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“Photovoltaic Systems & Energy Transition in Greece”

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Petros Papantonakos

ABSTRACT

Photovoltaic Systems & Energy Transition in Greece

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The goal of this thesis is to examine the issue of energy transition and to highlight the importance of photovoltaic systems in the attempt of Greece to decarbonize its economy. Additionally, the author examines the role of this technology in the country's energy security, society and energy system in general. During this process, there are mentioned the challenges that are derived from the need for further deployment of PV systems. Furthermore, the thesis investigates the opportunities that are appearing for Greece through embracing energy transition. These opportunities include the conversion of Greece to an energy hub or energy export country through the tool of international grid interconnections. Finally, a comparison between Italy and Greece in terms of energy transition is attempted. The present thesis concludes that energy transition is a necessity in a global level. Faced with this reality, Greece has to start producing energy exclusively from clean technologies. Photovoltaic systems can play a crucial role in the attempts of Greece and can provide the country with multiple benefits.

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TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

CHAPTER 1

INTRODUCTION

1.1. Preamble

In the recent years, more and more countries around the world have started to make serious efforts to reduce their greenhouse gas emissions and to make their economy more sustainable in order to protect the environment and to mitigate climate change. In many regions, states have set net-zero targets in the long term, followed by sustainable solutions related to every aspect of the economy, as well as adaptation projects for safer and more protected societies. Among the steps that have been pursued to achieve green national targets, maybe the most important is the ongoing global energy transition. Historically, there have been energy transitions in the past before, but this is different. This energy transition is about abandoning the use of fossil fuels that bring bad repercussions to natural environment and to embrace the use of renewable energy sources worldwide that will lead to a massive reduction in greenhouse gas emissions and will contribute to the mitigation of climate change.

Renewable energy sources have many advantages in comparison with fossil fuels. First of all, their harm to the environment is much less than this of fossil fuels and after the construction stage, for example during the production of electricity, in some cases is near to zero. Also, the use of domestic renewable energy sources (or RES) by a country enhances its energy security because it is not dependent from the geopolitical developments in regions that export oil or natural gas for instance and the consequent volatility of energy prices. Furthermore, the use of RES enhances a country's economy because it reduces energy imports from other countries and maybe it gives the ability to export its own renewable energy to neighboring states. Last but not least, we should not forget that unlike fossil fuels, RES will never be depleted, so the use of them will give humanity an endless source of energy.

Of course, RES historically have had their disadvantages too. For example, for many years their levelized cost of energy (LCOE) was higher than this of conventional energy sources, mainly due to technological and technical reasons. But in the last decade, the LCOE of renewable technologies like photovoltaic systems or wind turbines has been reduced dramatically, paving the way for them to dominate in the energy mix of many countries in the not so distant future. The reason for this massive reduction in their LCOE is probably related to the improvement of their technology, the increasing use of them, as a result of public policy measures in many occasions and of course the developments in the field of energy storage.

A major problem that PV systems or wind parks were suffering from was that they could not provide stable amount of energy during a day or a year because they are dependent from the sunlight or the wind. This feature, in combination with the fact that electricity could not be stored, had as a consequence limited penetration of PV systems and wind energy in the energy mix of most countries. However, in the last years there has been a great development in the field of electricity storage and this is going to be continued because of the massive investing interest for storage systems. Another issue that prevented the further penetration of RES was the capacity of the electricity grid in many countries. This is a real challenge if a state wants to electrify its economy even more in the future. Nevertheless, major investments are planned in the electricity grids too. If the issues of electricity storage and improvement of electricity grids be resolved, then the dominance of RES will be even bigger.

Global green energy transition will lead to climate change mitigation and is essential for the environmental goals that humanity wants to achieve. Around the world, there are different regions with different levels of success in this attempt until now. The region of European Union is maybe a leader in the energy transition process or definitely one of the leaders globally. Many decisive policies have been created that set ambitious goals for the next decades. Greece, as a member of European Union, has embraced this attempt for transition to more sustainable sources of energy and has adopted many measures that lead to that way.

