, R. Pujol, Carles Riba-Romeva, 2006; Michalis Karagiorgas, Theocharis Tsoutsos A. Moiá-Pol, 2007; Ifigenia Farrou, Maria Kolokotroni, Mat Santamouris, 2012]. The purpose is to assess the secondary data and apply the most relevant data and as realistic as possible for representing the context of Astypalaia island.

According to Michalis Karagiorgas, Theocharis Tsoutsos A. Moiá-Pol [2007], the examination of results in the form of specific energy indicators for 10 hotels in Greece is introduced. These hotels are classified to distinct star categories and hotel types such as 'Mount' for mountain, 'City hotels' for hotels in the city and 'Coastal type' or 'resorts' for hotels commonly encountered in coastal areas. In addition, it is demonstrated the energy flow through the hotel interface starting from the fuel input and concluding to five end-use services.

This report assumes the hotels and other accommodation types located in Astypalaia island to belong in the 'Coastal type' category, as the majority of these buildings are located in places close to the coastline. In addition, from information obtained through online research and phone-call discussions with local hotel managers, the majority of hotels and other accommodation types in Astypalaia includes traditional houses and studio complexes, as well as a small number of resorts and hotels. None of them is considered to have an infrastructure of such large capacity such as the hotels on the city or the mountain. Thus, it is considered adequate to assume that the hotels and other accommodation types in Astypalaia are in the 'Coastal type' category. This is important to clarify for the calculations to follow for the modelling of the reference scenario.

Regarding the hotels and other accommodations capacity, there are 3 different types of categories for hotels, the "Deluxe", "category B", and "category A" hotel types reflecting on the capacity and the hotel class [Michalis Karagiorgas, Theocharis Tsoutsos A. Moiá-Pol, 2007]. In this report, the type of hotels and other accommodation types are assumed to belong in the "category B" as mentioned in "A simulation of the energy consumption monitoring in Mediterranean hotels: Application in Greece", which describes small to medium capacity hotels. It is chosen as some samples presented in 'A simulation of the energy consumption monitoring in Mediterranean hotels: Application in Greece' are 'Coastal type' hotels in the island of Crete and other Greek islands. Thus, the energy consumption profiles and the secondary data available in 'A simulation of the energy consumption monitoring in Mediterranean hotels: Application in Greece' and applied in this report are chosen because they are the most relevant representation of typical hotels in Greek islands and thus in Astypalaia island. They can offer the most relevant secondary data for this thesis research case.

The total average energy consumption for the type of hotels examined is estimated to be 17.59 KWh per night spend (p.n.s). This average is calculated based on the energy consumption of 4 different coastal type hotels.[Michalis Karagiorgas, Theocharis Tsoutsos A. Moiá-Pol, 2007]

Furthermore, the electricity is the most significant energy intake, as it is accounted for 38% of the overall annual consumption Michalis Karagiorgas, Theocharis Tsoutsos A. Moiá-Pol [2007]. However, after a number of phone-call discussions with hotel managers in Astypalaia, it has been found that the majority of hotels and studios utilize in principal electricity for fulfilling the energy demand. In one case, an electric heat pump is used and solar water heaters for domestic hot water. Nevertheless, in this report, it is assumed that electricity is accounted for 100% of the energy consumption of a hotel or studio facilities in Astypalaia.

For Astypalaia island and the reference scenario model, the total average energy consumption considered in this report and as stated by Michalis Karagiorgas, Theocharis Tsoutsos A. Moiá-Pol [2007], is for the coastal type of hotels and equals to 17.59 KWh/p.n.s. The hotels and other accommodation services operate during the touristic season (summer months) which is from April to late October (210 days of operation). Hence, the total average energy consumption for the hotels and other accommodation types in Astypalaia is calculated to be 3693.9 kWh/year. It should be mentioned that this number does not reflect the true value of energy consumption in Astypalaia and it might deviate from the realistic value. Nevertheless it provides a pragmatic estimation.

As mentioned by A. Moiá-Pol, Michalis Karagiorgas, V. Martínez-Moll, R. Pujol, Carles Riba-Romeva [2006], hotels within the Mediterranean area may have have identical energy consumption profiles due to the similar types of technology, climate and customers. Nevertheless, the energy consumption per night spend may differ at a significant extent as it depends on several factors such as: facilities provided, category of hotel, occupancy, nationality of clients (different habits), architecture of buildings, design and control of installations and other. Since the actual energy consumption representing the hotels in Astypalaia island could not be found due to time restrictions and difficulty in correspondence with the responsible Greek authorities, the total average energy consumption for a hotel in Astypalaia island in a year, is considered to be equal to 3693.9 kWh/year during the operating season (April to October).

Thus, according to the existing infrastructure in Astypalaia as described in the commercial sector analysis in section 5.4.1, the total number of accommodation services (including both hotels and other accommodation types) is 103 (16 hotels and 87 other accommodation types).

Hence, the total electricity consumption for this sector is calculated as follows:

3693.9 kWh/year x 103 = 380471.7 kWh or 380471 MWh or 0.38 GWh.

From this number and according to 'A simulation of the energy consumption monitoring in Mediterranean hotels: Application in Greece', the following percentages for the electricity consumption are obtained: 61% space heating, 18% domestic hot water, 5% laundry, 3% catering, 7% shared lighting, 2% electricity for room, 2% lift and 2% VAC/HVAC. Thus, it is estimated that the percentage of electricity for heating purposes (space heating and domestic hot water) is 79%. In Astypalaia the hotels and studios are considered traditional buildings with no lifts and thus the percentage of electricity consumption by lifts is added to the VAC/HVAC, which gives 4% of VAC/HVAC.

Hence, the electric heating demand for hotels and other types of accommodation is 79% of 0.38 GWh and equals to 0.30 GWh and the electric cooling demand equals to 0.01 GWh.

The resulting data for the hotels and other accommodation types sector is summarized in figure A.3.

Hotels and other accommodation types sector		
Total number of hotels and other accommodation types	103	
Total annual electricity demand	0.38	GWh
Total annual electricity demand for heating	0.3	GWh
Total annual electricity demand for cooling	0.01	GWh

Figure A.3. Data for the hotels and other accommodation types in Astypalaia

Dinning businesses and food catering services

As described in section 5.4.1, the analysis identified 64 businesses for dining and food catering services. As it was challenging to obtain separate information for the average energy consumption of this sector, these types of buildings are assumed to have similar energy demand profiles for easing the data estimation process. Eventually, if the actual data and energy balances for the total number of dining businesses and food catering services in Astypalaia is collected, then the numbers can be adjusted according to the case.

Regarding the fuel utilization for energy provision in this sector, mostly electricity and LPG propane or natural gas tanks are being used. Electricity covers the majority of end-uses and LPG propane input fuel is utilized for the kitchen stoves and grills. A detailed description of the LPG consumption, the calculations for the LPG fuel input and the necessary input data in EnergyPLAN are described in section A.1.4.

It has been a challenge to obtain the actual shares in the final energy consumption according to the fuel type for the dining and food catering sector in Astypalaia. Therefore, in this report the energy consumption is divided according to the secondary data obtained from Euaggelos Spiliotis in the thesis 'Projections for the energy consumption in buildings and level of electricity use by using energy consumption indicators'.

In 'Projections for the energy consumption in buildings and level of electricity use by using energy consumption indicators' the percentages of energy consumption are given for 5 different climate zones for restaurants in the U.S.A. Each climate zone presents different energy consumption patterns according to the prevailing in the area temperatures. This report considers the following energy distribution profile as it is the most relevant profile matching the description and energy demands of a typical restaurant in Astypalaia. As described in the analysis of the sector in section 5.4.3, the cooling and heating consumption holds insignificant percentages and the priority is given to the water heating and cooking. The figure A.4 illustrates an -as close as possible- energy distribution profile and this is why it is chosen to be applied in the calculations for the reference scenario.

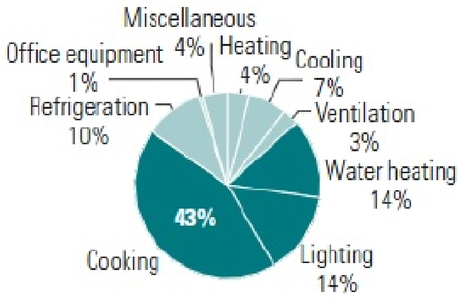

Figure A.4. Energy distribution for a typical restaurant in Astypalaia

As it can be seen from the pie chart, electricity is accounted for approximately 57% in the final energy consumption while the LPG propane for approximately 43% ,which is reflected in the pie chart by the percentage for the cooking purposes. Thus, as estimated, if 43% is 0.65 GWh to 0.87 GWh then the 57% equals to 0.93 GWh to 1.15 GWh of electricity. The values and calculations considered for the annual LPG consumption in the sector are described in section A.1.4. In this report the highest demand values are considered, 0.87 GWh of LPG propane and 1.15 GWh of electricity. The ranges can be taken into consideration in the sensitivity analysis.

