Master Thesis

Sustainable Energy Planning on the Power System of the Greek Islands based on Green Hydrogen development (Case study: The Island of Crete)

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Abstract

Renewable Energy Sources (RES) and pioneer Green Hydrogen technologies present great potential in the Greek Islands when it comes to eliminating the dependence on fossil fuels and contributing significantly in the development of a more sustainable energy future. The main target of this Master Thesis Project was to examine the feasibility of setting up a Sustainable Energy Planning in the Greek Islands, which focuses on Green Hydrogen development, by taking into account all the different parameters that might affect the energy transition. Based on the current conditions within the Greek islands, an analysis on the potential extensive integration of RES, focusing on solar and wind energy, and the utilization of Green Hydrogen as an ideal sustainable energy carrier for the future economy of the Greek islands was conducted. The capacity of the Greek islands to support this kind of technologies was further elaborated, by highlighting the remarkable solar and wind energy dynamic of the islands in general, and specifically for the island of Crete, that was selected as the case study unit. Finally, the potential challenges that might occur along the way were further explained and relative recommendations were provided. The findings indicate that the Greek Islands present great RES potential, both solar radiation and wind energy potential. This privilege can be further "exploited", and combined with the development of green hydrogen production and storage technologies can help the Greek Islands to follow the energy transition and secure an independent and reliable energy supply.

Acknowledgements

This thesis constitutes the completion of my Master's degree in Environmental and Energy Management (MEEM), at the University of Twente. The synthesis of this thesis feels like a long journey full of unique moments, great lessons, and new opportunities to broaden my horizons.

Now, that we are reaching the end, I would like to express my sincere gratitude to all the people who supported me, each one in his/her own unique way throughout this process. The whole "journey" was quite challenging and demanding, but I am more than grateful for all the experiences I got to live, even under these weird "covid-19" circumstances.

At this point, I would like to express my infinite gratitude to my first supervisor, Prof. Joy Clancy, for her willingness to help me and support me throughout this process. Her valuable and constructive contribution functioned as a stepping stone that gave me motivation to continue and always try to do my best. I would like also to offer my special thanks to my second supervisor, Dr. Frans Coenen, for providing me valuable insights and comments on the topic. With his suggestions, guidance and precious input I was able to comprehend better how to approach the topic and overcome all the potential difficulties I encountered. Also, I would like to thank all the interviewees who were eager to help me, by sharing their knowledge and advice.

Moreover, I would like to express my sincere gratitude to my parents, and of course my brother for their unconditional love, support and patience not only during this journey, but during all those years. Without their presence nothing would be the same. Finally, I want to thank all of my friends for their encouragement and critical advice.

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Abbreviations

GHG Green House Gas

HDNO Hellenic Electricity Distribution Network Operator

HTSO Hellenic Transmission System Operator

IEA International Energy Agency

NECP National Energy and Climate Plan

NII Non Interconnected Island

NIIPSs Non-Interconnected Island Power Systems

NIS National Interconnected System

PPC Public Power Corporation

PV Photovoltaic

RAE Regulatory Agency of Energy

RES Renewable Energy Sources

SNM Strategic Niche Management

TPES Total Primary Energy Supply

TUC Technical University of Crete

TWh Terawatt Hour(s)

Chapter 1: Introduction

1. 1. Background

In the contemporary world, we are witnessing an unprecedented growth in energy demand and this can be mainly attributed to the accelerated growth of population combined with the increase of personal income (Zhang et al., 2016). This steep rise in energy demand constitutes one of the most severe problems on a global scale (Abe et al., 2019), and can bring myriad harmful effects socially, environmentally, and economically (Ritchie et al., 2017).

Despite the fact that Renewable Energy Sources (RES) exploitation presented a significant progress during the last decade, the share of fossil fuels still comprises approximately 80% of the current global energy demand (Johnsson et al., 2019). Indisputably, this hyper-consumption of fossil fuels is extremely hazardous, since it is linked to extensive production of carbon dioxide (CO_2), that constitutes the largest driver of global climate change and air pollution (Ritchie et al., 2017).

Unfortunately, the same pattern in terms of energy production and consumption is engaged by the Greek society (Georgiou et al., 2011). In Greece, as in the rest of the world there has been observed an unprecedented growth in electricity demand, especially after 1990, with the main energy demanding and primary contributors to this significant rise sectors being the domestic and tertiary sectors (Georgiou, Mavrotas & Diakoulaki, 2011).

Greece is a Mediterranean country with unique geomorphological characteristics and numerous islands (Georgiou et al., 2011), which in most cases are also characterized by a highly pollutant fossil fuel energy system (IEA, 2006).

Unfortunately, the intense rise in energy consumption combined with the exhaustion of reserves of fossil fuel jeopardize the future of the energy and economic security of the country (Abe et al., 2019). Therefore, the modern energy power systems should focus more on alternative sustainable options, such as those related to Green Hydrogen development, in order to maximize the utilization of RES, especially the solar and the wind energy, that are predominant within the Greek Islands (Becherif et al., 2015).

RES and pioneer technological advancements such as those related to Green Hydrogen development are the key solutions for the amelioration of the energy system of the Greek Islands. Therefore, in this thesis, an analysis of the dynamic of the Greek Islands in terms of solar and wind energy generation will be executed, in order to further investigate the potential of the islands to follow the energy transition. The island of Crete is selected as the case study unit for further investigation. Finally, all the challenges that might occur along the way will be mentioned, and relevant recommendations for achieving the energy transition will be formulated.

1.2 Problem Statement

The Greek power system is made of two distinct sub-systems (Strantzali et al., 2017). On the one hand, there is the primary interconnected electricity system that extends to the mainland and on the other hand there is the remote power grid of the Greek islands (Georgiou et al., 2011). Greece comprises of more than 100 inhabited islands, and roughly 60 out of them are not interconnected to the mainland grid (Katsoulakos, 2019). These non-interconnected island power systems (NIIPSs) cover the needs of approximately 15% of the Greek population (Katsoulakos, 2019).

In most of the non-interconnected islands (NIIs) the electricity is being generated by local thermal power stations that are utilizing crude oil, heavy oil (mazut) and light oil (diesel) and in some cases by RES (RAE, 2018). Apart from the extensive consumption of fossil fuels, the NIIs face numerous challenges in terms of energy security and stability, since these islands remain dependent on imported energy resources (Katsaprakakis, 2021). On top of that, the current policy framework does not support the development of RES projects (Chatziargyriou et al., 2019). Even up to this day, sustainable projects remain economically unattractive, and when it comes to the licensing processes for these projects, bureaucracy still remains one major problem that creates numerous obstacles and delays (Boemi et al., 2013).

Therefore, the greatest challenge for the citizens of the NIIs is to find a way to meet the accelerating energy demand in a sustainable way and at reasonable cost (Christanis, 2010), and set the right example in terms of Sustainable Energy Development by unveiling the optimal practices for further integration of RES (Kougias et al., 2019) and Green Hydrogen technologies. However, the attempt to reorganize the energy system of the Greek Islands and make it more sustainable, is challenging. It requires regular monitoring of the general socio-economic and environmental framework of the Greek islands, so as to ensure that the transition towards a more sustainable energy future follows the general needs, demands and potential of the Greek society (Angelis-Dimakis et al. 2012).

This brief description indicated that the constantly rising energy challenges that the Greek islands have to deal with increase the necessity for a practical, adaptable and easy-to-apply approach to cover efficiently the future energy needs (Oikonomou et al. 2009).

1.3 Research Objectives

The overarching objective of this research revolves around the potential of creating a more sustainable future for the Greek islands where Green Hydrogen based technologies will be introduced in order to maximize the utilization of RES, predominantly solar and wind energy. Therefore, the primary objective will be to analyse from a theoretical point of view the formation of the energy system of the Greek Islands in order to determine the prerequisites and the feasibility of further development of RES and Green Hydrogen energy technologies within the islands.. Crete will be selected as the case study unit for further investigation. All the parameters that play an important role in the energy transition will be taken into account and will be investigated meticulously with the view to analyzing whether it is achievable for the Greek islands to follow a more sustainable path.

Moreover, the second objective of the research will be to provide details concerning the importance of Green Hydrogen development and to highlight from a theoretical perspective at which stage is Greece in terms of Green Hydrogen development. Therefore, it will be feasible to determine which alterations have to be made in order for such an innovative creation to be incorporated within the energy system of the islands.

Additionally, an examination of the unique characteristics of the Greek Islands in terms of solar and wind potential will be executed, in order to determine how these peculiarities could play a vital role in the energy transition and could be further exploited for the development of Green Hydrogen projects. This research will also focus on analyzing the challenges that might occur during the energy transition.

Indisputably, pursuing a low-carbon energy transition pathway is essential for the Greek Islands, however, this shift is an arduous process that implies a lot of risks along the way. All these challenges and the relative barriers will be further elaborated on this research. In this way, a realistic representation of the currently existing difficulties that impede the energy transition will be executed and the relative recommendations based on the actual needs of the Greek Islands will be presented.

1.4 Research Questions

Taking into consideration the problem and the objectives highlighted in the previous parts, the main research question and the subsequent sub-questions can be classified as following. It is highly important to clarify that the research objective and the research questions are interlinked, this means that each objective will be achieved by analyzing and providing an answer to the relevant sub-question. The main research question is quite generic, and for this reason individual sub-questions have been formulated in order to provide more details that will lead to the clarification and further analysis of the main research question.

- **Main Research Question**

What is the current feasibility of setting up a modern sustainable energy planning in the Greek Islands that focuses on Green Hydrogen-based technologies in order to maximize the utilization of RES?

➢ **Research Sub-questions**

i. *How is the energy system of the Greek Islands currently formulated?*

ii. *What is the current status of Green Hydrogen development and at which stage is Greece in this sector?*

iii. *Which are the most favorable characteristics for realistic incorporation of Green Hydrogen-based technologies in the Greek islands? Which challenges might occur during the energy transition?*

1.5 Research Cases - The selection of the island of Crete

In this research the Greek islands have been chosen as the research units, and more specifically during the synthesis of the thesis Crete was selected for further investigation. There are several arguments for the selection of the island of Crete as the case study unit. Crete constitutes the largest non-interconnected electricity system in Greece and presents favorable geo-morphological and climate characteristics that could facilitate the energy transition. More specifically, Crete possesses abundant solar -the highest solar radiation in Europe (Vourdoubas, 2020)-, and wind energy resources, and thus it constitutes a privileged region for RES and green hydrogen applications. In this island, there can be also found numerous favorable sites for wind parks installations, where the average wind velocity can even reach or exceed the high limit of 8.5m/s.

Additionally, professor Caralis, during our interview mentioned that due to the highly variable nature of RES, technical constraints are imposed by operators to ensure secure and reliable operation of the electrical grid, which often results in the curtailment of an amount of generated energy from RES systems. Therefore, pioneer solutions such as those related to green hydrogen production and storage are recognized as an underpinning technology that can contribute significantly in the resolution of all these challenges within the island of Crete, by storing the surplus energy and convert it back to electrical energy when it is needed.

On top of that, numerous reports and articles concerning the RES and green Hydrogen development in Crete are currently available, hence, the relative material for this research was sufficient and thorough. This is primarily linked to the fact that in Crete there is the Technical University (TUC), where scientists and researchers have already actively started familiarizing and experimenting with green hydrogen energy based technologies. Therefore the scientific background in this region is quite impressive and great effort is being made during the latest years in order for the energy transition to be met successfully.

Chapter 2: Research Approach

In this chapter there will be executed an analysis of the research approach applied in this thesis. More specifically, the strategy that was utilized so as to combine all the different components of the research in a coherent, rational, and well-organized way so that the research problem is sufficiently addressed will be further elaborated. These elements include the theoretical framework, the research methods and the research design.

2.1 Theoretical framework

The theoretical framework when examining energy transitions that promote sustainability is primarily formed by the Strategic Niche Management framework theory (SNM). SNM puts emphasis on the development and implementation of niches, which have an essential purpose to destabilize and reorganize the established regimes (Loorbach, 2006).

The term SNM can be characterized as the approach according to which "sustainable innovation journeys can be facilitated by creating technological niches, i.e. protected spaces that allow nurturing and experimentation with the co-evolution of technology, user practices, and regulatory structures" (Schot & Geels, 2008).

The primary targets of SNM are:

i. To determine the alterations in technology and in the institutional framework that can lead to financial success of the novel technology (Loorbach, D., 2006)

ii. To further discover the technical and economic feasibility of the variable technology options and in this way define the social desirability of the current technology innovation (Loorbach, D., 2006)

iii. To encourage the advancement of these technologies in order to accomplish cost efficiency in mass production (Loorbach, D., 2006)
iv. To clarify which are the necessary changes in the structure of the social organization that have to be made to assist the extensive dispersion of the new technology (Loorbach, D., 2006)

Despite the fact that technologies which promote sustainability typically can be proven more beneficial compared to the traditional ones, they often fail to be totally developed and incorporated in the market (Caniëls et al, 2008). SNM can be then utilized to comprehend and interpret this kind of obstacles and propose suggestions concerning the development of socio-technical experiments where the stakeholders should cooperate and share knowledge and information with the view to ameliorating the learning process that assists the creation of the new technology (Caniëls et al, 2008).

In this thesis, SNM theory is utilized as a conceptual research model to investigate further if it is possible for the Greek Islands to achieve the desired energy transition by meticulously analyzing all the different parameters that might affect it. A further investigation of whether such an initiative could be adopted or not, at a national level at first and then for the Greek Islands and specifically for the island of Crete will be executed. This analysis will be done by focusing on literature on the SNM theory that analyses the key parameters of local dynamics which assist the development of such an innovation combined with the challenges that might exist, which can have technical, environmental, social, economic and regulatory dimension.