One of the technologies that play a vital role in the energy transition process is photovoltaic (PV) systems. In the last fifteen years, the use of PV systems has been increased very much in many parts of the world and their cost has fallen massively. The use of solar energy represents a solution that is already and will be in the future very useful as a clean way to produce electricity. As we mentioned before, issues of the past like the problem of energy storage or the high cost of the investment that used to prevent PV systems from being more popular have started to withdraw fast and from now on this technology will represent a smart and cheap alternative solution that will take a bigger share of the energy mix in many countries and will replace in many occasions fossil fuels, especially for electricity production purposes. Greece, as a country of south-eastern Europe, has a very good potential for adopting sustainable energy technologies like PV systems or wind turbines, mainly because of its weather conditions.

1.2. Goal, Methods and Structure of this Thesis

The goal of this thesis is to analyze the concept of energy transition and to highlight the importance of clean technologies like PV systems in the energy transition process of Greece. More specifically, there will be an analysis of the issue of energy transition in general and a presentation of the role of photovoltaic systems during this process. After that, there will be an attempt to present the history and evolution of PV systems in the Greek energy market and to examine their role and their potential contribution to the country's environmental targets as well as its targets for reliable energy supply. Furthermore, there will be a reference to the challenges that the further penetration of PV systems in the energy system of Greece pose and which solutions could be applied in order to overcome these obstacles. Additionally, there is a part related to the international interconnections of Greece and their role as a useful tool for the country, as well as a part that examines the case study of Italy and attempts to make a comparison with Greece in terms of energy transition. Finally, a summary of the thesis and some conclusions will be presented.

In order to examine the above issues, there was a systematic review of the existing literature related to the topics included in every chapter. The research included information derived from reports and other documents of local and international organizations, articles and scientific papers of energy experts, as well as legislative measures. After reviewing the existing literature, the author attempted to analyze the information and to reach useful conclusions about the role that PV systems can play in Greece's energy transition.

CHAPTER 2

ENERGY TRANSITION AND PV SYSTEMS

2.1. Introduction

If we want to define the term "energy transition", we can say that is a *"transition of the way that energy is produced, distributed and consumed"* (OECD/IEA and IRENA, 2017). There have been some energy transitions in the history of humanity but this transition is about the production of energy from renewable energy sources that can provide a country with "clean" energy, not harmful for the environment. So, basically, we have to abandon fossil fuels and to replace them with sustainable ways to produce energy.

The term "sustainable" is also important. There is an ongoing attempt in many countries globally to achieve "sustainable economic growth", which means economic growth in ways that do not provoke harm to the natural resources and that ensure a specific level of life quality for the next generations. So, in other words, sustainable growth is a prerequisite in our attempt to limit climate change and to protect the environment, ensuring the continuity of the same level of quality of life in the next decades.

2.2. Global Energy Transition and Energy Transition in Greece

In the last years we have observed a rapid decline in the cost of some renewable technologies. This is crucial because it leads to rising investments that are necessary for the green energy transition that we pursue as humanity. If we want to achieve green energy transition, we will need the combined result of some things. For example, we will need innovation for the creation of new technologies, greater reduction in the cost of renewable energy sources that will boost even more investments and especially in developing countries, energy efficiency that will lead to lower energy consumption, widespread electrification of the global economy to abandon fossil fuels more easily, greater development of information and communications, as well as great investments in the field of infrastructure.

The first step to limit climate change is to reduce greenhouse gas emissions that are related to energy production. This fact makes energy transition very important for the whole attempt. Governments have a great responsibility in this process. They must ensure that there is a positive environment for the change we want using public policy, making investments easier for companies or independent players that want to invest in this new kind of business and industry. Governments must enable this process.

The energy transition will have wide-ranging benefits for the economies and societies that are involved. These benefits include better environmental conditions, as well as economic growth. Speaking of economic growth, it is true that energy transition maybe will lead to the reduction of some jobs that are related to fossil fuels industry. However, at the same time it will create some other jobs in other energy sectors that will be intertwined with more sustainable technologies for energy production. As for the better environmental conditions, the positive changes that will occur for people will be also linked to the better quality of the natural environment they live in, especially in regions that are near fossil fuels production. Also, there will be an improvement in public health that will be the result of the enhanced air quality and the reduction of air pollution.

The biggest percentage of the emissions that need to be reduced can be achieved by the accelerated use of renewable energy technologies and efficiency measures. For the rest of the emissions, maybe in sectors that is not easy to cut emissions completely, we could use carbon capture and storage or another technology used for the same purpose. When the cost of new renewable energy technologies will keep getting lower and lower, then investments will increase automatically because it will be the best option economically for energy production. However, there is a need to stop subsidizing the fossil fuels sector if we want to make the positive change happen. If the subsidies stop, then sustainable technologies will be even more competitive economically.