According to the pie chart, the 28% of the annual electric consumption is for ventilation (3%), space heating (4%), space cooling (7%) and water heating (14%). The above mentioned end-uses are fulfilled by electricity. Thus, the electric heating and cooling demands can be calculated based on this secondary data.

The resulting data for the dining businesses and food catering services sector is summarized in figure A.5.

Dining businesses and food catering services sector		
Total number of dining businesses and food catering services	64	
Total LPG propane demand (cooking purposes: kitchen stoves and grills)	0.87	GWh
Total annual electricity demand	1.15	GWh
Total annual electricity demand for heating	0.21	GWh
Total annual electricity demand for cooling	0.12	GWh

Figure A.5. Data for the dining businesses and food catering services sector in Astypalaia

School buildings

In this report, the school facilities situated at the island of Astypalaia are assumed to have similar energy consumption profile, since accurate realistic data for each of the buildings could not be obtained. Thus the secondary data collected, which reveals an average energy consumption per school building, is multiplied by 2 and represents the energy consumption for both school facilities of Astypalaia island.

Following the same approach as for the other services, firstly the average energy consumption for a school building is obtained and then according to the percentages of each fuel type in the total energy consumption and according to the end-use types, results are obtained for the electric consumption, electric heating and electric cooling demand.

The secondary data applied in this report is obtained from the scientific paper 'Energy Consumption in Non-Domestic Buildings: A review of schools'. In 'Energy Consumption in Non-Domestic Buildings: A review of schools' and as described by Richard A.R. Kilpatrick and Phillip FG. Banfill, a Greek school on average consumes approximately 57 kWh of electricity per square meter. Furthermore, Richard A.R. Kilpatrick and Phillip FG. Banfill in 'Energy Consumption in Non-Domestic Buildings: A review of schools' present key school details and total electricity consumption, in accordance with the school total floor area and the year of school construction.

The school building is assumed to belong in the category of school building with an estimated total floor area of 1225 square meters and year of construction in 1960, as presented in 'Energy Consumption in Non-Domestic Buildings: A review of schools'. Thus, the total electricity demand of a school of total floor area 1225 square meters is assumed to be 235543 kWh annually. Conclusively and as already mentioned in the beginning of this section, the total electricity consumption is multiplied by 2, which is the total number of schools situated in Astypalaia island. Thus the total annual energy demand for the 2 schools is estimated.

Total annual electricity demand for 2 school buildings of Astypalaia island: 471086 kWh or 0.47 GWh

In 'Energy consumption in schools: A review paper' it is presented the average energy use profile of schools in the USA and in this report it is assumed that this consumption profile is valid for the schools in Astypalaia. After literature research, it is found that the secondary data provided in 'Energy consumption in schools: A review paper' is the most reliable and recent, providing an adequate paradigm of an average energy distribution profile of a school building.

The average electricity use profile of schools in the USA are illustrated in 'Energy consumption in schools: A review paper' and concern the following: 47% space heating, 14% lighting, 10% cooling, 9% ventilation, 7% water heating, 5% other, 4% computers, 2% refrigeration, 1% cooking, 1% office equipment.

Applying this energy use profile for the case of school buildings in Astypalaia and since it is acknowledged that electricity is the only fuel for energy provision, estimations can be made for the total annual electric heating and cooling demand.

Hence:

Electric heating demand: (47% space heating + 7% water heating) of 471086 kWh = 254386 kWh or 0.25 GWh

Electric cooling demand: (10% cooling + 2% refrigeration) of 471086 kWh = 56530 kWh or 0.06 GWh

The resulting input data for the school buildings in Astypalaia are summarized in figure A.6.

School buildings and education sector		
Total number of school buildings in Astypalaia	2	
Total annual electricity demand	0.47	GWh
Total annual electricity demand for heating	0.25	GWh
Total annual electricity demand for cooling	0.06	GWh

Figure A.6. Data for the school buildings in Astypalaia

A.1.2 Heating

In EnergyPLAN tool the heat demand is categorized in i) the individual heating demand with the associated the fuel inputs and ii) the district heating demand . In addition, the user is able to establish an average heat demand per building and estimate the correct number of units needed for fulfilling the individual heat demand.

In present there is no district heating available on the island of Astypalaia and hence it is excluded from the energy simulation. In Astypalaia there is demand for individual heating and electric heating. Working in the same methodology framework as for electricity demand tab, each sector is examined separately for the individual heating demand and the fuel inputs.

Residential sector

A typical residence in Astypalaia and the energy sources utilized in the final energy consumption have been already described in section 5.3. The individual heating demand can be framed as the amount of energy needed for space heating provision. It has been noted already that the domestic hot water demand is fulfilled by electricity and electric boilers and is considered steady throughout the year.

Concerning the space heating demand and as outlined from the literature review and also validated by documentary evidence through phone-calls, a typical residence includes a fireplace or a heating stove for burning wood or other similar kind of fuel sources (pellet) to secure heating provision during the winter months and early spring. However, there is a number of residences which utilize the electric air-conditioning (A/C) units for space heating if necessary. Nevertheless, the exact number for the space heating demand in the residential sector from electricity as a fuel source is challenging to be obtained.

In EnergyPLAN, the fuel sources and supply units are required as an input. However, since there is no option for heating stoves or fireplaces, the most adequate option to represent heating stoves and fireplaces is chosen. For this reason, this report assumes that biomass boilers represent the heating stoves and fireplaces and the efficiency of which should be low, to realistically represent the amount of the heating output produced. Further information regarding this issue is presented in Supply section A.2, in the appendix.

It has been a significant challenge to calculate, based on actual data, the annual heat distribution for the Greek island of Astypalaia. Nevertheless, the literature review of similar completed studies have highlighted an adequate methodology for estimating the annual heat distribution on a daily basis and in the next stage, at an hourly basis. This concerns strictly the heating demand required for space heating.

For estimating the daily annual heating distribution the Heating Degree Day (HDD) method has been used. As stated by David Connolly in "Finding and Inputting Data into EnergyPLAN guide", the HDD indicate the level of heating required on a specific day. In further detail, the temperature within a building is 2-3 degrees Celsius more than outside. Hence, if the ambient temperature is 16 degrees Celsius then the indoor temperature of a building should be 18-19 degrees Celsius. If the ambient temperature is decreased then the indoor building temperature decreases accordingly. Thus, the space heating is necessary to provide heating and fulfill the heating demand.

Data obtained online from the website 'degreedays.net'. As stated in the website, 'degreedays.net' calculates degree-day data for energy-saving professionals worldwide and the software is developed based on temperature data from Weather Underground.In this software it is possible to choose a weather station and obtain data for the HDD in Celsius or Fahrenheit and for a chosen time frame. In this report and since Astypalaia does not have a local weather station, the closest weather station to the island has been chosen which is situated in Santorini island, on the west of Astypalaia. Since the annual hourly distribution profile for electricity is for the year 2017, the HDD chosen for the year 2017 as well.

A necessary input is to define a basic temperature according to which the temperature differences are created. As stated by Matzarakis A., Balafoutis C. in 'Heating degree-days over Greece as an index of energy consumption' (2004), the basic temperature is determined by the constructional specifications of buildings and their application in research. Furthermore, since the architecture and the constructional techniques differ from region to region (Matzarakis A., Balafoutis C.), it is challenging to establish a fixed base temperature for the whole Greek territory.

Nevertheless, in 'Heating degree-days over Greece as an index of energy consumption', Matzarakis A. and Balafoutis C. approximated a basic temperature of 14 oC by utilizing experimental and empirical methods of trial and error. As quoted by Matzarakis A. and Balafoutis C. the basic temperature of 14 oC corresponds realistically to the requirements of the Greek region. Therefore, this report applies this value of basic temperature (14 oC) in the calculations for the heating and cooling degree days (HDD and CDD).

After downloading the HDD for the year 2017, a conversion is achieved from HDD (which are in degrees Celsius) to the amount of heat energy per square meter needed for space heating. This action is completed by applying the necessary formula, in Excel spreadsheet and estimating the heat energy for every day of the year 2017. The formula can be seen in figure A.7.

$$Q = P_{specific} \times 24 \times \frac{D}{1000} \text{ [kWh]}$$

Figure A.7. Formula for calculating the total energy in kWh

The specific heat loss rate is Pspecific. This can be calculated as the sum of the heat losses per degree of each element of the buildings' thermal envelope (such as windows, walls, and roof) or as the average U-value of the building multiplied by the area of the thermal envelope of the building. In this research, it is assumed that the residential buildings are constructed by poured concrete and bricks covering a floor area of 0,50 meters squared. The estimated heat energy Q in this formula is given in in kWh per meters squared. (Wikipedia,2018)

In the next stage and since the average floor area of a typical residence in Astypalaia has been already estimated and described in section 5.4.3, the annual daily heat demand for one typical residence in Astypalaia is estimated. Conclusively, the annual daily heat demand is multiplied by the number of residential customers already estimated in section A.1.1 (445 residences). The result is to obtain data for the annual daily heat distribution for the residential sector in Astypalaia island and thus calculate the annual heating demand for the residential sector.