2.1.1 Strategic Niche Management in the context of the Greek Islands

The adoption of Green Hydrogen Energy Technologies in the energy system of the Greek Islands is the niche, since they are not widely used and they cannot be considered as a part of the existing regime. The regime is the standard procedure that is followed for so many years by the Greek society based on the traditional energy sources and the hyper-consumption of fossil fuels. In the case of Greek Islands the regime can be described as presented in the figure 2.

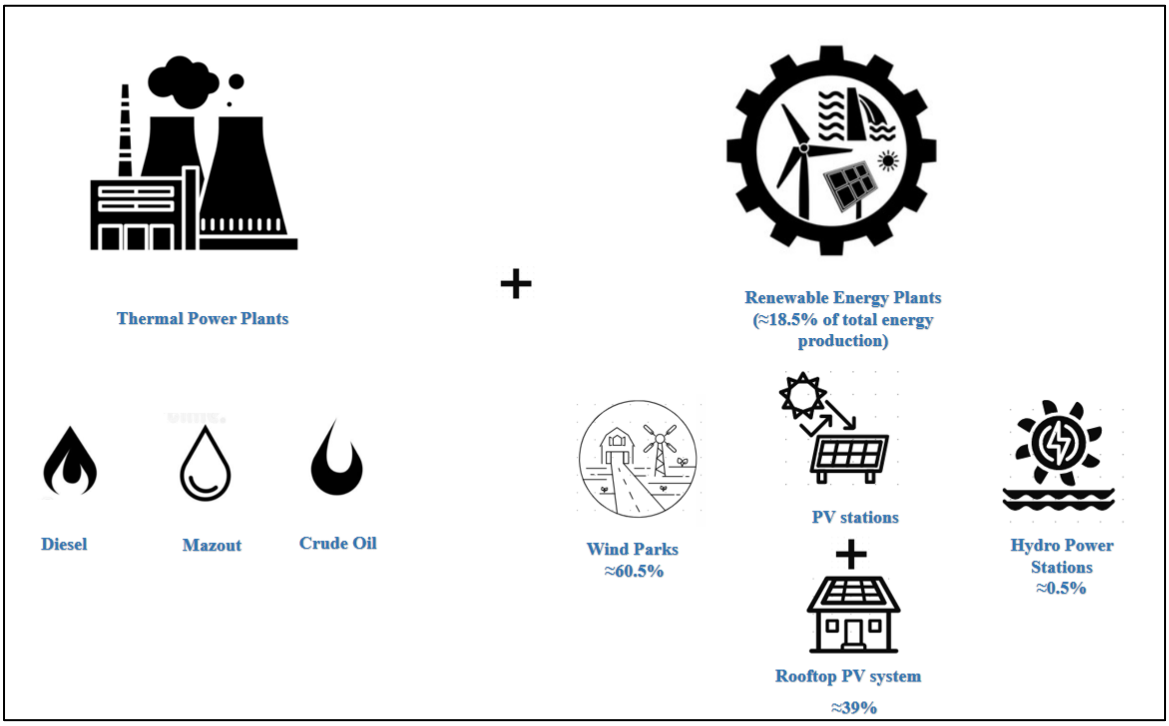

Fig.2 : Description of the current formation of energy system in the Greek Islands (regime).

The electricity is being generated mainly by local thermal power stations that are utilizing fossil fuels, and in some islands there can be found also RES plants that are representing a share of 18.5% in the total energy consumption. In this case, the RES production can be categorized as wind energy (≈60.5%), solar energy (≈39%), and hydro power energy (≈0.5%) (Katsoulakos, 2019).

In the meanwhile the implementation of Green Hydrogen Energy technologies in order to maximize RES utilization appear to be pioneer approaches, niches, that promise to change the whole structure of the energy system and make it more sustainable. The Greek Islands present exceptional potential to incorporate them within their energy system and achieve the desired energy transition. However, these alternative energy niches are not in accordance with the established regimes and can be considered as social niches (Tsagkari, 2020). These sustainable technologies are essentially diversified from the traditional energy systems concerning their structure, administrative and management methods. Subsequently, their incorporation into the existing energy system should be considered as an innovative diffusion of a pioneer and sustainable application that can bring upon significant benefits to the existing energy system and potentially create a new technological regime (Tsoutsos, & Stamboulis, 2005).

In this context the niche proposed during the synthesis of this thesis can be described as following. A pioneer approach that will foster a new economy based on green hydrogen production and storage within the Greek Islands, where traditional pipelines will be supplemented by hydrogen produced with RES. Hydrogen will be produced through water electrolysis and then it will be stored. The surplus of RES production within the Greek Islands, especially solar and wind energy, can be recovered via green hydrogen generation and it can be used to support the energy grid by returning the rejecting energy back to it. So, in this scenario the green hydrogen that will be produced within the island, will be stored so as to be used during periods of increased energy demand, for instance during summer when there is an accelerated number of tourists that visit the island. Simultaneously, the existing diesel generators will be kept as reserve margin. A schematic representation of this proposal is depicted in the figure 3.

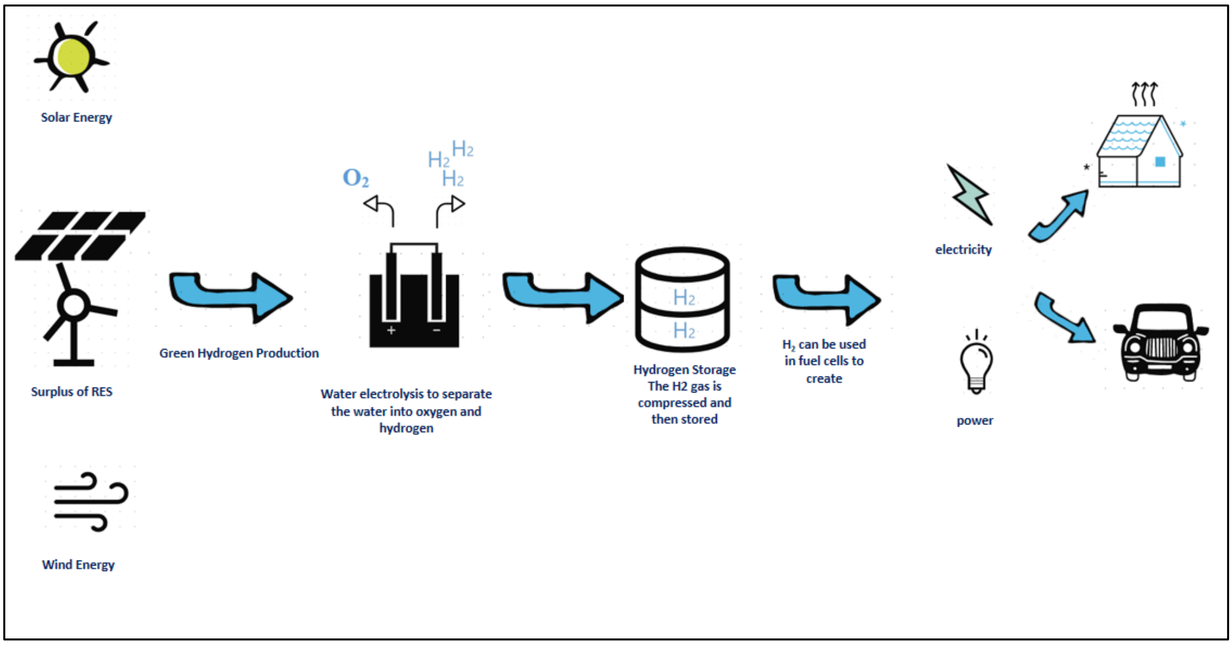

Fig.3 : Description of the niche proposed.

Therefore, Green hydrogen will gradually become the primary energy storage method that will assist RES to become a larger part of the energy grid of the islands. In this way, citizens and governments within the islands will stop depending on the importation of fossil fuels and instead they will develop their own fuel economy. In this report the potential of increasing the utilization of solar and wind energy and green hydrogen based methods in the context of Greek Islands as a niche that will alternate the existing regime will be examined.

2.2 Research Design

In this part there will be analyzed the methodology, the strategies followed in order for the research objectives to be met successfully.

2.2.1 Research Framework Design

According to *Verschuren and Doorewaard, 2010* a research framework is referred to a schematic representation of the basic components of the research analysis that combined can lead to the successful achievement of the research objective.

In this report, the research approach has been formulated as following:

i. Research Target

The main target of this research revolves around the potential of creating a more sustainable future for the Greek islands where green Hydrogen based technologies will be predominant.

ii. Research Object

This research mainly focuses on the energy supply system of the Greek Islands and analyses the alterations that can be adopted in order for the Greek Society to embark on the energy transition. A further analysis of the energy system of Crete is being provided for the case study approach.

iii. Research Methods

The data collection was performed through literature review and interviews to cover some potential deficiencies and create a more realistic analysis. The interviews took place in Greek and afterwards the findings were translated in English. Further details concerning the interviewees and the interview questions are provided in the appendix (page 74).

iv. Data Sources and Data Analysis

The necessary material for the qualitative analysis was gathered from scientific articles, books and research reports. Databases such as Scopus, Google Scholar and Science Direct, focusing on the concepts of RES and green Hydrogen based Techniques, as well as the concept of energy transition in the Greek islands were utilized. Detailed information concerning the current conditions within the island of Crete was gathered through interviews with experts of this field.

v. Schematic presentation of the research framework

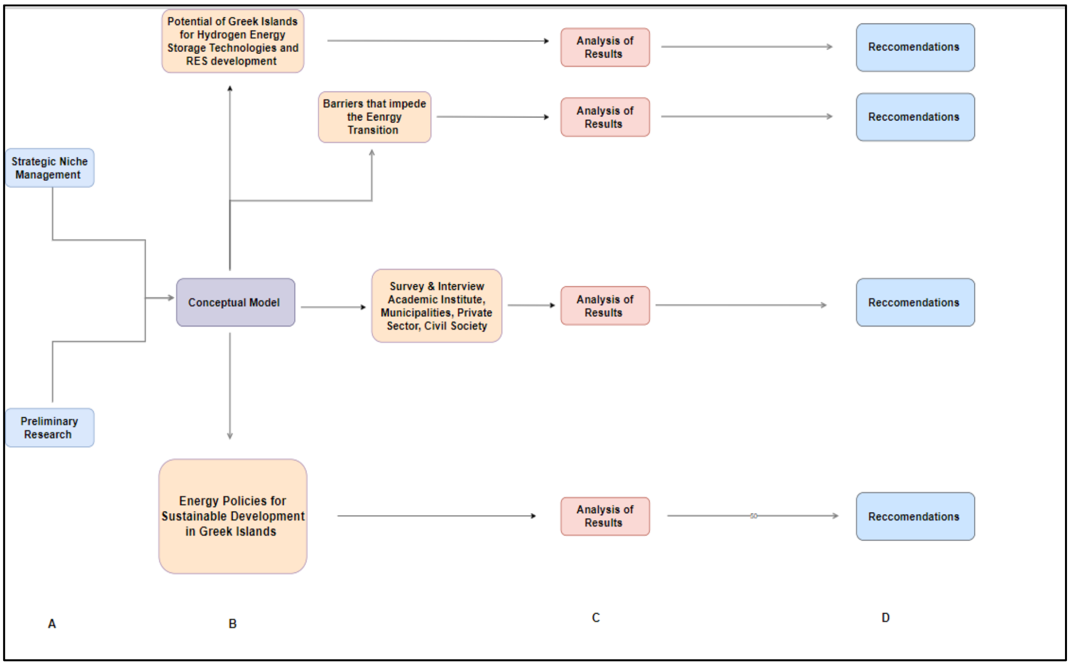

Fig. 4: Schematic Representation of the Research Framework

2.3 Research Boundaries

The limitations imposed during the synthesis of a thesis constitute solid decisions undertaken in the beginning of the process and describe the boundaries that are constructed for this research. During the development of this research, some boundaries were formed in order for the analysis to be completed effectively and punctually. First of all, this research constitutes an academic study report conducted as a master thesis. The research focused on the energy system of the Greek Islands and further investigation was executed for the island of Crete that was selected as the case study unit. The analysis mainly revolved around the feasibility of setting up a more sustainable energy system in the Greek Islands where RES and Green hydrogen applications will be predominant. It was chosen to take under consideration the solar and wind capacity of these regions in order to investigate how these natural resources could be could be further exploited and utilized during the energy transition. Finally. the analysis and the examination of the feasibility of the fulfillment of the proposed scenario focused on the energy system of the island of Crete, that was selected as the case study unit.

2.4 Data Collection and Research Methods

The two main research methods incorporated in this research are literature review and case study. A case study can be characterized as an empirical study analysis where the researcher has the chance to further investigate a case in a real world context (Yin, 2014). The primary target of the case study is to assist the researcher to analyze complicated phenomena within their natural surroundings, with the view to facilitating the process of comprehending them properly (Heale, 2018).