Furthermore, there is a danger of stranded assets if investors or countries keep investing excessively in fossil fuels. If energy transition continues to be a priority when we vision energy production process in the future, this will mean that in the next decades, fossil fuels will have a reduced share in energy consumption. Therefore, if investors keep investing in these sectors, there is a chance to not have the profits they expect in the long run. On the other hand, these stranded assets would take additional investments away for sustainable technologies, undermining in this way energy transition.

Dealing with climate change as a humanity includes two components. The first component is mitigation of climate change and the second one is adaptation to the new circumstances. Mitigation of climate change refers to the efforts that we make in order to limit temperature rise to 1.5 Celsius degrees or as lower as we can from 2 Celsius degrees (IRENA, 2023). Mitigation efforts encompass energy transition and greenhouse gas emission reductions. It also encompasses energy efficiency and technological innovations for sustainable growth purposes. Adaptation to the new circumstances is translated to infrastructure projects that are intended to protect societies from extreme weather conditions that in the future will be more frequent. Events like extreme draughts, floods, heat waves or wildfires are already more present than in the past and they will probably be more often in the future. This means that are necessary infrastructure projects that will make cities and agricultural regions more resilient to these new conditions and safer to live in.

The distribution of the available amount of money that is invested in climate change fight between mitigation and adaptation is not an easy task to deal with. There are countries, especially small island-states that maybe will be extinct in the future due to sea levels rise. There are also many regions that will face frequently serious destructions because of extreme weather events. It makes great sense that these regions are very interested in spending money for adaptation projects, enhancing their infrastructure.

Another important aspect of energy transition is the term “energy democracy”. In a few words, energy democracy is about the participation of the citizens in the energy sector and the decision – making process in energy issues through self-generation of energy. According to Szulecki, *“the elements of energy democracy that existing definitions identify, are increased citizen participation in decision making…increased civic, community, and/or public ownership of the means of energy production...which also means breaking up existing economic and power structures; and finally different positive co-effects: employment, sustainability, sufficiency, quality of life, and better personal relationships”* (Szulecki, 2017).

In his paper “Conceptualization of Energy Democracy”, Szulecki understands energy democracy *“as an ideal political goal, in which the citizens are the recipients, stakeholders (as consumers/producers) and accountholders of the entire energy sector policy”.* He also adds that *“governance in energy democracy should be characterized by wide participation of informed, aware and responsible political subjects, in an inclusive and transparent decision – making process relating to energy choices, with the public good as its goal. To create and safeguard civic empowerment and autonomy, high levels of ownership of energy generation and transmission infrastructure through private, cooperative or communal/public means are necessary”*. We can conclude that he is talking about a “citizen-prosumer”, which means someone who produces the energy that he consumes and participates energetically in the decision – making process as for energy issues.

Energy democracy, in general, has many positive effects. For example, it increases the participation of citizens and it makes them more invested in the energy transition process, they don't feel isolated from the developments, it is less probable to be opposed to the further penetration of renewable energy sources because they will produce clean energy themselves and they will have economic benefits, while at the same time they will contribute to their country's climate goals. Besides these, they will enjoy environmental benefits too. Conclusively, energy democracy through self-generation is something necessary if we want to achieve the further penetration of renewable energy sources in the global energy mix and to achieve the goal of net-zero emissions.

However, we should keep in mind something very important. Energy transition does not mean the same thing for every country or region. Some developing countries produce fossil fuels, so it is not so easy for them to reduce it and increase the share of renewable energy sources in their energy mix. Maybe the production of fossil fuels provides them with significant profits, which are used for public utility projects. In this case, maybe these countries are afraid that the reduction of fossil fuels production and the consequent reduction of their profits, will lead to social unrest because of the poverty that their society face. Also, it is possible that a very big part of their society is working on oil or coal production sector, so they will be worried that they will lose their jobs.

Apart from these, there are many regions in developing countries that still don't have access to electricity. This means that they would want to find the cheapest possible way to find access to electricity and they would not examine solutions that are not so cheap to produce energy. Developed countries and regions, for example Europe or North America, see energy transition from a different perspective than Africa or a large part of Asia. If we compare it to previous energy transitions, this transition is more complex because it has to be faster and is driven mainly by public policy and not so much from financial data. According to Yergin, there are four problems with this energy transition: 1. Energy security, 2. Scale, 3. Division between developed and developing countries, and 4. Materials of the transition (Yergin, The Energy Transition Confronts Reality, 2023).