The HDD and CDD method has an output of daily annual profile of demands for heating and cooling respectively. However, in EnergyPLAN tool the input for the distributions of heating and cooling demands should be in an hourly distribution profile. Therefore, a conversion from daily to hourly demand distribution per year is required. To accomplish this conversion from daily to hourly demand distribution profile, the following assumption is made and illustrated in figure A.8. This hourly heating demand profile is estimated based on the daily habits at an average basis for the population in Greece.

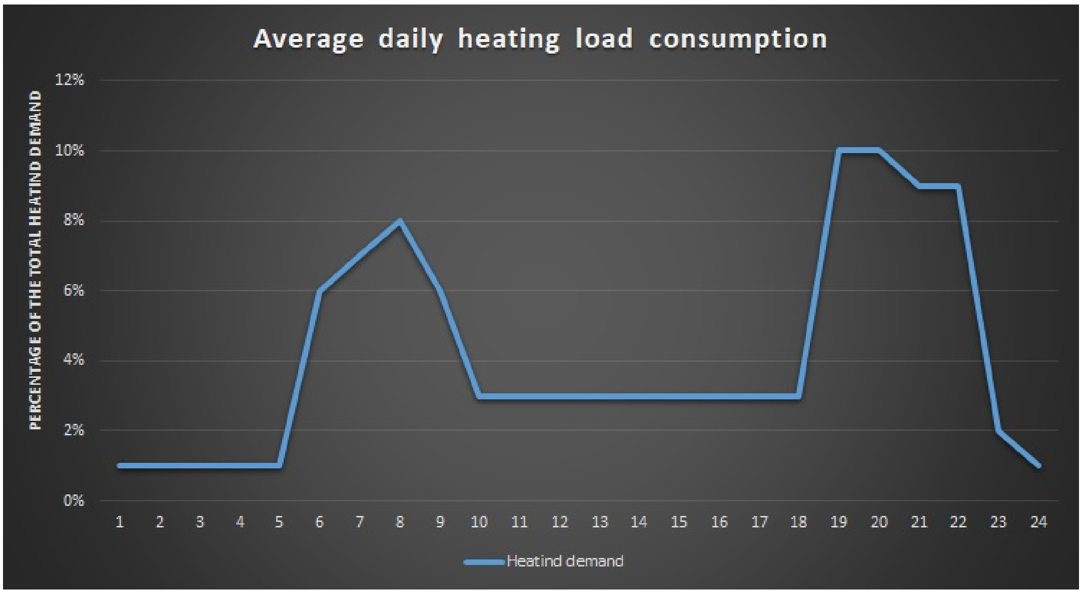

Figure A.8. Average daily heating load consumption profile

As illustrated in the graph, from 06:00 to 09:00 an increase in heating demand is observed. This increase is due to the need for space heating during the morning hours and breakfast time, which gradually decreases and stabilizes during the day. At 18:00 the heating demand marks a substantial increase which remains at elevated levels until 22:00 and gradually decreases to almost reach zero levels during midnight. This rapid increase during afternoon to evening hours is explained by the fact that most of population arrive at home after leaving work. Therefore, the space heating is turned on to heat the residence until the night when it is time to sleep. Applying the above described hourly heating distribution profile within each day for the year 2017, the hourly heating load distribution profile for

Astypalaia is estimated.

The results and the graph illustrating the annual hourly heating demand for the year 2017 and for a basic temperature of 14 oC, are presented in figures A.9 and A.10 respectively. The figure A.10 presented below illustrates the hourly heating load distribution for Astypalaia island in the year 2017.

Residential sector		
Number of residential customers	445	Residences
Total individual heating demand (biomass boilers)	0.19	GWh
Total electric heating demand	0.26	GWh
Total annual heating demand	0.45	GWh

Figure A.9. Results for the heating demand in the residential sector in Astypalaia

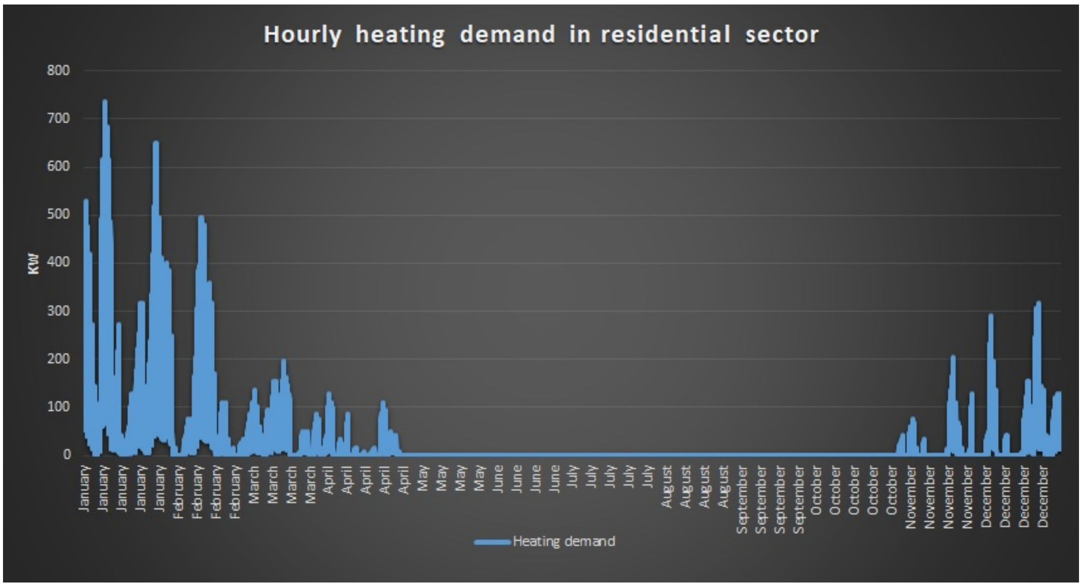

Figure A.10. Hourly heating demand for the residential sector in Astypalaia and for the year 2017

At this point it should be clarified that the value of the daily heat demand in residential sector is known (HDD method) and represents the space heating demand. The electric heating demand refers mostly to the domestic hot water demand and it is independent with the HDD calculations for the interior temperature of a building and its space heating demand. Only an unknown number of residences utilize electricity for space heating (through the use of A/C units), including the school buildings in Astypalaia. These facts are of major significance and to be take under consideration for the necessary hourly distribution input in EnergyPLAN.

In EnergyPLAN, the 'heating' tab includes both the individual heating demand and the electric heating demand. These demands are utilizing the same hourly demand distribution file for distributing the yearly demand into each hour of the year. Hence, the hourly heating demand distribution file which is an output of the HDD method is calculated only based on temperatures and regarding the space heating demand, excluding the electricity demand.

The percentages and hourly demand for electricity used for space heating and domestic hot water demand are unknown.

To overcome this issue, either accurate and realistic assumptions should be made and inserted in the HDD calculation method or an already existing hourly heating demand distribution profile should be selected. In this report and in order to provide a more accurate hourly distribution for the case of Astypalaia island, and acknowledging the fact that the electric heating is steady for domestic hot water throughout the year (including summer season), a different hourly heating demand distribution file is selected which is already created in EnergyPLAN data folder and is illustrated in figure A.11.

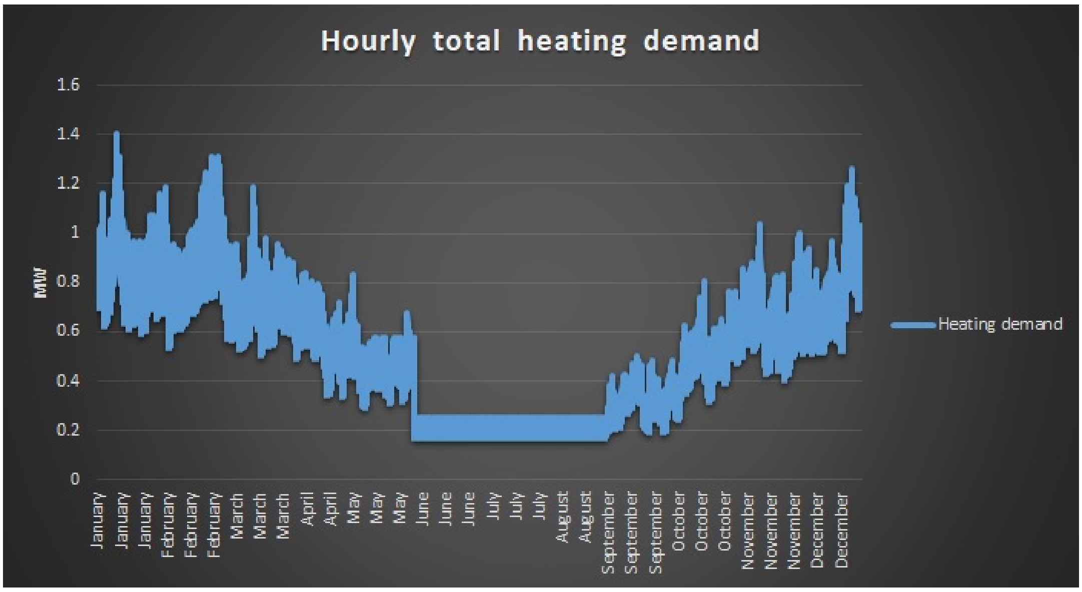

Figure A.11. Hourly heating demand distribution profile inserted in EnergyPLAN for the reference scenario calculations