Additionally, in a case study data validity and reliability are prerequisites. These two concepts assess the quality of the research (Broniatowski et al., 2017), and are necessary for the interpretation and generalization of the findings (Otieno-Odawa et al, 2014). The term reliability is interlinked with the consistency of the data gathered overtime and their ability to represent an accurate part of the whole population (Rust, 1994). Also, data reliability in a research is necessary in order to determine the stability and the quality of the data gathered and assist the researcher understand if the consensus of his/her judges and perceptions are right (Rust, 1994)

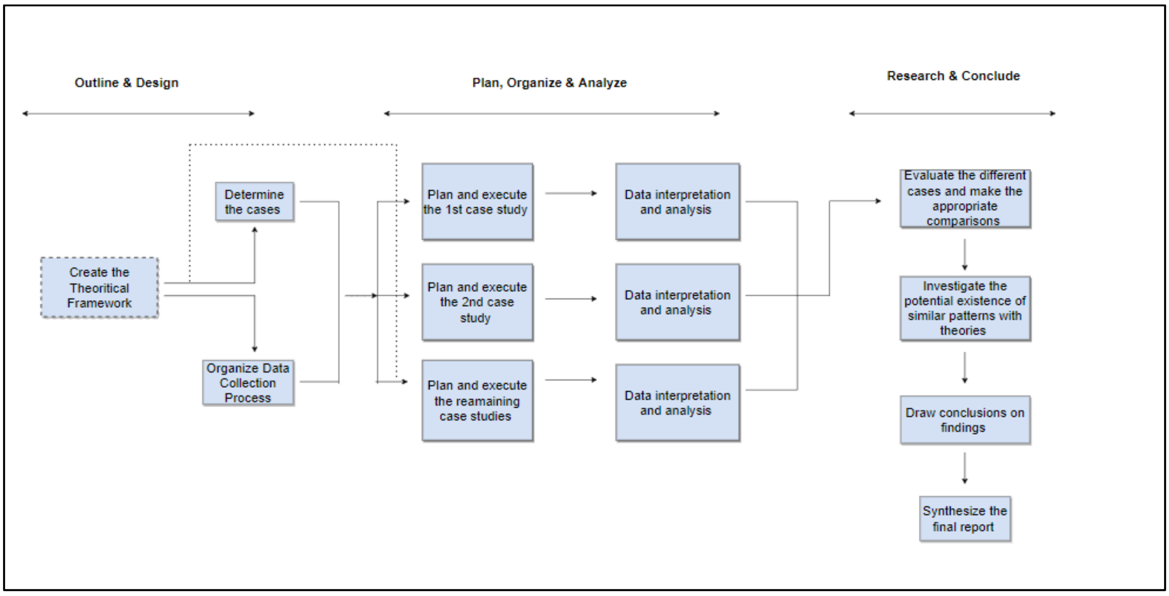

Fig. 5 : Case study process, diagram inspired by (Yin, 2014)

This type of research is proven significantly beneficial in this report, since it provides useful details and information concerning the regulatory framework and support instruments in terms of RES development and green Hydrogen-based technologies in the selected area, the island of Crete. The island of Crete is selected as a representative case study, since it represents a typical example that constitutes a part of the broader category that entails all the Greek Islands. In this way, it will be feasible to examine the feasibility of RES and green hydrogen development within this region and then customize the findings for the other islands. Detailed information concerning the existing local conditions were gathered through interviews.

2.5 Research Ethics

There are five ethical rules that have to be followed and respected during the research process (van Thiel, 2014). These include the parameter of beneficence the principle of veracity, the right of privacy and confidentiality,and the rule of informed consent (van Thiel, 2014). All of the aforementioned ethical principles were taken into account during the synthesis of this report and the research was structured in such a way in order to comply with the code of ethic of the University of Twente (UT).

Throughout the development of this research, semi-structured interviews with different participants were conducted. All interviewees before taking part in this project were given written pragmatic and sufficient information and details about the project. This implies that they were given the right, if they desired, to keep their participation anonymous. Except for that, an oral explanation was executed before the interview, to better inform them about the purposes of the research. Finally, a consent form was sent to them, as a way to ensure the protection of the interviewee's rights.

All the material collected from the interviews are protected and stored in a safe location. Finally, the references are formed based on APA- style, to provide clarity and validity to the research.

2.6 Validation of data analysis

According to (Patton, 1999) the triangulation method can be defined as the utilization of multiple methods or data sources in qualitative research to develop a comprehensive understanding of a specific phenomenon. During the synthesis of this Master Thesis this method was utilized in order to assure the credibility and the validity of the study. Different methods were used to collect the necessary data, avoid research bias, and maximize the trustworthiness of the results through the merging of information derived from different sources.

Chapter 3: The Energy Sector in Greece and in the Greek Islands

The core objective of this chapter is to analyse from a broader perspective how is the energy sector formulated in Greece, and then specifically for the case of the Greek Islands. Hence, the primary goal will be to describe from a theoretical point of view the Greek energy system by incorporating details in terms of RES development. Furthermore, similar analysis will be executed for the energy system in the Greek Islands and specifically for the case of Crete. Finally, an extensive investigation concerning the importance of the interconnection of the islands to the main grid will be carried out. In this context, further details will be provided concering the imminent interconenction of the island of Crete to the maingrid.

3.1 Topography of Greece

Geographically approached, Greece consists of the mainland region, the Peloponnese, that is separated from the mainland and is located at the southern part of the mainland (green area in fig.6), and approximately 6.000 islands and islets (IEA, 2017). Paradoxically, only 227 islands out of them are now inhabited (IEA, 2017).

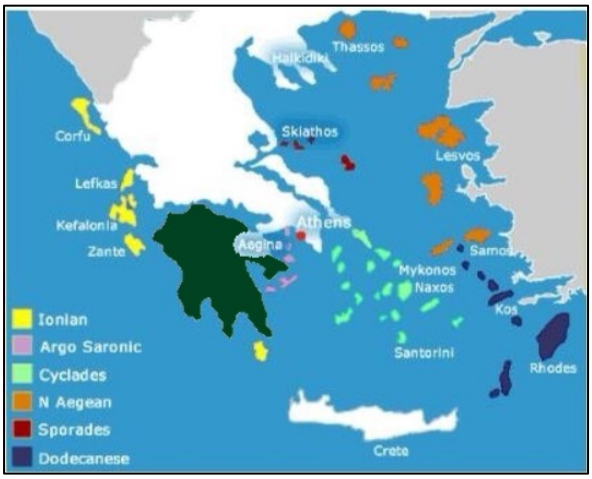

Fig.6 : Representation of the map of Greece, highlighting the region of Peloponnese (green area) and the Greek Islands. (http://www.maps-of-greece.com/maps-of-greece.htm)

3.2 Analysis of the Greek Energy System

The energy system of Greece can be divided into the power grid of the mainland, and the smaller individual local power grids of the non-interconnected islands (NIIs) (IEA, 2017). Greece is highly dependent on oil imports, and more specifically oil production in 2016 accounted for approximately 50% of the TPES (IEA, 2017). Coal constitutes the second most prevailing fuel consumed within the Greek energy system, predominately for electricity generation, representing 19% of TPES in 2016 (IEA, 2017). Finally, natural gas was first introduced in Greece the late 1990s, and it was not until 2016 when natural gas became the third most widespread fuel used in Greece, making up 15% of the TPES (IEA, 2017). In figure 7 the TPES for the period 1973-2016 is being illustrated.

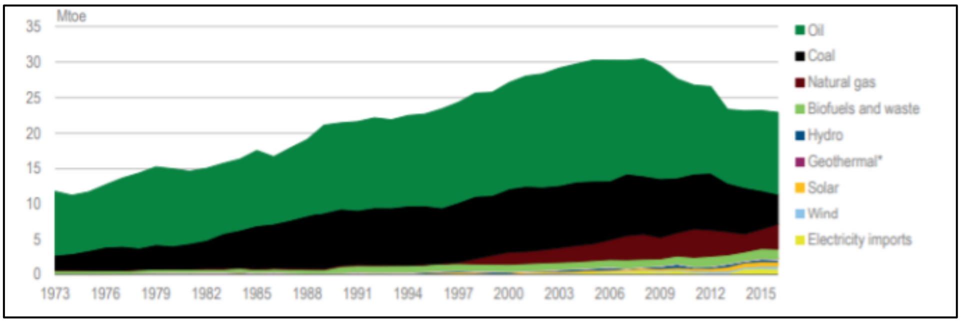

Fig.7: TPES by source in Greece for the period 1973-2016 (IEA, 2017)

3.2.1. RES Development in the Greek Energy System

RES development in Greece is at an average level compared to the rest IEA Member Countries (IEA, 2017). As it is illustrated in figure 8, 14 countries present a higher rate and 14 countries present a lower rate of RES share compared to Greece. It is worth mentioning that **solar share** in TPES in Greece is the second largest after Spain (IEA, 2017) .

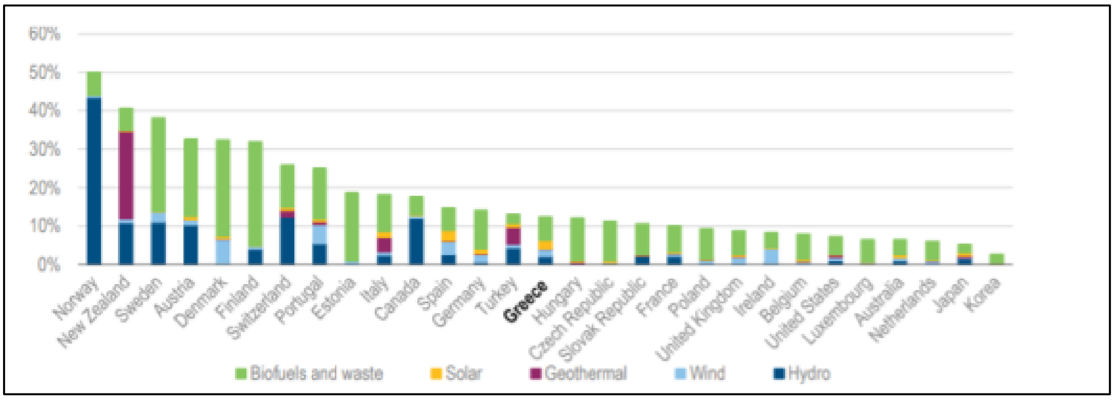

Fig. 8: Comparison of the IEA member countries in terms of RES share (IEA, 2017)

The accelerated solar and wind penetration combined with the decrease in total electricity supply during the latest years led to a remarkable growth of the RES share in electricity generation in 2016 (IEA, 2017). More specifically, Greece almost doubled its share from RES, from 6.9% of gross final energy consumption in 2004, to 15.2% in 2016 (European Environmental Agency, 2018). Wind energy consumption in 2016 accounted for 5.1TWh, and this can be translated to a percentage of 10.5% of the overall electricity generation (IEA, 2017). On the other hand, solar energy consumption presented an even greater growth, from 0.16 TWh in 2010 to 3.9 TWh in 2016 (IEA, 2017). Additionally, hydro power production accounted for approximately 11.4% of the total generation in 2016. In figure 9 the installed capacity of hydro, wind and solar energy are being demonstrated, covering the years 2000-2015.

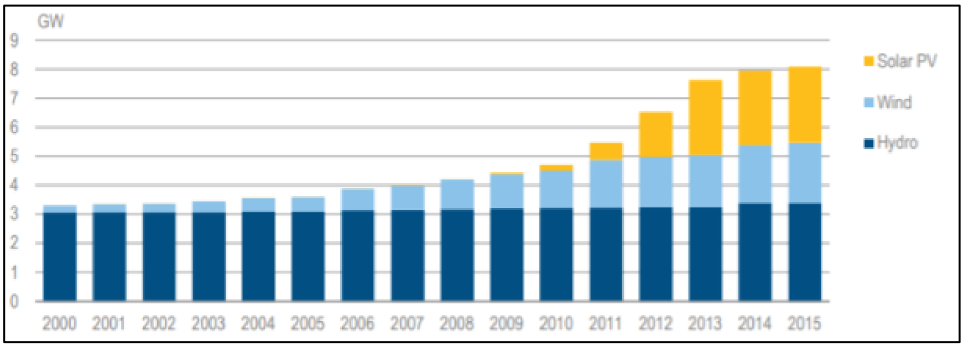

Fig. 9: Representation of the installed capacity of hydro, wind and solar energy in Greece during the period 2000-2015 (IEA, 2017).

3.3 The Greek Islands

Greece is composed of more than 6.000 islands (HSA,2018), but only 227 out of them are currently inhabited (Vourdoubas, 2021). Crete constitutes the largest island by area in Greece, and it is located at the southern part of the Aegean Sea (Tzanoudakis et al., 1995).

The Greek Islands are categorized as following (Tzanoudakis et al., 1995).:

1. The ***Ionian Islands***, that are situated in the Ionian Sea
2. The ***Crete and Kythira*** Islands, in the southern part of the Aegean Sea
3. The ***Cyclades Islands***, situated in the central part of the Aegean Sea
4. The ***Dodecanese***, situated in the southeast between Crete and Turkey
5. The ***East Aegean Islands,*** in the west coast of Turkey
6. The ***Argo-Saronic Islands***, that are situated near Athens
7. The ***Sporades***, a small sized group of islands
8. The ***North Aegean islands***, located in the west coast of Turkey

Fig.10: Analysis of the different group of islands in Greece
(https://voiosummer.blogspot.com/2019/03/maps.html)

3.3.1 The Non-Interconnected Islands (NIIs)

As Non-Interconnected Islands (NIIs), are determined the islands that are not powered by the energy system of the mainland of Greece and must be electrified by autonomous electrical systems and grids (Regulatory Authority of Energy, RAE). Even nowadays, as it can be depicted in table 1, and it was mentioned by all the interviewees, most of the Greek Islands are not connected to the mainland (Caralis et al., 2020).