As for the issue of energy security, we see that in the last years this issue has been a priority for many countries globally. To put it in another way, after the recent global energy crisis, every country takes more seriously its energy security. Nowadays, that energy security has come to the surface again, because of the war in Ukraine and the energy crisis countries are not so willing to give up fast fossil fuels. The second issue is about scale. It is a fact that the biggest part of the world economy depends on the current energy system, which means it depends on fossil fuels. Therefore, it will not be an easy and simple task to change the energy system so fast, especially when most of the countries are developing and not developed.

This leads us to the third issue that Yergin warn us to keep in mind. We mentioned that also before. Energy transition is not seen in the same way in every part of the world. In Europe, for example, climate change mitigation is a top priority and public policy has been trying to solve this issue. In Africa or large parts of Asia, climate change mitigation co-exists with other priorities too like reducing poverty or having access to electricity for every region and boosting economic growth. According to data published from IEA, in 2023 there are still 745 million people that don't have access to electricity. The region that faces this issue the most is Sub-Saharan Africa (Cozzi, Wetzel, Tonolo, Diarra, & Roge, 2023). Of course, there has been an improvement since 2015 when the 7th goal of United Nations for sustainable development was decided, included in 2030 Agenda. This goal is trying to ensure that everyone will have access to clean and affordable energy until 2030. However, access to electricity remains a serious problem for many regions around the world. Given this data, is not easy for every country to use clean technologies to produce energy, unless these technologies are very cheap.

If we want to make energy transition happen globally, we must ensure that renewable energy sources will be the best option for developing countries, by reducing their cost or through subsiding. There should be more help to developing countries in order to continue pursuing energy transition. After all, climate change is mainly a creation of the developed world and their endless efforts for economic growth. Developing countries like China are blaming on west developed countries for climate change, so they are wondering why should everyone pay the cost of energy transition. It is true that developed countries have the historical responsibility to help developing countries financially in order to make energy transition just for all.

The forth and last issue that we have to bear in mind, is the issue of the materials that are needed for the global transition. Renewable technologies, as well as, electric vehicles require significant quantities of specific minerals, like lithium and cobalt. The demand for these minerals will be very high in the future because they are crucial for these necessary technologies. This maybe will lead to some geopolitical changes too and further implications for a country's energy security.

To sum up, we can easily understand that this energy transition is not a simple process but is also necessary if we want to build a more sustainable future. As a global issue, it requires organized international efforts and cooperation. Developed countries must lead in these efforts and pave the way for developing countries to follow, through financing their efforts for sustainable development and through making renewable energy technologies cheaper. Opinion of the writer is that energy transition could be achieved in an international level but not until more countries realize its importance and make it a higher priority. Of course, crucial would be this realization from powerful countries like United States that would help other smaller countries too in this process.

As we analyzed before, energy transition is a process that requires consistency and long-term planning. Greece has been trying to follow this process and has set some ambitious goals that will guide the country in the next decades and they will lead it to the goal of net-zero emissions until 2050. The net-zero emissions target and the mitigation of climate change in general is important for Greece and its society because they will protect them from extreme weather conditions in the future, for example long heat waves or wildfires, floods and consequent reduction of crops. Unfortunately, Greece is already facing some of the consequences of climate change and phenomena like big wildfires, destructive floods and long heat-waves are more common in the last few years. These events are bad not only for the well-being of the citizens and their sense of safety but they are also bad for the country's economy because they are translated to large state compensations to communities that are hit from the destructions and attempts to rebuild houses, villages and public infrastructure like roads and bridges that have been destroyed. As a result, we see that climate change poses a threat to Greece's security in general and this makes steps to net-zero target even more important and necessary.

Of course it is important to take steps not only for the mitigation of climate change but also for the adaptation to new conditions. There must be completed infrastructure projects that will ensure the better state's response to events like the ones we mentioned before. These "adaptation" measures are equally important to happen in the future in the country. However, the first step if we want to ensure a better future is the attempt for "mitigation" of climate change that will start with the process of energy transition as a fundamental part.

We saw that energy transition is a significant priority for Greece because if it happens globally, it will prevent more extreme weather events to happen in the future through the mitigation of climate change. Greece has been trying to follow EU guides and has set some ambitious goals that will make green energy transition not only a vision but also a future reality for the country.