The graph illustrated in figure A.11 is closely related with the actual and realistic hourly heating demand distribution profile in Astypalaia island, considering both the electricity and individual heating demands and the end-type uses (space heating and domestic hot water). The purpose for not inserting the hourly distribution file obtained from the HDD calculations is that it only includes the space heating demand and the heating demand from electricity is not included in the calculations. As already mentioned above, the assumptions and additions required for creating the actual hourly heating demand distribution profile may have deviated at a significant extent from the actual case. Hence, it is decided in this report to chose an already existing file as an input in EnergyPLAN, which represents as closely as possible the pragmatic hourly profile of Astypalaia. The HDD method and calculations are necessary for assisting this research to define an hourly distribution profile which concerns the Greek environment and with data obtained from a neighboring to Astypalaia island weather station.

The process is that, firstly HDD method contributes in this research by outlining the hourly heating demand distribution profile which is assumed to be valid for Astypalaia. The second step is to identify a suitable existing hourly heating demand distribution profile which is similar to the HDD output file and which also includes a steady heating demand (referring to electric heating) during the summer months. The research in the already existing files in EnergyPLAN tool identified the file 'Hour_indv-heat-50procent' (graph illustrated in figure A.11) to be an adequate input in EnergyPLAN, representing the hourly distribution in Astypalaia for the modelling of the reference scenario.

It was challenging to identify the exact share and percentages of electric heating used for space heating through A/C units and the electric boilers usage for domestic hot water, at an hourly basis. Thus, the chosen hourly heating demand distribution profile is applied in the calculations in EnergyPLAN and it can be changed at a later point, if the data required for the actual hourly distribution profile is acquired.

Hotels and other accommodation services

The hotels and other accommodation services are assumed to utilize only electricity for heating through electric A/C units. It should be again clarified that the operating season for the hotels and other accommodation types concerns the summer season, as during the winter season they are not operating. The operating season for the hotels and any other types of accommodation for tourists lasts up to 7 months, from April since late October. Thus, there is no significant if no heat demand at all during the rest of the year and during the summer months there is no need for space heating but only for domestic hot water.

Conclusively, hotels and other accommodation services are not considered in the individual heating demand calculations and in the HDD method besides for the electric heating where they have a specific heating demand presented in figure A.3, in section A.1.1.

Dinning businesses and food catering services

In order to estimate the individual space heating demand for the total number of dining businesses and food catering services, the HDD method is utilized.

Since the total floor indoor area of the dining businesses and food catering services differs from that of a typical residence in Astypalaia, the value of total floor area is changed according to the indoor average. This average is estimated according to the primary data collected through a number of phone-calls with managers of restaurants and cafe bars. The average indoor total floor area is considered to represent all the dining businesses and food catering services in Astypalaia.

As described in section 5.4.3, typical dining businesses and food catering services have indoor spaces ranging from 40 to 80 square meters. This report considers the 80 square meters to represent an average business of the sector and thus this value is input in the HDD calculations for the annual hourly heating demand. The daily consumption percentage profile and the basic temperature for the HDD calculations are considered to be the same as for the residential sector. Conclusively, adjustments can be made in each case if the actual daily heat distribution profile of all the dining businesses and food catering services in Astypalaia is obtained.

It has to be clarified that from the documentary evidence obtained from the phone-calls with managers, the majority of the dining businesses and food catering services might occasionally use fireplaces or heating stoves for heating provision during the winter days.

Despite the fact that a number of restaurants might be closed or operating at a very low level due to lack of customers, this research includes this sector in the heating demand calculations.

The actual heating demand and fuel consumption for the dining businesses and food catering services and for space heating provision might deviate from the assumptions made in this report. The precision of the resulting data would be increased if actual data from each dining business and food catering service is obtained. Since this process is difficult to be achieved within the established time frame of this research, the data inserted in the calculations in EnergyPLAN for the reference scenario model, is the output of the HDD method.

After inputting the average total floor area of the indoor space, the daily annual heating demand can be estimated per dining business or food catering service business. The total number of businesses in this sector is already acknowledged and described in analysis section 5.4.1., and thus the annual hourly heating demand is multiplied with the total number of businesses in this sector. The resulting hourly heating demand profile represents the space hating demand for the dining businesses and food catering services sector.

Figure A.12 presents the summary of results for the heating sector of the dining businesses and food catering services in Astypalaia. Figure A.13 shows the hourly heating demand for the dining businesses and food catering services sector for the year 2017.

Dining businesses and food catering services sector		
Total number of dining businesses and food catering services	64	
Total LPG propane demand (cooking purposes: kitchen stoves and grills)	0.87	GWh
Total annual electricity demand for heating	0.21	GWh
Total annual individual heating demand (biomass boilers)	0.036	GWh
Total annual heating demand (withount LPG propane demand)	0.25	GWh

Figure A.12. Results for the heating demand in the dining businesses and food catering services sector in Astypalaia

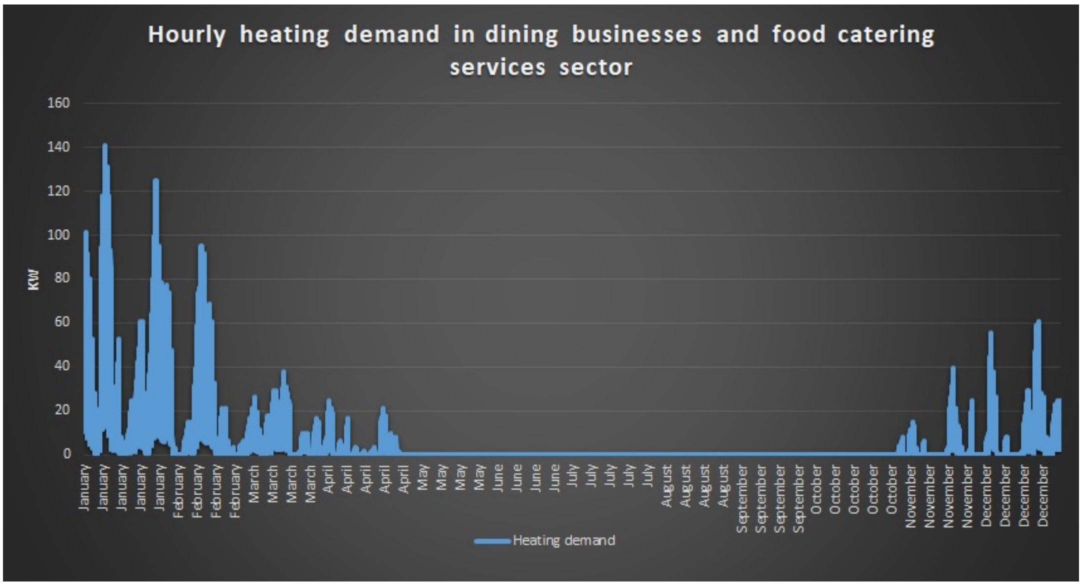

Figure A.13. Hourly heating demand for the dining businesses and food catering services sector in Astypalaia and for the year 2017

Another type of heating demand for cooking purposes is the consumption of LPG propane fuel. This is accounted for the kitchen stoves and grills of the dining services and food catering services. The LPG propane fuel demand is not considered as space heating demand and thus it is considered as an input demand in the 'Industry and other fuel' tab in EnergyPLAN. It is described further in the 'Industry and other fuel' section A.1.4.

School buildings

The school buildings of the island are assumed to fulfill the heating demand exclusively by electric heating. Thus the are not included in any other calculations for other fuel inputs in the final heating consumption. The electricity demand for heating purposes is already presented in section A.1.1 and in figure A.6.

Heating demand per building in Astypalaia

The heat demand per building is used to calculate the cost per unit for individual heating. Individual buildings in this report are assumed to be the residential buildings, the hotels and other accommodation types, the buildings of the dining businesses and food catering services sector and the two school buildings. The average heat demand per building is estimated by the following formula:

Heat demand per building = Total yearly heat demand/Number of buildings in Astypalaia.