Area	Island	Current Power System Situation
Crete	Crete	Non-interconnected with local power stations
Cyclades complex	Amorgos, Anafi, Donousa, Kythnos, Milos-Kimolos, Serifos, Sifnos, Thira (Santorini)-Thirasia	Non-interconnected with local power stations
	Delos, Keros, Makronisos	Non-interconnected without local power stations
	Andros-Tinos, Kea, Mykonos, Syros, Paros-Antiparos-Folegandros-Ios-Irakleia-Koufonisi-Naxos-Sikinos-Schinousa	Interconnected with the mainland
Dodecanese complex	Agathonisi, Astypalaia, Rhores-Chalki, Kos-Kalymnos-Lipsi-Nisiros-Pserimos-Telendos-Tilos, Karpathos-Kasos, Patmos, Megisti, Simi	Non-interconnected with local power stations
	Arkoi, Levitha	Non-interconnected without local power stations
Ionian islands	Antikithira, Erikousa, Othonoi	Non-interconnected with local power stations
	Scorpios, Strofades	Non-interconnected without local power stations
	Antipaxoi, Kefalonia, Corfu, Zakynthos, Ithaki, Kalamos, Kastos, Kythira, Leukada, Mathraki, Meganisi, Paxoi	Interconnected with the mainland
Sporades Complex	Skyros	Non-interconnected with local power stations
	Adelfoi, Alatas, Kyra Panagia, Peristera, Piperi	Non-interconnected without local power stations
	Alonisos, Evoia, Palio Trikeri, Skiathos, Skopelos	Interconnected with the mainland
Islands of North Aegean	Agios Efstratios, Lesvos, Lemnos	Non-interconnected with local power stations
	Agios Georgios	Non-interconnected without local power stations
	Ammoulianoi (Agio Oros), Samothraki	Interconnected with the mainland
Islands of East Aegean	Chios-Psara-Oinousses, Samos-Fournoi-Thymaina, Ikaria	Non-interconnected with local power stations
	Agios Minas, Samiopoula	Non-interconnected without local power stations
Saronic Gulf	Dokos, Spetsopoula, Trikeri	Non-interconnected without local power stations
	Agkistri, Aigina, Hydra, Poros, Salamina, Spetses	Interconnected with the mainland
Lybian Sea	Chrisi, Gaudopoula, Gaudos	Non-interconnected without local power stations

Table 1: Analysis of the power system of the most important Greek Islands at the end of 2020 (Caralis et al., 2020)

These NIIs have an electricity market which consists of thirty-two autonomous systems that are further categorized based on the peak load demand into three separate energy systems (RAE, 2018).

According to RAE, 2018 these three distinct systems are developed as following:

i. 19 small-scale autonomous systems with a peak load up to 10 MW

ii. 11 medium-scale autonomous systems with a peak load ranging from 10 MW to 100 M, and

iii. 2 large-scale autonomous systems with a peak load higher than 100 MW (islands of Crete and Rhodes).

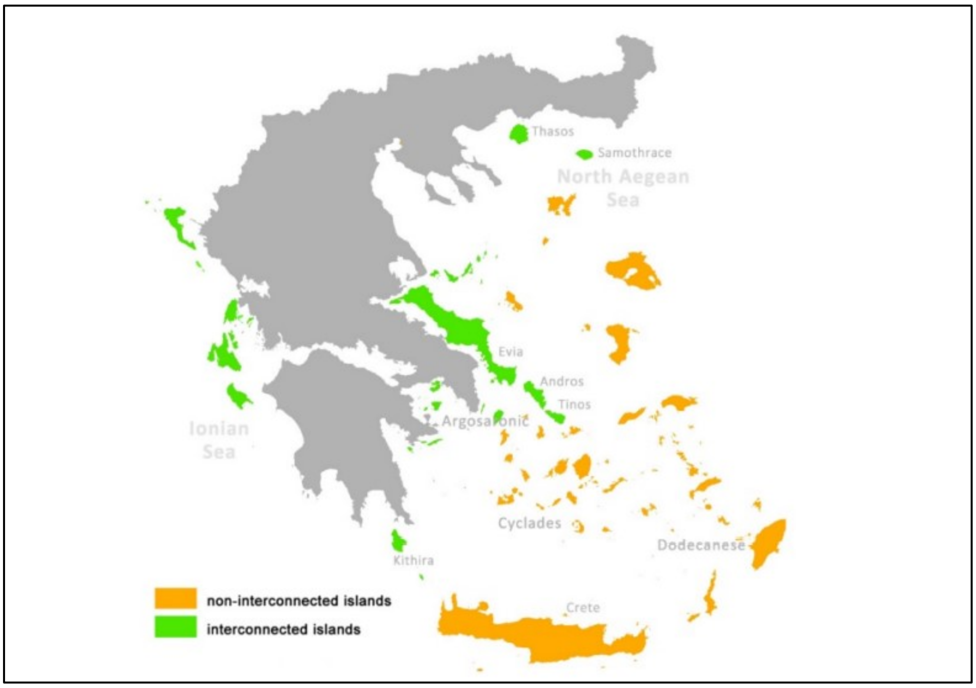

Fig.11: Schematic representation of the interconnected and non-interconnected islands in Greece (RAE, 2018)

The Hellenic Electricity Distribution Network Operator (HDNO) has analyzed meticulously the characteristics and the peculiarities of these islands, leading to the following conclusions (Chatziargyriou,2016):

i. NIIs present notable differences in terms of population and in most cases they are not easily accessible, especially from the sea (Chatziargyriou, 2016).

ii. They cannot transfer or receive electricity from another system (Chatziargyriou, 2016). Therefore, the reliability and the security of the energy supply of these systems are severely affected since there are frequently problems in terms of voltage stability and frequency, specifically during periods of high RES penetration (Chatziargyriou, 2016).

iii. These islands present great RES potential, especially when it comes to solar and wind energy exploitation (Chatziargyriou, 2016).

iv. During summer there are some fluctuations of the energy demand and when the maximum energy demand is much higher than the average one then the load factor values are low (Chatziargyriou et al., 2018).

3.3.2 The Energy System of the Non-Interconnected Islands

In most of the NIIs the electricity is being generated by local thermal power stations that are utilizing crude oil, heavy oil (mazut) and light oil (diesel) and in some cases by RES (RAE, 2018). The main drawback of an non-interconnected energy system is the high cost that its function entails (Katsoulakos, 2019). In some islands there can be found also RES Plants that are representing a share of 18.5% in the total energy consumption. More specifically, RES share can be categorized as following:

i. 60.7% wind energy production

ii. 34.3% solar energy produced by photovoltaic stations

iii. 4.7% solar energy produced by rooftop photovoltaics and net-metering

iv. 0.3% from a hydro-station with nominal capacity of 0.3 MW and a small biogas unit with nominal capacity 0.5 MW, that are operating in Crete.

The installed capacity of these stations -both thermal and RES- is analyzed in table 2 (Katsoulakos, 2019).

NII System	Capacity of thermal stations (MW)	Capacity of RES stations (MW)	NII System	Capacity of thermal stations (MW)	Capacity of RES stations (MW)
Agios Efstratios	0.84	0.02	Lesvos	94.88	22.79
Agathonissi	0.64	0.00	Lemnos	23.60	4.93
Amorgos	6.20	0.29	Megisti	1.73	0.00
Anafi	1.15	0.00	Milos	22.98	3.27
Antikyhtira	0.41	0.00	Mykonos	67.49	2.24
Arkioi	0.41	0.00	Othoni	0.66	0.66
Astypalea	3.83	0.32	Paros	93.72	17.07
Gavdos	0.43	0.00	Patmos	8.93	1.35
Dosnoussa	0.99	0.00	Rhodes	232.93	66.71
Erikoussa	0.77	0.00	Samos	49.63	12.75
Thira	75.09	0.25	Serifos	6.69	0.10
Ikaria	15.89	1.39	Sifnos	11.48	0.20
Karpathos	16.50	2.39	Skyros	8.45	0.32
Crete	796.82	279.38	Symi	8.60	0.19
Kythnos	5.92	0.91	Syros	39.25	3.83
Kos-Kalymnos	133.66	23.98	Chios	77.78	14.25

Table 2: Total Installed Capacity of the existing Thermal and RES stations in NIIs (2017) (Katsoulakos, 2019)

3.3.3 The advantages of the interconnection of the islands to the main grid

The interconnection of the islands' grid to the main one can be proven really beneficial in many ways (Katsaprakakis et al., 2019). First of all, this alteration will foster the energy supply security as well as the dynamic safety of the islands' system and will assist the installation of more RES plants (Katsaprakakis et al., 2019). On top of that, the current electricity production cost in every island will be reduced, since the existing thermal generators that are consuming diesel oil with notably elevated cost of production will finalize their operation once the interconnection is being completed (Katsaprakakis et al., 2019).

Professor Katsaprakakis during the interview mentioned that, even up to this date the Greek Islands remain dependent on imported energy resources, and therefore the energy system of these islands remains vulnerable to alterations in the price of the diesel oil at an international level. Therefore, problems related to security and stability of the energy supply still exist. However, these challenges will start to fade away once the interconnection of the islands to the energy system of the mainland is being finalized (Katsaprakakis, 2021).

Additionally, many investors across the world have shown remarkable interest for the Greek islands and they are eager to start installing solar PV-systems and several wind parks (Vourdoubas, 2021). Nevertheless, this kind of investments cannot be currently executed within the islands, due to the fact that the electric grids are autonomous and the incorporation of this type of technologies can affect the stability of the energy system in a negative way (Vourdoubas, 2021). Hence, the interconnection is expected to increase the share of RES within the islands since the investments in solar and wind energy sector will be intensified (Vourdoubas, 2021).

Professor Katsaprakakis also claimed that it cannot be guaranteed that the aforementioned problems will disappear entirely (Katsaprakakis, 2021). There are numerous examples of islands that were interconnected either with “neighbour” islands or with the continental Greece where there were flaws in the line of interconnection and the island remained with no electricity for some days (Katsaprakakis, 2021). For instance the interconnection of the islands Kassos - Karpathos in 2003 lead to a loss of electricity within the system for 5 days. A similar problem was present within the interconnection of the islands Tilos - Kos in 2016, where for some hours there was no electricity supply for some hours (Katsaprakakis, 2021). Professor Katsaprakakis, concluded that in order for the interconnection of the islands to be successful and efficient, sufficient and consistent electricity supply has to be guaranteed. This entails the function not only of wind or solar parks but mainly of units where the energy production is being controlled (Katsaprakakis, 2021).

3.4 Case Study: The Island of Crete

3.4.1 The Energy System of Crete

Crete constitutes the largest non-interconnected electricity system in Greece and plays a key role in the Mediterranean due to its unique and special characteristics (Caralis et al., 2019).

The electricity generation in Crete is primarily based on fossil fuels and RES consumption (Vourdoubas, 2021). Roughly 80% of the annual electricity in the island is being generated by the three thermal power plants that are currently operating within the island (Vourdoubas, 2021). The rest 20% is being produced by RES, principally by solar PV-systems and wind parks that are being developed across the island (Vourdoubas, 2021).

Crete hosts three conventional power plants that can be found in the west, central and east side of the island (Marinos, 2018), and more specifically in the areas of Atherinolakkos, Linoperamata and Chania (Caralis et al., 2019).

In table 3, analytical data concerning the electricity generation and carbon emissions by source for the year 2018 in Crete are being presented (Vourdoubas, 2021)

Type of Fuel	Annual Fuel Consumption (tons)	Annual Electricity Generation (MWh)	%	Annual CO_2 Emissions (tons)	%
Fuel oil	455.684	1.762.612	57.91	1.435.405	70.30
Diesel oil	195.055	635.070	20.87	606.621	29.70
Total fossil fuels	650.739	2.397.682	78.78	2.042.026	100
Solar Energy	0	134.808	4.43	0	0
Wind Energy	0	510.059	16.76	0	0
Hydro-Electric Energy	0	257	0.	0	0
Total RES	0	645.1124	21.22	0	0
Total	650.739	3.042.806	100	2.042.026	100

Table 3: Electricity generation and carbon emissions by source for the year 2018 in Crete (Vourdoubas, 2021).

3.4.2 Interconnection of Crete to the main grid

The electrical interconnection of the island to the main electric grid has already been designed and started (Katsaprakakis et al., 2019). This initiative will be proven extremely beneficial since in an autonomous electric system, as in Crete, a lot of challenges arise that affect in a negative way the stability of the electric grid (Vourdoubas, 2021).

According to the data derived from the interview with Professor Katsaprakakis, there will be two interconnections in total. Firstly, there is the “small” one, in length and capacity, that connects the south-east cape in Mani with Kisamos (west Crete) (Katsaprakakis, 2021). This interconnection has already started and will be completed within the next months. The second interconnection, known as the “large” one, will start from Lavrio (a city in the southeast part of Attica) and will end approximately 30km west from Heraklion (next to the center of the island) (Katsaprakakis, 2021). This interconnection has not started yet but it is expected to begin within the next months (Katsaprakakis, 2021) and to be finalized by 2023 (Vourdoubas, 2021). It has been planned and designed that two undersea electric cables will be utilized to connect the island's grid to the main one (Vourdoubas, 2021). The first cable is supposed to transfer 150-180 MW, while the second one has a greater capacity, reaching the level of 350MV (Vourdoubas, 2021).