Thus: 1.25 GWh / 445+64+2+103 = 2035 kWh per building. This input in EnergyPLAN gives the number of individual heated households of 614 individual heated household units.

A.1.3 Cooling

In EnergyPLAN the cooling tab includes i) the individual cooling which includes a field for electricity for cooling, and ii) the district cooling which is characterized by the different

CHP groups and heat pumps or chillers for cooling.

In Astypalaia island the cooling demand is covered by electric air-conditioning and thus the only input in EnergyPLAN is the electricity for cooling. This value is already calculated in section A.1.1 and for each sector.

Additionally, following the same calculation procedure in Excel spreadsheet as for the HDD and the hourly heating demand profile in Astypalaia, the cooling demand and the hourly cooling demand profile are estimated.

The base temperature is the same as for the heating demand (14 oC) and the same weather station for data collection is chosen. The exact same calculation steps are applied as described in A.1.2 for the residential sector. The only difference is that the data obtained from the website Degree days.net concern the cooling and not the heating.

The purpose of the cooling demand calculation applying the CDD method is not the actual number of cooling demand, but for obtaining the hourly cooling demand distribution profile which is required as an input for EnergyPLAN and for the reference scenario modelling. The daily hourly cooling load distribution profile applied in the calculations is approximated according to Giannakopoulos C. and Psiloglou E. B., in 'Trends in energy load demand for Athens, Greece: weather and non-weather related factors'. Figure A.14 illustrates the daily hourly heating demand profile applied in the calculations. In figure A.15 the hourly cooling demand distribution profile is presented.

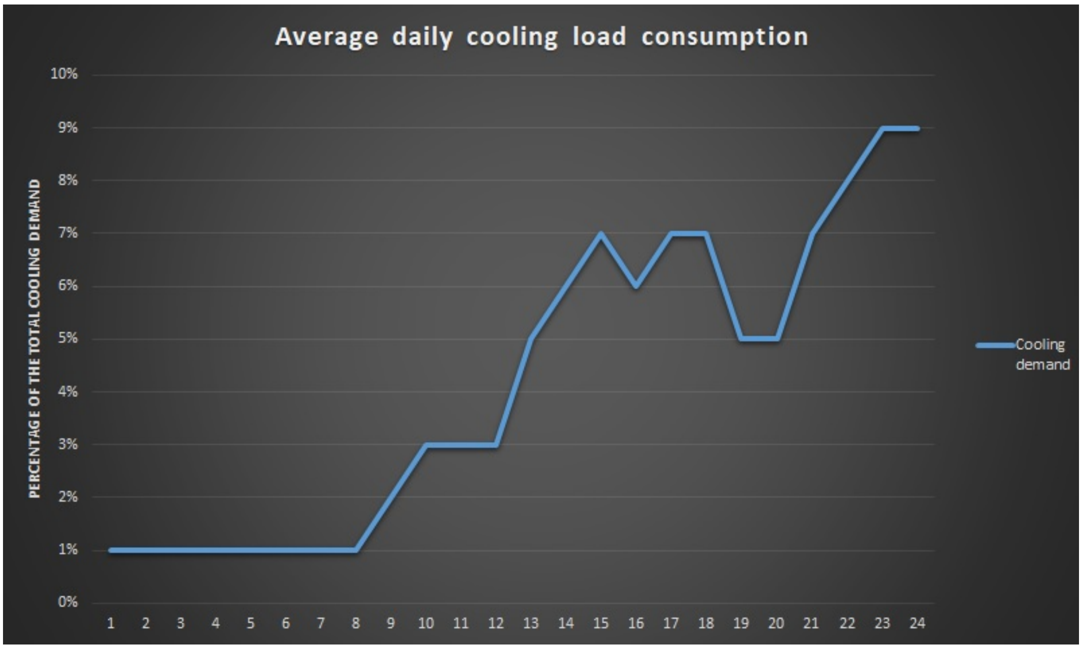

Figure A.14. Hourly cooling demand distribution percentages for an average summer day

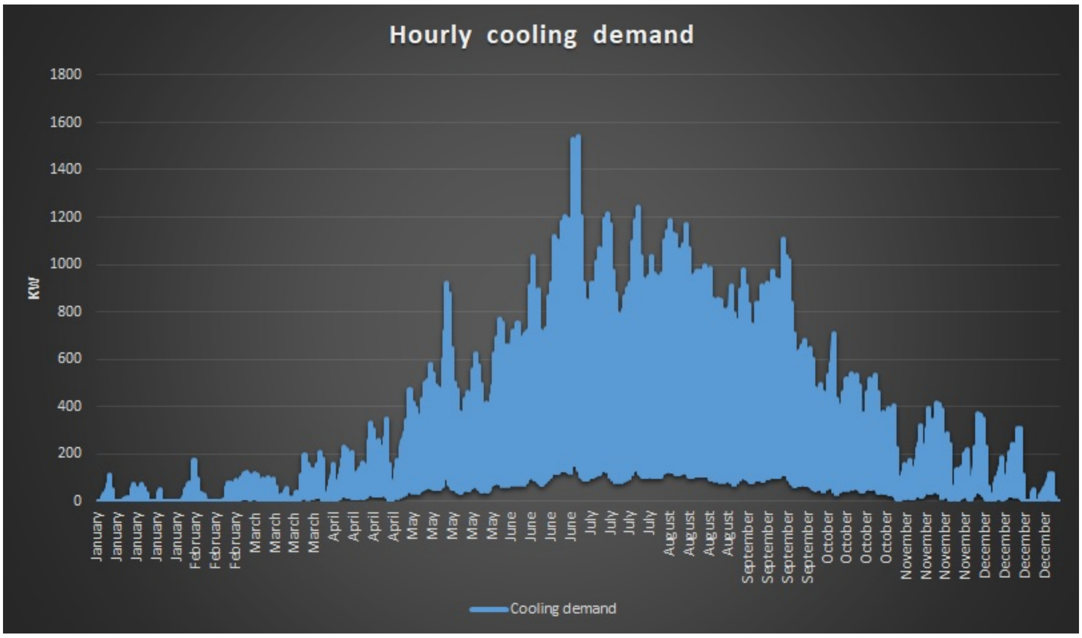

Figure A.15. Hourly cooling demand distribution profile in Astypalaia and for the year 2017

In this report and as also already set in EnergyPLAN tool, the COP of the electric air-conditioning units is assumed to be 2.

Conclusively in figure A.16 are shown the resulting input data for the cooling tab in EnergyPLAN.

Input data for cooling tab in EnergyPLAN		
Total annual electicity demand for cooling	0.19	GWh
Total annual cooling demand	0.38	GWh
Coefficient of Performance for A/C units	2	

Figure A.16. Resulting input data for the cooling demand tab in EnergyPLAN

A.1.4 Industry and other fuel consumption

In this research and according to the established delimitations described in section 3.3, there is no accurate data available for the industrial sector, the transport and the water demand. Thus these demand tabs are excluded from the reference scenario.

Nevertheless, according to the perspective of this report, the LPG propane fuel consumption is considered as an input within the 'Industry and other fuel' tab in EnergyPLAN as it is separated from the space heating and domestic hot water heating purposes. It should be noted though that in this tab in EnergyPLAN there is no option for inserting LPG as an input fuel. Hence, the field 'Ngas' referring to natural gas is filled in with the assumption that it represents LPG propane.

Regarding an estimated annual input fuel consumption and as acknowledged from the phone-call discussions with dining businesses and food catering services managers, the estimated annual consumption of LPG propane tanks on average is ranging between 30-40 tanks of 25kg each. According to 'elgas.com', 1 kg of LPG (Propane) equals to 49 MJ and

1 MJ equals to 0.278 kWh. Thus the calculations for the annual LPG propane demand for the restaurants and cafe bars can be estimated.

Thus the following calculations give the total annual LPG propane demand:

30 - 40 LPG tanks x 25 kg each gives 750 to 1000 kg of LPG annually for a restaurant or cafe bar on average. According to the conversion units this number corresponds to 10216.5 - 13622 kWh. Since the total number of dining businesses and food catering services in Astypalaia is 64, then the total annual LPG propane demand can be calculated as the following:

64 x 10216.5 to 13622 kWh = 653856 kWh to 871808 kWh of LPG propane annually or 0.65 GWh to 0.87 of LPG propane.

To provide a more realistic hourly consumption profile, an LPG propane hourly demand profile is established and according to the operation level of the dining businesses and food catering services which is related to the touristic season. The operating season for this sector commences on late April to early May and finishes in late September. The maximum amount of tourists arrives on the island during August.

Moreover, it is assumed in this report that the restaurants operate at highest levels during lunch time (12:00 to 16:00) and during the evening hours and dinner time (20:00 to 23:00). The hourly LPG propane demand on a typical summer day and for the purposes of this report is illustrated in figure A.17, while the annual hourly LPG propane demand is shown in figure A.18. The LPG consumption as can be seen in the graph is considered almost steady throughout the operating period. Even though it is not considered actual LPG propane consumption of the sector, since it is challenging to identify the exact LPG propane use, it provides a realistic hourly distribution profile as an input for the reference scenario modelling in EnergyPLAN.

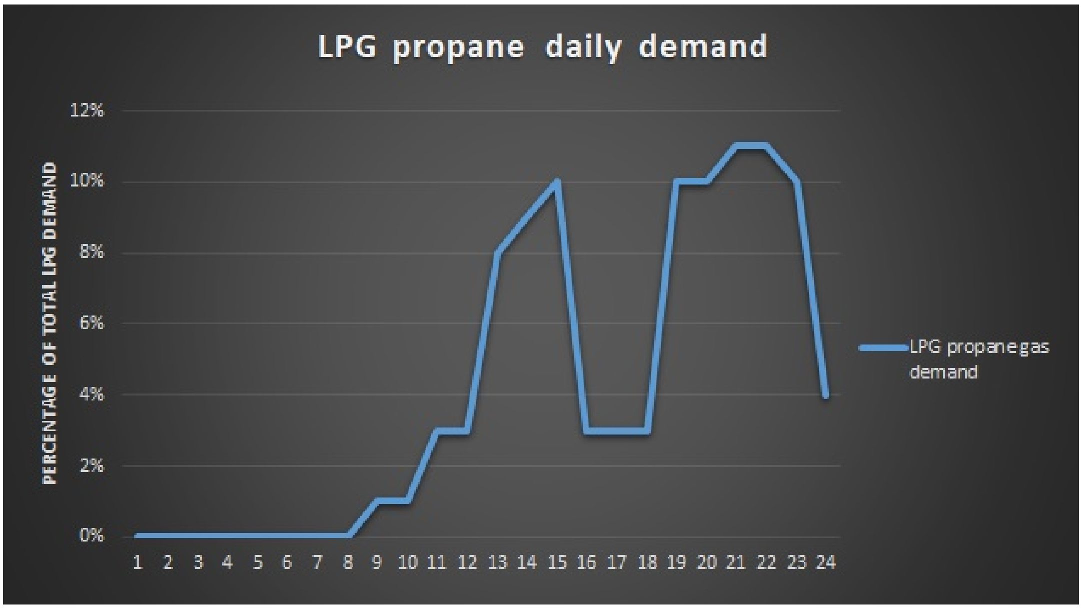

Figure A.17. Hourly LPG propane demand in a daily basis during the summer season

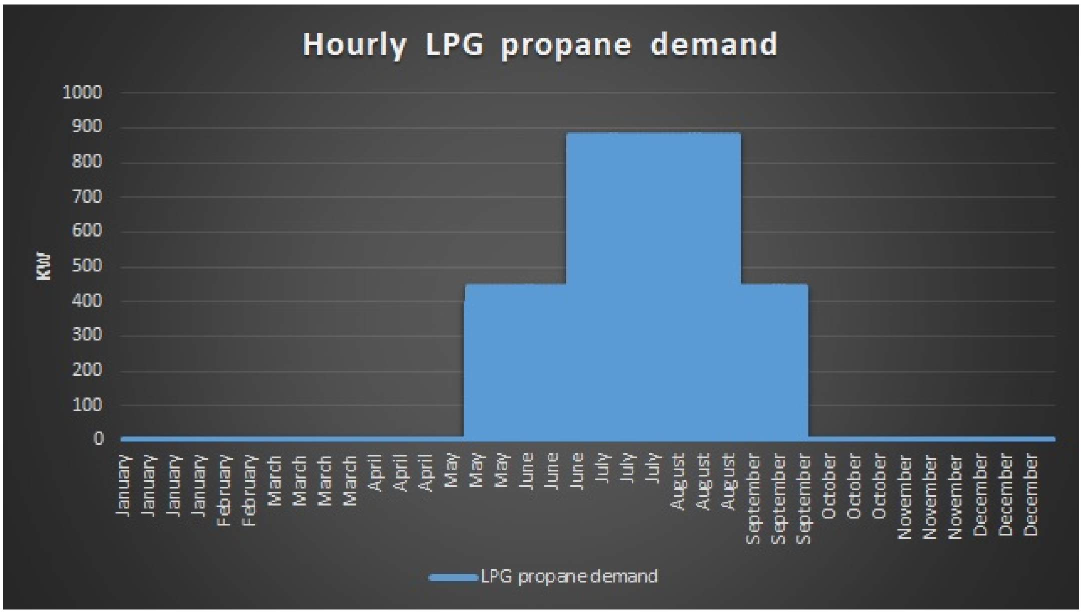

Figure A.18. Annual hourly LPG propane demand during the summer season

A.1.5 Summary of input data for the 'Demand' tab

The summary of the input data for the 'Demand' tab in EnergyPLAN, as applied in this report and for the development of the reference scenario model, is shown in figure A.19.

Total annual electricity demand	6.56	GWh
Annual electric heating demand	1.02	GWh
Annual electric cooling demand	0.28	GWh
Hourly distribution file for Astypalaia obtained from (HEDNO) and for the year 2017		
Annual individual heating demand	0.23	GWh
Biomass boiler efficiency	0.5	
Annual fuel input in biomass boiler (wood, wood-chips,pellet)	0.46	GWh
Annual electric heating	1.02	GWh
Total individual heat demand	1.25	GWh
Hourly distribution file for Astypalaia heating demand : Hour_indv-heat-50procent from EnergyPLAN distribution file		
Annual electricity for cooling (individual cooling)	0.28	GWh
COP for the electric air-conditioning (A/C) units	2	
Hourly distribution file for Astypalaia cooling demand obtained from the CDD method (basic temp 14oC)		
Industry and other fuel consumption : Ngas (as LPG propane) fuel intake	0.87	GWh
Hourly distribution file for Astypalaia LPG demand created by the author and based on hourly consumption assumptions		

Figure A.19. Input data and hourly distribution files in the 'Demand' tab in EnergyPLAN for the reference scenario model

A.2 Supply

In the Supply tab in EnergyPLAN tool there are different types for energy provision. It includes the plants for supplying heat and electricity, electricity only, heat only, and the distribution of fuels. It also includes the option for waste incineration for the supply of energy, liquid and gas fuels and carbon capture and storage or recycling.

In this report and in the reference scenario for Astypalaia island the only type of power supply existing on the island is the power plant accounted for the provision of electricity only. Thus the tabs in which data is input are the "Electricity only" and the "Fuel distribution" tab. The rest of the tabs are with no data as an input.

A.2.1 Electricity only

Thermal power station

The power generation units in Astypalaia have been already described in the energy system analysis and section 5.2. The power provision in Astypalaia island is achieved by a thermal power station (condensing power plant) of a total nominal capacity of 3.83 MW and licensed capacity of 3.30 MW. The technical characteristics for the current power generation units in Astypalaia are taken from the Hellenic Electricity Distribution Network Operator (HEDNO) for the year 2017.

The efficiency of the thermal power station in Astypalaia can be calculated from the data obtained by HEDNO. As presented in figure 5.2 in the energy system analysis in section 5.2, the amount of input fuel and specific consumption is known and depends on the operation level of the thermal power station. The value of the total electricity production (energy output) for the year 2017 has been already calculated and equals to 6558.35 MWh. The amount of input fuel for the plant considering an average operation rate of 75%, is 1448214.847 kg. Thus the efficiency is calculated to be 0.45 which is the input value in EnergyPLAN tool.

A.2.2 Fuel distribution

This tab shows the distribution of fuel on the different technologies. The field which is completed is the 'PP1' field with oil as an input fuel.

To calculate the GWh/year of fuel intake, the total annual fuel intake for an operation of the thermal power station at 75% is known and is 1448214.847 kg. The calorific value in diesel oil fuel as taken from the European Automobile Manufacturers Association (ACEA) is roughly 45.5 mega-joules per kilogram (MJ/kg). Thus the total calorific value of 1448214.847 kg of diesel oil is calculated to be 65893775.53 MJ. A conversion from MJ to GWh gives 18.30 GWh of fuel intake per year.

A.2.3 CO2

In this tab the CO2 content of the input fuels utilized for the modelling of the reference scenario is needed. This data is taken from Energistyrelsen (2015) and is the following:

Coal: 93,95 kg/GJ
Fuel Oil / Diesel / Petrol / JP: 73,58 kg/GJ
Natural gas: 56,95 kg/GJ
LPG (propane): 63,1 kg/GJ
Waste: 36,79 kg/GJ

In this report the carbon capture and storage technology (CCS) is not considered as currently there is no CCS technology and facilities in Astypalaia island.

A.2.4 Summary of input data for the 'Supply' tab

The summary of the input data for the 'Supply' tab in EnergyPLAN, as applied in this report and for the development of the reference scenario model, is shown in figure A.20.