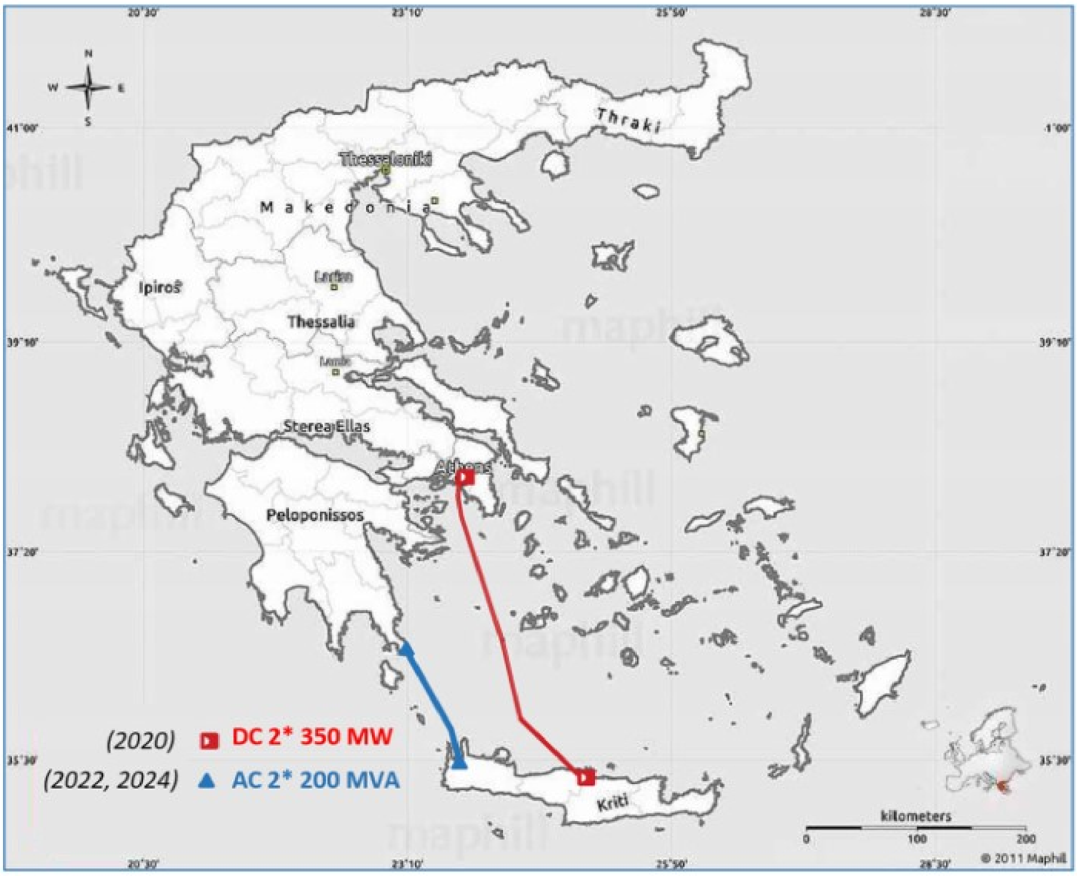

Fig.12 : Schematic representation of the interconnection of the island of Crete with the energy system of the mainland (Kabouris,2017).

3.4.3 RES development in Crete

Advancements in the field of RES are notable and this progress renders RES technologies more reliable and cost-effective within the island of Crete (Vourdoubas, 2021). During the latest years, the number of wind farms and solar-PV systems installed in the island increased significantly (Vourdoubas, 2020). In 2018, 41 wind farms with total power of 200 MW as well as 80 MW of Photovoltaic parks (PV) and 15 MW of PV on the roofs were being detected around the island (Marinos. 2018). Currently, the electricity generation from solar and wind sources within the island accounts for 20% approximately of the total annual electricity generation of the island (Vourdoubas, 2021).

Solar-PV systems have presented a rapid growth during latest years in Crete and they are currently an indispensable component of the energy system of the island (Vourdoubas, 2020). A variety of Solar-PV systems has been introduced, some of them have been installed in grid connected buildings, and others are in off-grid buildings in remote areas (lighthouses and mobile telephone's antennas) (Vourdoubas, 2020).

In terms of wind energy penetration, the island presents a remarkable potential that has to be exploited (Katsaprakakis et al, 2019). It has been calculated that the average velocities of wind annually exceed the limit of 8.5 m/s in numerous different regions (Karnavas, 2006), and in some cases this figure can get even more elevated, reaching the point of 9 m/s or even 10 m/s (Katsaprakakis et al.). It has also been noticed that the electricity produced by wind energy presents a lower cost compared to the cost of electricity generated from fossil fuels (Vourdoubas, 2020). .

Unfortunately,wind parks can not be further incorporated within the energy system of the island, since Crete's electric grid is interdependent and the development of additional parks could provoke serious problems in the stability of the system (Vourdoubas, 2020). Subsequently, only by incorporating the electric grid of the island in the main grid of Greece will it be plausible to secure the development of more wind parks within the island (Vourdoubas, 2020).

Finally, despite the fact that wind energy potential in many different regions of the island is elevated, installation of small wind turbines remains limited. Small wind turbines combined with solar-PV systems, have been solely incorporated in some residential buildings in remote areas (Vourdoubas, 2020). At present, it is not allowed to utilize the small wind turbines in residential buildings and hotels, and thus this innovative technology is not widely commercialized yet (Vourdoubas, 2020).

3.5 Conclusions from chapter 3

The energy system of Greece can be divided into the power grid of the mainland, and the smaller local grids of the NIIs. From a general perspective, Greece is highly dependent on oil, coal and natural gas. On the bright side, Greece almost doubled its share from RES, from 6.9% of gross final energy consumption in 2004, to 15.2% in 2016. Concerning the case of the NIIs, the electricity is being generated by local thermal power plants that are utilizing crude oil, heavy oil (mazut) and light oil (diesel), and in some cases by RES which are representing a share of 18.5% in the total energy consumption. The interconnection of the islands' grid to the main one can be proven really beneficial since it will foster the energy supply security and the dynamic safety of the islands' system. Additionally, it will decrease the cost of the current electricity production and it will accelerate the number of solar and wind parks installed.

The case study unit, the island of Crete, constitutes the largest non-interconnected electricity system in Greece where roughly 80% of the annual electricity is being generated by the three thermal power plants and the rest 20% is being produced by RES. The interconnection of the island to the main electric grid has already been started and it is expected to be finalized in 2023.

Chapter 4: Energy Transition within the Greek Islands

The accelerating energy demand within the Greek Islands especially during summer, combined with the fact that in these regions the electricity networks are extremely susceptible and continuously exposed to side vulnerabilities, increase the necessity for a practical, adaptable and easy-to-apply approach to cover efficiently the future energy needs. In this context, the maximization of RES utilization within the islands and the incorporation of Green Hydrogen production and storage technologies, seem as promising initiatives that could assist effectively in the resolution of the aforementioned challenges (Vourdoubas, 2021). Therefore, in this chapter there will be provided an analysis on the unique characteristics of Green Hydrogen as an energy carrier that can support decarbonization within the Greek Islands, combined with an elaboration on green hydrogen production techniques. Additionally, the EU strategy concerning the production of green hydrogen will be investigated, and finally the status of green hydrogen development in Greece will be examined.

4.1 The unique characteristics of the Green hydrogen

“Clean hydrogen”, "Renewable Hydrogen" or "Green Hydrogen" is produced by the electrolysis of water using electricity created from RES and emits no GHG during its production (Turner et al., 2008).

Green hydrogen is considered to be a promising solution for the future economy since it is considered to be a possible cost-efficient clean fuel (Abe et al., 2019) due to its following unique characteristics.

i. It is the most abundant element in the universe, and it forms more than 90% of all atoms (Pareek et al., 2020)
ii. It constitutes a zero emission or emission free fuel which can be effortlessly developed by domestic sources (Pareek et al., 2020)
iii. It is the lightest element but in the meanwhile it presents the highest energy content (heating value) compared to the rest of the available fuels (Abe et al., 2019)
iv. It is considered as a highly sustainable fuel (Abe et al., 2019)
v. In comparison with natural gas, coal and petroleum it is environmentally friendly and extremely beneficial to the environment since during its conversion to energy the only exhaust product produced is water (Abe et al., 2019)

Hydrogen presents an exceptional energy storage capacity and it has been calculated that the energy contained in 1 kg of hydrogen is about 120 MJ (¼33.33 kWh), a number that surpasses double of the majority of conventional fuels (Abe et al., 2019). Therefore, green Hydrogen after its generation it can be stored and then it can be utilized in many different fields such as in transportation, in power generation systems using fuel cells, and in internal combustion engines or turbines (Abe et al., 2019).

For all the aforementioned reasons, green hydrogen is considered to be one of the key energy solutions for the 21st century (Edwards et al., 2008). However, the high production cost still remains a bottleneck that prevents green Hydrogen from becoming a common energy source (Liu et al., 2020). Therefore, experts and scientists should focus more on creating a cost-efficient, feasible, reliable and sustainable with low environmental impact technique for green Hydrogen production (Liu et al., 2020).

4.2 Green Hydrogen Production and Storage

The principal challenge of the RES producers is to provide consistently power to the consumers in order to cover efficiently their needs (Segev,2020). However, RES production follows an unstable pattern (Komorowska et al., 2018), since wind energy provision depends heavily on the weather patterns, while solar power is influenced by potential presence of clouds and periodic variations in daylight (Segev, 2020). It is inevitable and widely acceptable by all producers that RES generation will present extreme variations even during the same day (Segev, 2020).

Energy storage is regarded to be an efficient, reliable, safe, stable and durable solution to the aforementioned challenge (Segev, 2020). Principally, with the storage of energy it will be feasible to reserve the surplus of energy that is being generated during the peak hours and then this sum of energy can be distributed when there is high energy demand (Segev, 2020). Electrolysis can be used as a way to produce hydrogen by utilizing the surplus electricity created by RES.

The steps that have to be followed when using the surplus of RES to create Hydrogen via electrolysis can be described as following:

i. When the energy produced from RES exceeds the energy demand, this surplus current can undergo a process called electrolysis. During this process the water (H_2O) is split into Hydrogen (H) and oxygen (O).

ii. The hydrogen produced can be then stored in a pressurized tank, and it can be used in the future

iii. In the next step, the hydrogen that has been stored can be transported to fuel cells where it can be combined again with oxygen to produce electricity.

(Ariizumi, 2010)

Green Hydrogen production can be ideally achieved through electrolysis (Kothari et al., 2008). Professor Arampatzis during our interview underlined that through the process of electrolysis high product purity is achieved, and it is plausible to incorporate this method of hydrogen production not only on small scales but also on larger ones.

Water can be decomposed using direct electric current and in this way hydrogen and oxygen will be generated from the water through redox reactions (Zhang et al., 2008). During the latest years, there has been made a significant scientific progress in this field and there have been created different systems for electrolysis (Chi et al., 2018). These systems include, alkaline water electrolysis (AWE), proton exchange membranes (PEMs) and solid oxide water electrolysis (SOE).

i. Alkaline Water Electrolysis (AWE)

These type of electrolysers operate at low temperature (60–80°C). The hydrogen produced in this case is 99% pure (Chi et al., 2018). However, these electrolyzers given the fact that their loading response is not fast, they can not initiate their operation rapidly (Chi et al., 2018). Therefore, it is quite challenging to adapt these electrolyzers to the changeable character of RES (Chi et al., 2018), and thus they are primarily used with a constant energy input (Chi et al., 2018).

ii. Proton exchange membrane (PEM) electrolysis

The high degree of gases purity combined with the significantly high level of safety are the two characteristics that are making PEM standing out and have a privilege compared to the traditional water alkaline electrolyzers (Grigoriev et al., 2006). PEM water electrolysis constitutes the most promising option that can ensure high pure efficient hydrogen generation from RES (Kothari et al., 2008). This type of water electrolysis also presents numerous other advantages such as compact design, high current density, high efficiency, fast response, small footprint and it operates under lower temperatures (20–80°C) (Kothari et al., 2008). However, it is more expensive compared to the alkaline water electrolysis (Kothari et al., 2008).

iii. Solid oxide electrolysis (SOE)

The basic advantage of this type of electrolysis compared to the rest, is that it operates in higher temperatures (Kothari et al., 2008), and this entails lower voltage and lower energy consumption (Chi et al., 2018). On the other part, high temperatures present some challenges in terms of material stability and degradation that have to be confronted before proceeding to commercialization on a large scale (Kothari et al., 2008). Additionally, the hydrogen produced is not entirely pure, so it has to go through additional treatment to be highly purified (Kothari et al., 2008).

4.3 EU Strategy for Hydrogen production

The European Commission, in July 2020, issued a **Hydrogen Strategy for a climate-neutral Europe**, with the view to hasten the generation of clean hydrogen and ensure its role as a cornerstone for a climate-neutral energy system by 2050 (European Commission, 2020). The hydrogen strategy of the European Commission incorporates a steady process that composes of three different phases of development concerning the Hydrogen Economy. More specifically, according to the European Commission, 2020:

i. During the years **2020-2024**, the primary target of the strategy will revolve around the decarbonization of the current Hydrogen Production and its gradual incorporation in many different sectors (European Commission, 2020).

ii. During the years **2020-2030**, green Hydrogen is anticipated to constitute an essential part of the energy sector. During these years, hydrogen will be gradually utilized in alternative operations such as maritime transport applications (European Commission, 2020).

iii. Finally, during the years **2030-2050**, Renewable Hydrogen Applications will be widely used in large scale applications as a key parameter that will contribute significantly in the decarbonization of the heavily-emitting industry sectors that are currently relying on fossil fuels (European Commission, 2020).

4.4 Green Hydrogen Development in Greece

The Greek Governments' plans related to green Hydrogen development are still at initial levels and the relative legislation is anticipated to be released in the second half of 2021 (Farley et al.,2021). The primary target of the Greek Government's strategy is to finalize the operation of all lignite-fired power stations by 2028, and this alteration can be facilitated with the expansion of PV, wind and other RES applications in Greece within the next years (Farley et al.,2021). A green hydrogen strategy is an indispensable component of the Greek Government's energy plan and if approached correctly it can foster the utilization of RES for transport and heating purposes (Farley et al.,2021).

4.4.1 Green Hydrogen in the context of the National Energy and Climate Plan (NECP)

In 2019 the Greek Government published the ***Greek National Energy and Climate Plan ("NECP")*** which analyses the targets, the policies and the measures that have to be followed by Greece in order to achieve its energy and climate goals by 2030.

The adoption of the green Hydrogen solutions could contribute to the fulfillment of the following targets:

1. **Greece's targets in terms of RES development that have to be met by 2030 . According to the NECP these objectives are set as following:**

a. 35% in the gross final consumption of energy

b. 60% in the gross final consumption of electricity

c. 40% in the heating and cooling sector; and

d. 14% in the transport sector

2. **Decarbonisation:** The NECP states that the Greek Government has engaged to finalize the operation of the lignite-fired power stations by 2028.