Central Power Plants :	Condensing PP2	3300	kW-e
Power plant efficiency		0.45	
Annual fuel intake		18.3	GWh
CO2 content in fuels :			
Coal		93.95	kg/GJ
Fuel oil diesel petrol/JP		73.58	kg/GJ
Ngas		56.95	kg/GJ
LPG		63.1	kg/GJ
Waste		36.79	kg/GJ
CCS and CCR :			
CO2 captured by CCS		0	kt
Electricity Consumption		0	MWh/t CO2

Figure A.20. Input data in the 'Supply' tab in EnergyPLAN for the reference scenario model

A.3 Balancing and storage

The balancing and storage is not included in the reference scenario as there is no data for balancing and storage units in the Greek island of Astypalaia. Thus the electricity, thermal and liquid and fuels storage are not considered in this report and in the calculation in EnergyPLAN.

A.4 Cost

In this section the total number of inputs related with the associated costs for the Reference scenario and the data sources are described.

A.4.1 General

In the 'general' costs tab in EnergyPLAN the price for the CO2 emissions is required. This value is included in the marginal production prices and as identified by the Organization for Economic Co-operation and Development (OECD), in Greece for the year 2012, the average permit price was equal to 7,24 EUR per tonne of CO2. This price is taken into account for the calculations in this report.

The interest rate is the next required input in EnergyPLAN. The long term interest rate for Greece and as set according to "ycharts" equals to 4,27% for March 2018. At this point it should be clarified that the interest rate for economic calculations of a project might vary depending if the calculations are business-economic (including taxes) or socio-economic (no taxes included) and it is dependent on the potential investors. Assuming to represent a realistic long term interest rate for this type of projects, this report considers the interest rate of 4,27% in the EnergyPLAN calculations.

CO2 price: 7,24 EUR / t CO2
Greece long term interest rate: 4,27%

Moreover, it should be highlighted that the above mentioned data are not the main focal point of this research and they can be adjusted at a later point if more accurate numbers are found. This research focuses on the comparison of different scenarios and the incorporated technologies under constant fixed values. Thus, since the price per CO2 emissions and the interest rate is constant for all the examined scenarios, the results are not significantly influenced and important conclusions can be outlined.

A.4.2 Investment and fixed O&M

In this tab of the EnergyPLAN tool are included all the investment and fixed operation and maintenance (O&M) costs for distinct sources of energy generation.

For modelling the reference scenario in Astypalaia island in the tab "Heat and electricity" the category of large power plants can be found.

From data obtained from the Hellenic Electricity Distribution Network Operator S.A (HEDNO) the construction and commissioning costs for a new conventional power station in Astypalaia are classified according to the input fuel. The power generation units utilizing heavy fuel oil have construction and commissioning costs of 1,3 million EURO / MW while the power generation units utilizing light fuel oil have 1 million EURO / MW construction and commissioning costs. This research assumes the costs of construction and commissioning as the total investment costs and the costs for power generation units utilizing heavy fuel oil are considered.

Furthermore, the fixed operation and maintenance costs as obtained from HEDNO and accounted for the power station in Astypalaia island are equal to 155 EURO / MWh. In EnergyPLAN the operation and maintenance costs are expressed as a percentage of the total investment costs and thus they are calculated according to the chosen investment costs for Astypalaia case.

The total lifetime selected represents the total lifetime of the power generation units in Astypalaia. According to information obtained from HEDNO which is presented in section 5.2, the type of units is Mitsubishi S16R-PTA. The technical lifetime of each units is dependent on the total operating hours.

This report assumes according to 'Technology Data for Energy Plants Updated chapters' by Energinet.dk, 2016, that the installed units in Astypalaia have a technical lifetime of 25 years and currently are in the period of extended lifetime of 15 years. Thus, the 15 years lifetimes is input in EnergyPLAN calculations for the reference scenario.

In summary the investment and fixed operation and maintenance costs are the following:

Cost of construction and commissioning of a new conventional station (considered as investment costs in this research)

· 1.3 million €/MW for heavy fuel power generating pairs

· 1,0 million €/MW for light fuel power generating pairs

· 155 € / MWh fixed operating and maintenance costs of the Astypalaia conventional power station.

This report to simplify the cost calculations considers that each unit utilizes heavy fuel diesel oil, since specific fuel input for each unit is not known. Thus, the cost for each unit in the calculations of the reference scenario is considered to be equal to 1.3 million €/MW.

Regarding the 'Cost' tab and the sub-tab 'heat infrastructure', the costs for the individual boilers, which in this case are the heating stoves and the fireplaces, as well as the costs for the electric heating units (electric A/C units) are required. The prices regarding electric A/C units vary from 600 EURO to 1400 EURO, from information gathered from price catalogues from the markets in Greece. Thus it is assumed that per unit 1000 EURO is the total investment, which is the value applied in the calculations in EnergyPLAN. The same price is considered for the individual boilers as there is no relevant and realistic data for this tab.

For the reference scenario none of the other shown tabs in the 'investment and fixed O&M' are filled in. The tabs are filled accordingly with the current energy infrastructure of Astypalaia island which includes the power plant and the heat infrastructure for individual boilers and electric heat.

A.4.3 Fuel

The 'fuel' tab in EnergyPLAN includes the world market prices of fuels, the fuel handling costs and the taxation on fuels and electricity. The world market prices for fuels input in EnergyPLAN are obtained from David Connolly (2015) and 'the FIDE guide'. The LPG world market price is obtained from 'https://www.mylpg.eu/stations/greece/prices' as it is not included in the calculations by David Connolly. The LPG price is for Greece and concerns minimum and maximum record prices. In this report and for the calculations the minimum record price of LPG is considered. According to David Connolly and 'the FIDE guide', the purchasing costs for each fuel were obtained for the years 2007, 2010/2015 and 2020 and recommended by the International Energy Agency and the Danish Energy Authority. In this report the costs for the year 2010/2015 are considered and expressed in EURO per Giga-Joule. This is because it is assumed that in 2020 the current energy system will not be used as the smart energy system would have been implemented. Thus the fuel prices should be relevant for the year 2017 and the closest dates to this year. The fuel prices considered in this report are the following:

Coal: 3,19 EURO/GJ

Fuel oil: 9,60 EURO/GJ
Diesel/Gas-oil: 17,00 EURO/GJ
Petrol/JP: 18,00 EURO/GJ
Natural gas: 8,16 EURO/GJ
LPG: 0,575 EURO/L = 230 EURO/GJ
Biomass: 7,01 EURO/GJ

Since the handling costs for Greece could not be obtained, this research considers the costs valid for Denmark and according ti Connolly David, [2015]. It is possible at a later point for the handling costs to be changed according to the case when the actual handling costs representing Greece are found. The fuel handling costs considered in this report are presented in figure A.21:

€/GJ	Fuel oil	Gas oil/Diesel	Petrol/JP	Coal	Natural gas	Biomass
Power Stations (central)	0,228	0,228	-	0,067	0,428	1,160
Distributed CHP, district heating and industry	1,914	1,807	-	-	1,165	1,120
Individual households	-	2,905	-	-	2,945	6,118

Figure A.21. Fuel handling costs according to Danish Energy Agency (DEA)

Lastly, since it is a socio-economic analysis, the taxation is not included and hence the fields related to 'taxes' are not included. The costs for fuel are presented in the following table.

A.4.4 Variable O&M

Power plants and individual variable O& M costs are considered as inputs for the reference scenario. Since HEDNO only provided the fixed operation and maintenance costs, the variable operation and maintenance costs should be assumed. These assumptions are based on David Connolly and 'the FIDE guide'. As mentioned in 'the FIDE guide', for the condensing power plant the variable operation and maintenance costs are obtained from the technology data for energy plants by the Danish Energy Agency and Energinet.dk. The variable O&M costs from David Connolly and 'the FIDE guide' are applied in the calculations for the reference scenario and are 1,8 EURO per MWh produced. It should be mentioned that these costs do not represent the actual costs for each power generation unit in Astypalaia island. However they are considered reliable and are used in the calculations.

The costs representing the individual supply side are taken from NVE (2015) and converted to EURO currency, since information about the current pricing context in Greece could not be obtained. These costs and as stated in NVE include the variable O&M cost for the following:

Individual boiler: 1,57 EURO/MWh-th
Individual CHP: 0 EURO/MWh-e
Individual heat pump: 0,21 EURO/MWh-e
Individual electric heating: 0,10 EURO/MWh-e

A.4.5 Summary of input data for the 'Cost' tab

In figure A.22 the input data in the 'Cost' tab it is presented. The handling costs have been already presented in figure A.21 in section A.4.3 and the variable O&M costs in section A.4.4.

General costs :		
CO2 price (included in marginal production prices	7.24	EURO/t CO2
Interest rate	4.24	%
Investment and fixed O&M : Heat and Electricity tab		
Large Power Plants investment cost	1.3	kEURO pr. Unit
Period in years	15	
O&M as a percentage of the investment	8.9	%
Investment and fixed O&M : Heat Infrastructure		
Individual boilers investment cost	1	kEURO pr. Unit
Individual boilers O&M as a percentage of the investment	8	%
Individual electric boilers investment cost	1	kEURO pr. Unit
Individual electric boilers O&M as a percentage of the investment	8	%
Fuel costs :		
Fuel price (world market prices) :		
Coal	3.19	EURO/GJ
Fuel oil	9.6	EURO/GJ
Diesel Gasoil	17	EURO/GJ
Petrol/JP	18	EURO/GJ
Ngas	8.16	EURO/GJ
LPG	230	EURO/GJ
Biomass	7.13	EURO/GJ

Figure A.22. Input data in the 'Cost' tab in EnergyPLAN for the reference scenario model

A.5 External electricity market

The external electricity market costs are not taken into account in this research.

EnergyPLAN results B

In this Appendix section the results for the reference scenario are presented in figures B.1 and B.2.

Input Astypalaia_Reference scenario.txt — The EnergyPLAN model 13.0

Electricity demand (GWh/year):		Flexible demand	0.00
Fixed demand	5.26	Fixed imp/exp.	0.00
Electric heating + HP	1.02	Transportation	0.00
Electric cooling	0.28	Total	6.56

District heating (GWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	0	kW	0.00	GWh/year	0.00	Grid
Photo Voltaic	0	kW	0	GWh/year	0.00	stabili-
Wave Power	0	kW	0	GWh/year	0.00	sation
River Hydro	0	kW	0	GWh/year	0.00	share
Hydro Power	0	kW	0	GWh/year		
Geothermal/Nuclear	0	kW	0	GWh/year		

	Capacities		Efficiencies		
Group 2:	kW-e	kJ/s	elec.	Ther	COP
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	0		0.45		

Heatstorage: gr.2: 0 MWh gr.3: 0 MWh
Fixed Boiler: gr.2: 0.0 Per cent gr.3: 0.0 Per cent

Electricity prod. from	CSHP	Waste (GWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.00	0.00

Regulation Strategy:	Technical regulation no. 2	
CEEP regulation	000000000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	kW
Minimum PP	0	kW
Heat Pump maximum share	0.50	
Maximum import/export	0	kW

Distr. Name :	Hour_nordpool.txt	
Addition factor	0.00	EUR/MWh
Multiplication factor	2.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	227	EUR/MWh
Gas Storage	0	MWh
Syngas capacity	0	kW
Biogas max to grid	0	kW

Fuel Price level: Basic

	Capacities kW-e	Storage MWh	Efficiencies elec.	Ther.
Hydro Pump:	0	0	0.80	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:		0.000		

(GWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	0.00	0.00	0.00
Household	0.00	0.00	0.00	0.46
Industry	0.00	0.00	0.00	0.00
Various	0.00	0.00	0.87	0.00

Output

District Heating

	Demand: Distr. heating kW	Production: Solar kW	Waste+ CSHP kW	DHP kW	CHP kW	HP kW	ELT kW	Boiler kW	EH kW	Ba-lance kW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
GWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Electricity and Exchange

	Consumption: Elec. demand kW	Flex.& Transp. kW	HP kW	Elec-trolyser kW	EH kW	Hydro Pump kW	Production: Tur-bine kW	RES kW	Hy-dro kW	Geo-thermal kW	Waste+ CSHP kW	CHP kW	PP kW	Balance: Stab-Load %	Imp kW	Exp kW	CEEP kW	EEP kW	Exchange Payment Imp (1000 EUR)	Exp
January	542	0	0	0	187	0	0	0	0	0	0	0	729	100	0	0	0	0	0	0
February	458	0	0	0	191	0	0	0	0	0	0	0	649	100	0	0	0	0	0	0
March	394	0	0	0	163	0	0	0	0	0	0	0	557	100	0	0	0	0	0	0
April	425	0	0	0	131	0	0	0	0	0	0	0	556	100	0	0	0	0	0	0
May	460	0	0	0	102	0	0	0	0	0	0	0	562	100	0	0	0	0	0	0
June	768	0	0	0	46	0	0	0	0	0	0	0	814	100	0	0	0	0	0	0
July	1166	0	0	0	46	0	0	0	0	0	0	0	1213	100	0	0	0	0	0	0
August	1287	0	0	0	46	0	0	0	0	0	0	0	1334	100	0	0	0	0	0	0
September	751	0	0	0	71	0	0	0	0	0	0	0	822	100	0	0	0	0	0	0
October	449	0	0	0	106	0	0	0	0	0	0	0	555	100	0	0	0	0	0	0
November	418	0	0	0	139	0	0	0	0	0	0	0	558	100	0	0	0	0	0	0
December	434	0	0	0	166	0	0	0	0	0	0	0	600	100	0	0	0	0	0	0
Average	631	0	0	0	116	0	0	0	0	0	0	0	747	100	0	0	0	0	Average price	
Maximum	2173	0	0	0	326	0	0	0	0	0	0	0	2218	100	0	0	0	0	(EUR/MWh)	
Minimum	53	0	0	0	41	0	0	0	0	0	0	0	204	100	0	0	0	0	-	-
GWh/year	5.54	0.00	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.56		0.00	0.00	0.00	0.00	1000 EUR	0

FUEL BALANCE (GWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Electro-Fuel	Wind	PV	Wave	Hydro	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Net	CO2 emission (kt): Total	Net
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Oil	-	-	-	-	-	14.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	14.58	0.00	14.58	3.86	3.86
N.Gas	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.87	0.87	0.00	0.87	0.18	0.18
Biomass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.46	-	0.46	0.00	0.46	0.00	0.00
Renewable	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
H2 etc.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear/CCS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	14.58	-	-	-	-	-	-	-	-	-	-	-	-	0.46	0.87	15.91	0.00	15.91	4.04	4.04

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Figure B.1. Page 1 of EnergyPLAN results for the reference scenario

Output specifications Astypalaia_Reference scenario.txt The EnergyPLAN model 13.0

District Heating Production

	Gr.1 District heating kW	Gr.1 Solar kW	Gr.1 CSHP kW	Gr.1 DHP kW	Gr.2 District heating kW	Gr.2 Solar kW	Gr.2 CSHP kW	Gr.2 CHP kW	Gr.2 HP kW	Gr.2 ELT kW	Gr.2 Boiler kW	Gr.2 EH kW	Gr.2 Storage kW	Gr.2 Balance kW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year GWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00

	Gr.3 District heating kW	Gr.3 Solar kW	Gr.3 CSHP kW	Gr.3 CHP kW	Gr.3 HP kW	Gr.3 ELT kW	Gr.3 Boiler kW	Gr.3 EH kW	Gr.3 Storage kW	Gr.3 Balance kW	RES specification RES1 Wind kW	RES2 Photo kW	RES3 Wave kW	RES 4-7 kW	Total kW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year GWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00

Own use of heat from industrial CHP: 0.00 GWh/year

ANNUAL COSTS (1000 EUR)		
Total Fuel ex Ngas exchange =		527
Uranium =	0	
Coal =	0	
FuelOil =	516	
Gasoil/Diesel=	0	
Petrol/JP =	0	
Gas handling =	0	
Biomass =	12	
Food income =	0	
Waste =	0	
Total Ngas Exchange costs =		26
Marginal operation costs =		13
Total Electricity exchange =		0
Import =	0	
Export =	0	
Bottleneck =	0	
Fixed imp/ex=	0	
Total CO2 emission costs =		29
Total variable costs =		595
Fixed operation costs =		431
Annual investment costs =		1007
TOTAL ANNUAL COSTS =		2033

NATURAL GAS EXCHANGE

	DHP & Boilers kW	CHP2 CHP3 kW	PP CAES kW	Indi-vidual kW	Trans port kW	Indu. Var. kW	Demand Sum kW	Bio-gas kW	Syn-gas kW	CO2Hy gas kW	SynHy gas kW	SynHy gas kW	Stor-age kW	Sum kW	Im-port kW	Ex-port kW
January	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	99	99	0	0	0	0	0	0	99	99	0
June	0	0	0	0	0	224	224	0	0	0	0	0	0	224	224	0
July	0	0	0	0	0	362	362	0	0	0	0	0	0	362	362	0
August	0	0	0	0	0	351	351	0	0	0	0	0	0	351	351	0
September	0	0	0	0	0	145	145	0	0	0	0	0	0	145	145	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	99	99	0	0	0	0	0	0	99	99	0
Maximum	0	0	0	0	0	957	957	0	0	0	0	0	0	957	957	0
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total for the whole year GWh/year	0.00	0.00	0.00	0.00	0.00	0.87	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.87	0.87	0.00

RES Share: 2.9 Percent of Primary Energy 0.0 Percent of Electricity 0.0 GWh electricity from RES 22-May-2018 [17:55]

Figure B.2. Page 2 of EnergyPLAN results for the reference scenario