In this context a *Master Plan for Fair Development Transition* was synthesized in December 2020. This plan analyses the commitments of the Greek Government for the post-lignite period and additionally it highlights the importance of investments in green Hydrogen

3. **Energy storage**: The NECP supports that, "*there is also interest in power-to-gas (e.g. hydrogen) storage applications, in the context of which the interconnection of electricity and gas networks is also investigated"* (*National Energy and Climate Plan,* 2019)

Greece is one of the 23 European countries that signed the "Manifesto for the development of a European Hydrogen Technologies and Systems value chain". According to it, all the countries that participate are obliged to embark on the energy transition and make ambitious changes in order to foster decarbonization and promote the utilization of green Hydrogen. On May 5th 2021, the most powerful energy companies in Greece submitted the National proposal for Hydrogen technologies, entitled "White Dragon", in the framework of the Greek call for expression of interest for Hydrogen "IPCEI" (Geropoulos, 2021).

Mr. Kitsikopoulos during our interview mentioned that, the primary target of this project is to steadily replace the lignite power plants of Western Macedonia (Southern part of continental Greece), and promote more sustainable ways of energy production, in order to fully decarbonize Greece's energy system. The "White Dragon" project visualizes that large-scale renewable electricity will be used in order to produce green hydrogen via electrolysis in Western Macedonia. The hydrogen produced will be then stored and through Advent's high-temperature fuel cells (that provide heat and electrical power) will supply all Greece with clean energy (Geropoulos, 2021).

4.5 Conclusions from chapter 4

The analysis executed in chapter 4 provides the answers to the second sub-question that is related to the current status of green Hydrogen development in Greece. Taking everything into account, it can be supported that the Greek Governments' plans related to green Hydrogen development are optimistic but still at initial levels. Private companies have shown significant interest in promoting green Hydrogen technologies and embark on the energy transition. Undoubtedly, all the attempts are on a more experimental and theoretical level, however practical solutions are being engaged during the latest years. If the initiative undertaken by the Greek Government in the continental Greece goes as planned then similar steps could be engaged by the islands and then the energy transition and the promotion of green Hydrogen technologies will be easily incorporated within the energy system of the Greek islands too.

Chapter 5: Opportunities and barriers for achieving the the energy transition

Chapter 5 deals extensively with the analysis of the solar and wind dynamics of the Greek Islands, including Crete, in order to investigate if large-scale integration of RES and Green Hydrogen applications can be feasible and profitable within these regions. Additionally, the challenges that might occur during the energy transition will be further examined, since such an initiative is a demanding process that entails numerous barriers on technological, environmental, social, economic and legislative level.

5.1 Potential of RES and green Hydrogen development in the Greek Islands

Greece is an peninsular and insular country with a 17,400 km of coast length and a maritime surface of 114,507 km^2 and presents a significant potential in RES exploitation (Ganea et al., 2017). This is primarily interlinked with the fact that Greece constitutes the country with the maximum available solar radiation within the European Countries (with the exception of Cyprus), and the highest installation of solar thermal water heater collectors per capita in Europe (Hatziargyriou et al., 2006).

Scientists and experts claim that due to the great RES potential of the Greek Islands, the adequate introduction and implementation of pioneer technologies, such as those related to RES share increase and green hydrogen production and storage, could cover up to 100% of local energy needs (Mondol et al., 2013).

Currently, investment opportunities in the RES sector in the Greek Islands present a steep rise, and this is interlinked with the abundance of RES share within these regions (Mondol et al., 2013). Except for the ongoing RES projects in the Greek Islands, new ones are being developed during the latest years including wind, photovoltaics (PVs), bioenergy, solar thermal and hydro pump-wind hybrid technology (Zafeiratou et al., 2018).

5.1.1 Wind Energy Potential

According to Ganea et al., 2017 the great wind potential of the Greek Islands is interconnected with the Mediterranean climate of Greece. This type of climate is characterized and influenced to a considerable extent by the Etesian winds (Ganea et al., 2017). By this term, experts are referred to the intense winds that appear around May and they end up in October, with a high frequency in July and August (Ganea et al., 2017). The Etesian winds are more intense during the afternoon and blow from the northeast to the north in the northern Aegean basin, while in the central part of the basin blow from the north (Hellenic National Meteorological Service, 2016).

Most of the installed wind parks until now can be found in the eastern part of the country, mainly on the islands (Hatziargyriou et al., 2006).The total wind power capacity of Greece is approximately 567MW, and about 165MW of the wind parks are located in the Greek Islands (Hatziargyriou et al., 2006). As demonstrated in the map of figure 13, remarkable wind dynamics exists in the Crete, the Cyclades Islands and the Dodecanese. This can be mainly attributed to the high winds predominant in the North-NorthEast direction, primarily affecting the Aegean sea (Kabouris et al., 2006).

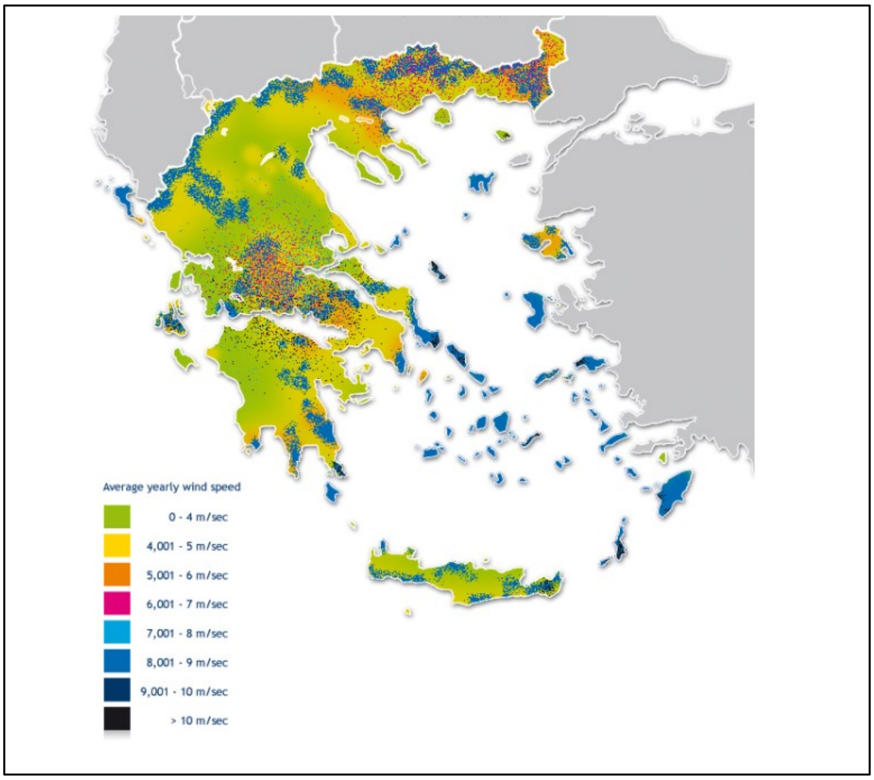

Fig. 13: Wind dynamics and geographical distribution of applications for wind farms in Greece (Caralis et al., 2020)

In table 4, the installed wind capacity (MW) of each island group is being presented (Hatziargyriou et al., 2006), in order to better comprehend the allocation of the wind energy parks within the islands.

Island Group	**Installed Wind Capacity (MW)**
Crete	**105.15**
Northern Aegean	28.5
Cyclades Islands	8.7
Dodecanese Islands	22.24
Rest Islands	0
Total	**164.59**

Table 4: Wind capacity of the Greek Islands by region (Hatziargyriou et al., 2006)

5.1.2 Solar Energy Potential

Greece is a country with significantly high potential for solar energy development and especially for PV applications (Mondol et al., 2013). This can be mainly associated with the high insolation in Greece all year round, that is among the highest in Europe (Tsoutsos, 2004). Researchers have shown that, the average annual solar radiation is estimated to reach the level of 1570 kW h/m^2. In the continental Greece, the sunshine hours exceed the limit of 2700 h/year, or 7.5 h/day accordingly (Mondol et al., 2013). Concerning the Greek Islands, the hours of sunshine are approximately 3100 h/year or 8.5 h/day (Mondol et al., 2013). This privilege can be used then for heating and electricity production in the country (Mondol et al., 2013). The number of solar hot water systems (SWHS) that are installed every year in the households are more than 50.000, with the total number approaching the number of 1.000.000 (Mondol et al., 2013).

In table 5, the average annual solar irradiation in the largest Greek Islands is being demonstrated (Mondol et al., 2013).

Island Group	**Installed PV Capacity (MW)**
Crete	**510**
Northern Aegean	8
Cyclades Islands	182
Dodecanese Islands	37.5
Rest Islands	65
Total	**802.5**

Table 5: Solar PV capacity of the Greek Islands by region (Hatziargyriou et al., 2006)

Finally, in figure 14 the annual solar irradiation on average under optimum angle (KW h/m^2) in the largest Greek Islands is being demonstrated

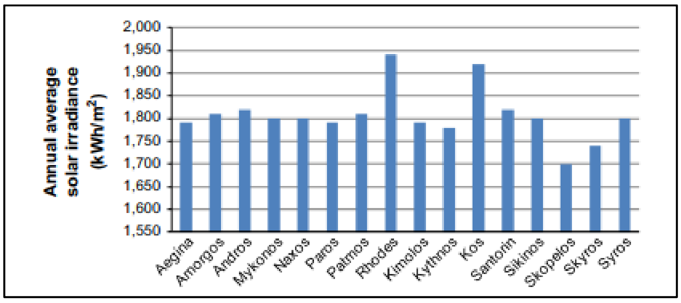

Fig.14 : Annual solar irradiation on average under optimum angle (KW h/m^2) in the largest Greek Islands (Mondol et al., 2013)

Currently, based on official data derived from the Regulatory Authority of Energy at the end of 2018, the total wind and PV capacity in the NIIs has reached the point of 319.7 and 161 MW, respectively (Caralis et al., 2020). In most of the islands there is more wind than PV capacity (Caralis et al., 2020). Actually, 50% of PV capacity and approximately 66% of wind capacity can be found in Crete (Caralis et al., 2020). In the table 6 wind and PV capacity are demonstrated per island.

Non-Interconnected Power System	Installed Capacity (MW)—December 2018	
	Wind	PV
Astypalaia	-	0.32
Serifos	-	0.10
Amorgos	-	0.29
Kythnos	0.67	0.24
Simi	-	0.19
Skyros	-	0.32
Patmos	1.2	0.15
Sifnos	-	0.20
Ikaria	0.99	0.40
Karpathos	1.23	1.16
Milos	2.65	0.62
Lemnos	2.88	1.89
Syros	2.84	0.99
Thira	-	0.25
Mykonos	1.2	1.04
Samos	8.38	4.37
Chios	9.08	5.17
Paros	12.96	4.21
Lesvos	13.95	8.84
Kos-Kalymnos	15.2	8.78
Rodos	49.15	18.16
Crete	200.31	78.29

Table 6: Wind and PV installed capacity in the NIIs (Caralis et al., 2020)

5.2 Challenges in terms of RES and Green Hydrogen development in the Greek Islands

SNM theory that is selected as the conceptual model in this thesis contributes to the identification of all the challenges that might arise during the energy transition within the Greek Islands. By distilling the relative literature, it was feasible to identify all the risks that accompany such an alteration, at a national level at first, and then for the Greek Islands, and specifically for the island of Crete. These challenges cover a whole spectrum of the contemporary Greek society, having have technological, environmental, social, economic and regulatory dimension. A synopsis of the aforementioned limitations is being presented in diagram 1.

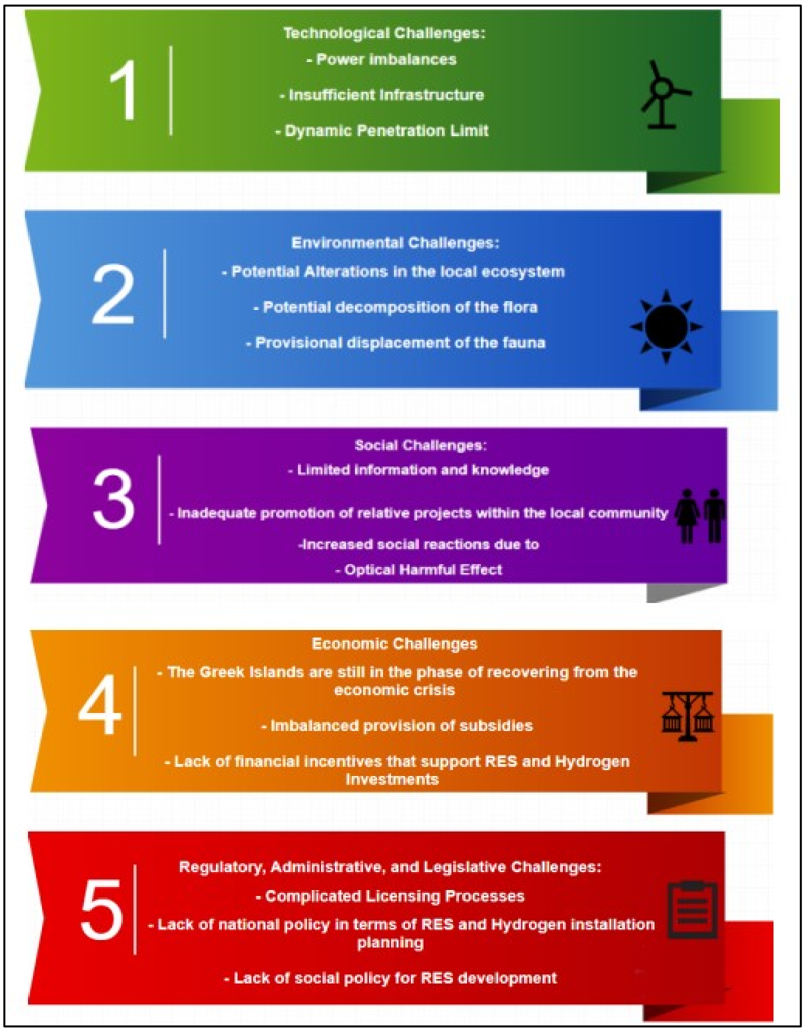

Diagram 1: Challenges that might impede the energy transition within the Greek Islands.

In the following section these barriers will be further analyzed.

5.2.1 Technical Challenges

There has been noticed that in the Greek Islands the currently available infrastructure presents some important limitations and technological inadequacies (Oikonomou et al., 2009). Long and short-term imbalances between power generation and demand are a usual phenomenon that until now remains unsolved. This can be mainly attributed to the fact that RES supply is not stable and continuous, therefore it is susceptible to seasonal variations (Oikonomou, et al., 2009). Increased share of RES implies that high reserves need to be maintained in order to ensure available energy generation during large and sudden production variations (Chatziargyriou et al., 2018).

"Dynamic penetration limit" is another limitation that NIIs have to deal with (Chatziargyriou et al., 2018). This constraint is referred to the dynamic stability of the system and is related to the characteristics of the NIIs, for instance the size, the type of conventional units or the load type (Chatziargyriou et al., 2018). In the case of the Greek Islands, problems in terms of voltage and frequency are usual due to faults or unplanned disconnection of units (Chatziargyriou et al., 2018). Therefore, proper management of voltage and frequency is mandatory, specifically in this case where inertia of the system and other technical limitations are predominant since there is no interconnected power system support (Chatziargyriou et al., 2018).

On top of that, Professor Caralis highlighted that in the Greek Islands there is a lack of facilities, institutions and adequate infrastructure for making experiments and testing new pathways for electricity generation. Therefore, the development of RES and green hydrogen applications is being hindered and delayed. Except from this, as mentioned by Professor Katsaprakakis the lack of skilled personnel exacerbates the situation. Undoubtedly, RES and hydrogen applications have specific installation requirements and they demand skilled and specialized employees in order to be established efficiently and safely. This entails that the personnel have attended seminars and have acquired the appropriate knowledge, in order to be involved in such type of projects without sacrificing their own and their colleagues' safety.

5.2.2 Environmental Challenges

When it comes to the environmental aspect of the energy transition, SNM theory suggests that the following barriers have to be taken into account (Oikonomou, et al., 2009). First of all, while establishing the new sustainable infrastructure numerous changes in the local ecosystem will be executed. This implies that, potential decomposition of the flora around the wind parks and provisional displacement of the fauna until the finalization of the installation process will be inevitable (Oikonomou, et al., 2009).

Moreover, the landscape will be affected due to the necessary infrastructure processes that have to be followed, such as road opening and transportation of cables (Oikonomou, et al., 2009). This implies that the level of noise and dust during the installation process will be elevated, and this increases the concern and the reactions of the local habitats (Oikonomou, et al., 2009). Indisputably, this kind of disturbance could bring serious problems especially during the summer period when the tourism in the Greek Islands is significantly high (Oikonomou, et al., 2009). However, each intervention within the natural landscape has to be to the minimum possible extent, and the area has to return to its original format (Oikonomou, et al., 2009).

5.2.3 Social Challenges

By approaching the topic superficially it could be argued that generally people are willing to follow a more sustainable path and support the RES and other pioneer projects. However, numerous objections and oppositions arise by people that live close to the areas of the proposed installations. This is rational since when for instance wind parks are created, social reactions increase significantly, due to aesthetic reasons. This tendency is known as the "optical harmful effect" (Oikonomou, et al., 2009). This is more intense in areas that are more developed due to tourism, and in this case the number of the turbines is the primary component that bothers the local citizens (Oikonomou, et al., 2009). Thus, their number should be carefully determined (Oikonomou, et al., 2009).

On top of that, it has been noticed that governments and investors have as a primary target the maximization of their profits and they do not prioritize the protection of the natural environment (Karydis, 2013). Therefore, in the case of Greek Islands where there is a great touristic potential, the problem of "conflicting interests" between the local citizens and the investors is inevitable (Karydis, 2013)

Also, the sources of information provided to the local citizens concerning the energy transition and its benefits are insufficient. More specifically, in tourist regions such as Crete or the Dodecanese, the infiltration of wind energy, requires a well organized promotion of the RES benefits to the local community (Oikonomou, et al., 2009). This can be as simple as mentioning for example that new employment positions that will be developed (Oikonomou, et al., 2009).

On the bright side, during the latest years Greece has made a significant progress in terms of social participation in the energy market and steadily strives to make the appropriate alternations in order to foster citizens' participation and create a framework that supports the energy democracy (Boulogiorgou et al., 2020).

5.2.3.1 The formation of the Energy Communities

A breakthrough at an EU level in the perception of the importance of the participation of the local communities and the citizens in the energy sector occurred for the first time in 2018 (Vasilakis et al, 2020). During this year the term "Energy Communities" was introduced by the EU Commission (Vasilakis et al, 2020), that had as a primary target to reinforce social participation in the energy market and emphasize the necessity for promoting social economy and eliminating the energy poverty (Boulogiorgou et al., 2020).

The "Energy Communities" were further elaborated with the implementation of two separate laws (Vasilakis et al, 2020). The first one was the Renewable Energy Directive (EU) 2018/2001 (revised format) that presents the framework of the "Renewable Energy Communities" in terms of RES share (Vasilakis et al, 2020). The second one is the Internal Electricity Market Directive (EU) 2019/944 (revised format) that redefines and develops new roles and obligations for the "Citizen Energy Communities" in the energy system concerning all the energy types (Vasilakis et al, 2020).

On top of the Renewable Energy Directive (EU) 2018/2001, Greece in 2018 shared the proper definition of the term "Energy Communities" under the law 4513. According to it, an energy community can be defined as "the cooperative that aims at fostering the social and solidarity economy and innovation within the energy sector, addressing the energy poverty and promoting sustainable energy production, storage, energy management, self-consumption, distribution and energy supply, as well as enhancing energy self-sufficiency and security" (Vasilakis et al, 2020). Mr. Kitsikopoulos, Co-founder of ELECTRA ENERGY, a certified social cooperative that works with citizens and local energy communities highlighted the fact that Greece decided that the energy communities have to be developed in a non-profit way, without of course excluding the involvement of profit-based enterprises. However, until now, the establishment of Energy Communities in the Greek Islands is limited, with the exception of Crete where five (5) Energy Communities are already active.

Finally, in 2018 the Greek Ministry of Environment and Energy issued the Energy Community Act in order to reinforce local actors, such as municipalities and small and medium-sized enterprises to take part in the energy transition and the energy planning by actively participate in the formation and the development of the energy projects (Ministry of Environment and Energy, 2018).

5.2.4 Economic Challenges

When approaching this topic from an economic point of view, it can be argued that the lack of financial resources is regarded to be the most important barrier that delays the energy transition (Elefteriadis et al., 2015).

Greece is obliged to implement the National RES plan within the context of the European energy policy, in terms of RES consumption, reduction of GHG emissions, and energy saving (Nanaki et al., 2018). However, this remains a quite challenging process since Greece is facing some significant economic difficulties and is still recovering from an economic crisis (Nanaki et al., 2018).

Generally, the subsidies provided by governments to promote projects based on fossil fuel sources is overshadowing the wide use of more sustainable options (Dulal et al., 2013). On the other part, the investment cost for sustainable energy projects is significantly elevated since it incorporates the cost for purchasing and installing the equipment (Afgan & Carvalho, 2002). Additionally RES projects have longer payback periods compared to the projects that promote traditional sources of energy such as fossil fuels (Zhang et al., 2012). On top of that, the unstable regulatory framework deteriorates the existing conditions (Elefteriadis et al., 2015). Specifically, in the case of wind parks where the initial construction cost is significantly elevated, the inadequate provision of financial resources can create numerous problems (Elefteriadis et al., 2015).

Finally, is not economically viable and feasible to utilize the wind energy for domestic or commercial purposes (Oikonomou, et al., 2009). This means that, there is no tax-free income against the expenditure for purchasing small domestic wind turbines and the costs for investing in such a purchase remain extremely elevated (Oikonomou, et al., 2009). Therefore the implementation of financial motivations for investing more in domestic turbines could facilitate the creation of more wind parks within the island without notable social reactions (Oikonomou, et al., 2009).

5.2.5 Regulatory, Administrative and Legislative Challenges

The Greek Ministry of Environment, Energy and Climate change has developed a specific mission in order to reduce the environmental degradation and protect the natural environment and resources (Ministry of Environment, Energy and Climate change, 2012). Investments in solar and wind energy technologies are presenting a significant rise and the government is striving to standardize and make the licensing process for RES development and offshore wind projects less complex (IEA, 2021).

Stavroula Pappa, during our interview, highlighted that all the energy targets set by the EU Commission are formed at an EU level, and then each country has to transpose them at a national level and formulate its legislation accordingly. Currently, the energy targets set by the EU are becoming more and more ambitious and optimistic and therefore new measures have to be implemented in each country. At this moment in Greece, all the regulations are being revised and new proposals are being created in order for the new targets to be reached successfully. The deadline for the revised proposal was June, 2021.

Even up to this date, the relevant project proposals remain economically unattractive (Chatziargyriou et al., 2018). The prices for electricity have increased significantly and the levies are subjected to major alterations and revisions during the last 4 years (Chatziargyriou et al., 2018). When it comes to the licensing processes for these projects, bureaucracy still remains one major problem that creates numerous obstacles and delays (Boemi et al., 2013). Unfortunately, as it can be shown in figure 15, in reference to the average lead time for total licensing process in Europe, Greece's position still remains significantly low (Boemi et al., 2013).

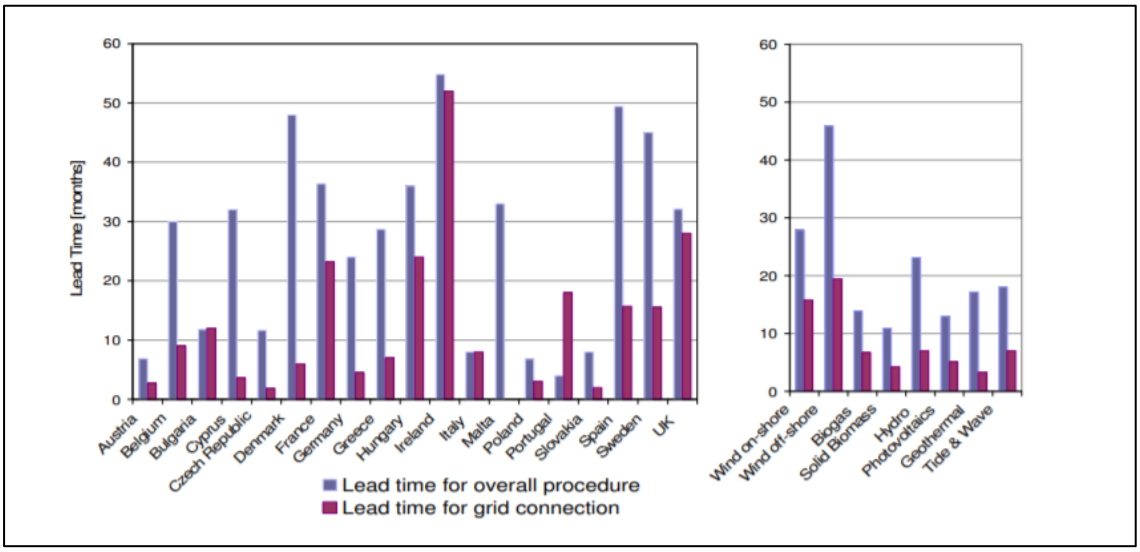

Fig. 15: Average lead time for overall authorisation procedure and for grid connection (Coenraads et al., 2008)

The complexity of the licensing procedures is profound when it comes for instance to the duration of the entire procedure for the licensing of a new **wind park**, that in some cases might last more than 3 years (Boemi et al., 2013). More specifically, the first steps, that last 3-6 months, can be incorporated in the preparation phase. During these months the determination of the area as well as relative research and organization take place (Boemi et al., 2013). The following 9-18 months the authorization of the relative project takes place. This process entails numerous different parameters such as the approval of the detailed studies regarding the installations or the technical requirements that have to be finalized (Boemi et al., 2013). In the last step, the installation of the wind park, as well as its interconnection to the main grid and an operational testing take place (Boemi et al., 2013).

Regarding the installation of a **PV park**, more than ten crucial documents are required (Boemi et al., 2013). The first phase requires approximately three months and it incorporates the precise theoretical planning of the installation of a new PV park (Boemi et al., 2013). The following stage lasts from two up to nine months and encompasses all the bureaucratic procedures (Boemi et al., 2013). Finally, during the next 1 to 7 months -depending on the size of the park- the purchase, the installation and the interconnection of the relative equipment take place (Boemi et al., 2013).

5.3 Conclusions from chapter 5

Greece presents exceptional RES potential primarily due to its geomorphology, climate and abundance in natural resources. There are numerous areas across the Greek territory where the wind speed exceeds 10 m/s at 30 m height, while the solar energy potential approaches 1900 kWh/m^2 (Kaldellis et al., 2012). Therefore, large-scale integration of RES applications could be the key solution for achieving a gradual and efficient energy transition within the Greek Islands. Thus, all these unique characteristics of Greece should not be neglected, but on the contrary they should be thoroughly “exploited”. It is crucial then for the Greek island communities to embark on the energy transition and adopt new more sustainable ways of producing and storing energy

On the other part, the incorporation of RES and green hydrogen technologies is a demanding process that entails numerous challenges on technological, environmental, social, economic and legislative level. Especially for the case of Crete these challenges are not negligible, and primarily the parameters of limited social acceptance mainly due to insufficient knowledge combined with technical limitations related to inadequate infrastructure and lack of well-trained personnel impede severely the dispersion of niches.

Chapter 6: Conclusions-Recommendations

6.1 Conclusions

The aim of this study was to evaluate the current feasibility of setting up a pioneer Sustainable Energy Planning in the Greek Islands, that focuses on Green Hydrogen Energy development and Storage in order to maximize the utilization of RES. This was fulfilled by utilizing SNM as a conceptual research model to investigate further if it is possible for the Greek Islands to achieve the desired energy transition and Crete was selected as the case study unti for further actual investigation. A literature analysis was conducted so as to have a realistic representation of the potential of the Greek Islands to follow such a transition, by investing also the challenges that might occur along the way, on a national level at first and then specifically for the Greek Islands and finally for the case of Crete.

For that purpose the following research question was formulated:

"What is the current feasibility of setting up a modern sustainable energy planning in the Greek Islands that focuses on Green Hydrogen-based technologies in order to maximize the utilization of RES?

Since, SNM is founded on a multi-level conceptualization of the existing regimes, embedded in a slowly changing landscape it was rational that an investigation of the currently existing situation was performed, in order to fully comprehend it and decide whether it is feasible to proceed to the transition, that could lead to further societal changes if this niche is appropriately adopted. The potential development of green hydrogen technologies within the Greek Islands was researched with a sociotechnical systems approach that could lead to a comprehensive understanding of the niche and its possibility of being implemented. Therefore, the main research question was divided into the following shorter research sub-questions, that were collectively used as a tool to answer the main research question.

"How is the energy system of the Greek Islands currently formulated?"

The purpose of this question was to provide an extensive analysis of the Greek islands' energy system by highlighting the situation in the island of Crete. As it was demonstrated the energy system of Greece is divided into the power grid of the mainland, and the smaller individual local power grids of the NIIs. In most of the NIIs, including Crete, the electricity is being generated by local thermal power stations that are utilizing fossil fuels and RES development is at an average level.

"What can be learned from literature in terms of Green Hydrogen development and at which stage is Greece in this sector?"

The objective of this question was to give an insight into the energy transition within the Greek Islands by highlighting from a theoretical point of view the significance of green Hydrogen as an alternative fuel. Green Hydrogen production and storage was further analyzed, combined with an examination of Green Hydrogen development in Greece. At the bright side, Greece is significantly interested in promoting green Hydrogen technologies and embark on the energy transition. However, the country is at an early stage in terms of green Hydrogen development, since it was not until 2021 when the most powerful energy companies in Greece expressed their interest and their willingness to invest in green hydrogen technologies.

"Which are the most favorable characteristics for realistic incorporation of Green Hydrogen-based technologies in the Greek islands? Which challenges might occur during the energy transition?"

The target of this question was to underline the unique characteristics that the Greek Islands present and could be further exploited. In this context a numerical analysis in terms of solar and wind capacity within these regions was provided. It was concluded that the Greek Islands, including Crete, present exceptional RES potential primarily due to their geomorphology, climate and abundance in natural resources. Therefore, large-scale integration of RES and Green Hydrogen applications can be easily achieved if approached correctly. Finally, from extensive analysis of the relative literature it was feasible to examine whether the niche proposed will be developed or not, by illustrating the basic challenges that might arise. From this analysis the most important finding is that the energy transition is a demanding process that entails numerous challenges on technological, environmental, social, economic and legislative level. Specifically in the case of Crete these challenges can not be neglected, since parameters such as the intense social reaction, the lack of adequate infrastructure, combined with the limited knowledge and the complicated licensing processes concerning the establishment of new projects might impede severely the dispersion of niches.

Taking everything into account, the main findings of this Master Thesis Project indicate that the Greek Islands could be the **"perfect candidates"** to develop a mini hydrogen economy, where they can produce extensively RES, mainly solar and wind energy, and they can create their own fuel to cover their needs. By investing more on RES and green hydrogen applications, there is a great chance that the Greek Islands will become energy independent during the next years and simultaneously they will motivate other regions to follow a similar path.

6.2 Recommendations for further research

In this section there will be provided analytical recommendations that could be used as a starting point for further research. On a theoretical basis, the constantly rising energy challenges that the Greek islands have to deal with increase the necessity for a practical, adaptable and easy-to-apply approach that promotes sustainability and can cover efficiently the future energy needs. However, even the slightest alteration requires governmental support and assistance.

Henceforth, government's energy policy should prioritize the interconnection of the Greek islands in the energy system of the mainland in order to assure security of electricity supply and assist the expansion of RES. In this way, Greece will fulfill its RES targets and will achieve a considerable reduction in the percentage of GHG emissions. Synchronously, Greece should invest more on entrepreneurial storage systems (such as Hydrogen Energy Storage), taking always into account their financial and technical feasibility within each island. In order for a more sustainable framework that maximizes the utilization of RES to be designed and adopted, a **strategic and well organized plan is essential**. This plan should be formulated based on the needs and the potentials of each island, the level of social acceptance and familiarization as well as the political willingness within each island.

During the last decade the development of RES projects was not approached properly. More specifically, the numerous time-consuming and complicated procedures for the licensing of large size wind parks and secondary photovoltaic stations hindered the whole process. Therefore it is highly important that during the next years this type of procedures will be simplified and the Greek Government will implement 'smart' targeting policies with the view to foster RES and Hydrogen development and support the establishment of the appropriate infrastructure.

A focus should also be brought on the amelioration of the flexibility of the energy system. In the case of the Greek Islands, energy storage methods can be then utilized as a key solution that can bring numerous benefits, specifically on smaller islands with high RES potential. The Greek Government should then fund energy storage devices, in order to reduce the operation and the balancing costs and ensure adequate energy security and efficiency of electricity **transmission** and **distribution.** However, attentive estimation of the total cost for the purchase of the necessary infrastructure for energy production, storage, transportation and distribution in the Greek Islands and determination whether it is feasible for Greece to support such kind of investments is required beforehand.

On top of that, when arranging the alterations that have to be executed, the environmental aspect should not be neglected. The RES and Hydrogen exploitation should be dictated by the obligation to protect and preserve the environment. Despite the fact that the Greek Islands present remarkable RES potential and numerous alterations could be formed there, the necessity to protect their unique natural characteristics and cultural heritage should be prioritized. Additionally, the limited carrying capacity of RES installations in some islands should always be taken into account and over exploitation should be prohibited. In this context then, the principle of proportionality can be utilized as an adequate legislative tool for the balancing of conflicting situations where the amplified RES development can cause negative environmental repercussions.

Finally, social acceptance is an indispensable component for achieving the energy transition. It has been proven that there is a profound connection between citizen's knowledge and awareness about climate change and its impacts, and their willingness to act and participate actively in the energy transition. Intensified awareness normally maximizes the acceptance of climate-friendly technologies within the communities as a way to counteract climate change. Social reactions can be decreased with a suitable "dispersion" of knowledge on the level of local communities. The formation of the energy communities is a great initiative that should be preserved, however as it was concluded also from the interviews all people that are a part of it should not be driven by any form of personal interest.

Chapter 7: Reflection

In this Master Thesis project the proposed solution that entails the incorporation of green hydrogen based technologies and the maximization of RES production within the Greek Islands, as an alternative way to meet the National and International energy targets imposed, has the potential to be a breakthrough for Greece and become a "shining example" for further research in the future.

A characteristic of this Master thesis project that is worth-mentioning is the fact that it proposes a pioneer solution based on the development of Green Hydrogen Technologies within the Greek Islands, a topic that is completely new for the case of Greece. As it was illustrated during the analysis of the results Greek Government is eager to follow a more sustainable path and incorporate green hydrogen technologies within the Greek energy system, but it was not until this year that the first proposal was imposed. Therefore, the solution proposed constitutes an entrepreneurial approach with great potential, that can motivate and incentivise all the interested parts to reflect and invest more on alternative solutions such as those related to hydrogen development.

Additionally, another significant component of this research is interlinked with the fact that by distilling the relative literature it evaluates all the challenges that might occur during the energy transition in order to lay the foundations on how the energy transition should be effectively approached. However, it does not cover the topic superficially by only focusing on the economic and technical barriers, that are profound especially for the case of the crisis-stricken Greece, but it examines meticulously the parameter of social acceptance, which as it was proven plays a vital role in the energy transition and finally determines the viability of the proposed scenario.

Taking everything into account, it can be argued that this research constitutes a valuable addition to the currently available scientific literature, since it proposes a pioneer plan that in the long run can alternate the whole structure of the energy system of the Greek Islands and create the foundations for turning the Greek Islands energy independent.

Additionally, it is highly important to determine which were the *limiting aspects* of this research. First of all, a significant barrier that had to be taken into account “a priori” is the limited availability of notable data concerning Green Hydrogen Energy Technologies specifically in the case of the Greek Islands. Since Green hydrogen development is a pioneer approach that has recently been discovered, there was the risk that the available data are limited. For that purpose, the selection of the appropriate material was carried out assiduously and a variety of different sources and empirical papers were used in order to incorporate sufficient material and cover the whole spectrum.

As it was highlighted from most of the interviewees numerous different participants are involved in the RES sector in the Greek Islands, and therefore numerous problems arise in terms of proper coordination and communication. More specifically, all the different actors that are involved in the RES field have different interests and perception concerning the development of RES and Green Hydrogen technologies. On the one hand, private producers in the RES sector aim primarily at maximizing their profits with the minimum environmental impact while at the same time public policy makers and governments mainly focus on developing technologies that promote sustainability and can be easily applied at a large scale.

Finally, it seemed quite vague and challenging to determine the appropriate period of time that this research would focus on. It is clear that RES and Green hydrogen based technologies are innovative alterations that face an impressive development specifically during the latest years. Subsequently, it was challenging enough to define a representative period for this research. After thorough analysis it was concluded that the last decade is considered to be an appropriate examined period, mainly due to the fact during that time a well-regulated and organized way of promoting RES was introduced by the Greek Government. As a result, this time-frame seemed satisfactory for the accumulation of sufficient relative material.

Chapter 8: Appendix

In this section the following appendices will be incorporated:

i.Informed consent form

ii.List of participants in the interviews

iii.Interview Guide

iv.Reference List

8.1 Informed Consent Form

Informed consent form for individual interviews for the Master Thesis Entitled

"Sustainable Energy Planning on the Power System of the Greek Islands based on Hydrogen Energy Storage in order to maximize the utilization of Renewable Energy Sources (RES)"

By Baltima Anastasia-Anna
Master's Program: Environmental and Energy Management (MEEM)
University of Twente
Academic Year: 2020-2021

I .... ,
declare to be adequately informed about the type, the approach and the main objective of this research project. I voluntarily agree to participate in it and I provide my informed consent. However, this implies that I have the indispensable right to end my involvement at any time without further notice or explanation. My personal responses will be utilized only in the context of this research project. In its publications, they may *(please tick one of the options):*

☐ Be included anonymously
☐ Solely be incorporated as information source but not anonymously

During the execution of the interview I have the right to restrict the use of (some of) my answers further than indicated above.

Name of the participant:

Date: May 28, 2021

Signature of the participant: …...…………………………………………………

I declare to adhere entirely to the above.

Name of the researcher: Baltima Anastasia-Anna

Signature of the researcher:  Date:

8.2 List of participants in the interviews

	Name of the Interviewee	Specializarion of the Interviewee
1.	Arampatzis Georgios	Professor of Chemical Engineering, National and Technological University of Athens
2.	Caralis Georgios	Professor of Mechanical Engineering, National and Technological University of Athens
3.	Katsaprakakis Dimitrios	Professor of Mechanical Engineering, Technological Educational Institute of Crete
4.	Kitsikopoulos Dimitrios	Co-founder of ELECTRA ENERGY
5.	Pappa Stavroula	EU Qualified Lawyer - Project Manager at REScoop.eu
6.	Anonymous	
7.	Anonymous	

8.3 Interview Guide

- **First Part**

Introduction

i. Question whether the interview can be recorded or not
ii. Briefly introduce myself
iii. Analyze the topic and the targets of my Master Thesis
iv. State that the ethical issues will be of course respected and
v. Ask the interviewee whether he/she wants his/her participation to remain anonymous

- **Interview Questions**

Related to the 1st sub-question

i. How is the energy system of the Greek Islands formulated at this moment?
ii. Are there problems in terms of energy security and severe environmental degradation related to energy production/use?
iii. Which are the climate targets stated by the energy policy for the upcoming years?
iv. At what stage are the Greek Islands in terms of RES development and what types of RES are primarily used? What are the driving forces for RES?

Related to the 2nd sub-question

v. Which is your perception on the importance of energy storage for energy transition in the Greek Islands ?
vi. Hydrogen can be used as a clean fuel that promises to mitigate the environmental degradation. What is the current status of development in the field of Hydrogen Energy Storage within the Greek Islands?

Related to the 3rd sub-question

vii. What kind of unique characteristics do the islands present that can be “exploited” for further development of Hydrogen Energy Storage?
viii. Are there companies available there that are specialized in this field?
ix. Are there any Greek Islands that possess the necessary equipment for the storage and the transportation of the hydrogen produced?
x. What kind of changes must be formed to fully adopt this innovation and face these challenges?

Related to the 4th sub-question

xi. What are the main challenges that the Greek Islands will face when trying to adopt this pioneer technology (Hydrogen Production & Storage) ?
xii. What is the reaction of the citizens? Do they want to embark on the energy transition or they are hesitant?
xiii. The presence of covid-19 has influenced severely the efforts made until now towards the energy transition?
xiv. Are there any developments in legislation or regulation for RES development within the Greek Islands?
xv. Are there any subsidies? If yes, what are they for? And is so are they enough? If no, do you think they would speed up the energy transition?
xvi. Are you optimistic about the energy transition?

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