In 2019 Greece published its National Energy and Climate Plan (NECP), which is a scheme that provides specific directions for energy and climate issues, sets targets and includes policy measures and investments plan for the next decades. It is the main guide that Greece follows in order to achieve green energy transition. The NECP got revised in 2023 and includes more ambitious goals than in 2019. More specifically, Greece's revised NECP sets as target approximately -55% greenhouse gases in 2030 in comparison with 1990 with a view of net-zero emissions in 2050. The same percentage in

NECP of 2019 was 40%. Also, it sets that renewable energy sources will present 44% of total energy consumption in 2030 and almost 80% of electricity production. Similarly, the same percentages in NECP of 2019 were 35% and 61% (Greece - Draft Updated NECP 2021-2030, 2023).

The NCEP sets as a priority the further penetration of RES in the national energy mix because they are considered as the main vehicle in the attempt to decarbonize the economy. Greece wants to ensure that in the long run electricity production will come only from renewable sources and this will be the first important step in its attempt for net-zero emissions in 2050. The goal that Greece is trying to achieve is to electrify most parts of its economy and the electricity will come from renewable sources. Of course, this vision requires large investments in the electrical grid of the country and also policy that favors the further penetration of renewables in its economy.

Apart from the increased participation of renewable energy sources, the revised NECP sets also some other targets: 1. Increased energy storage in order to protect and support the grid, 2. Energy efficiency which means energy upgrading of buildings, smart systems, management of energy consumption, 3. Electrification of light vehicles with investments in infrastructure and interconnection with the grid, 4. Eco-friendly alternative fuels, 5. Gaseous fuel system, 6. Bio-economy, 7. Creation of hydrogen infrastructure and market and use of hydrogen in sectors that cannot be easily electrified, 8. Innovation, 9. Support to new industries and business activities developing a domestic value chain for green energy transition technologies.

We can observe in the above targets that in many of them, the issue of infrastructure enhancement is crucial. For example, in order to electrify thousands of light vehicles, we will need the appropriate infrastructure like abundant charging stations in every region of the country. Similarly, energy efficiency means also new buildings that will be better constructed in order to be warm in the winter and cool in the summer. Creation of hydrogen market will need of course the creation of the appropriate infrastructure for hydrogen development. Specifically for the hydrogen, it is a very important component of the net-zero process of Greece because it will be used in sectors and industries like cement, for instance, or heavy transportations that would not be electrified easily. The utilization of hydrogen in these sectors will make it easier to reduce the emissions related to them.

Therefore, we conclude that infrastructure projects are of great importance in the energy transition process in Greece. These projects, however, will need large investments and some decades to happen in the scale that will be needed. So, another big issue that is related to energy transition in Greece is the attraction of the appropriate investments in the country and specifically in the sectors of energy and infrastructure. Besides these investments, European Union could provide a great financial help to the country with programs like the Recovery and Resilience Facility (RRF) or other financial instruments.

Apart from the other targets that are mentioned in the NECP, the first and probably most important is the further penetration of renewable energy sources in Greece's energy mix. This further penetration will make green energy transition a reality in the country and will reduce dramatically the country's greenhouse gas emissions. There are some specific challenges in this attempt and will be examined later too. First of all, the cost of renewable energy sources that until a few years ago it was significantly higher than the cost of conventional energy sources. However, in the recent years the cost of some renewable technologies has fallen dramatically. These technologies are mainly photovoltaic systems and wind turbines. The massive use of solar energy and wind energy would provide the country with very cheap and clean energy in the future. These technologies have already become a valuable part of Greece's energy mix. However, there will be a need for lower cost for other renewable technologies too if we want to achieve the goal of net-zero emissions in 2050. These technologies could use geothermal energy or biomass treated in a sustainable and "green" way.

Another challenge that we have to take into consideration and that poses obstacles to the further penetration of renewables is the grid capacity. Unfortunately, the current national electrical grid is not yet prepared to include the amount of green energy that we need in order to achieve our goals as a country. This leads to many problems. First of all, it discourages the further investments in renewable energy projects because these projects face serious delays in their connection to the grid. The current grid cannot provide the necessary space in order to include all of the necessary renewable energy projects. Therefore, we observe again the absolute necessity of major investments in infrastructure in order to make energy transition in Greece a reality. These investments include the national electrical grid. At the moment, big investments are happening in the grid of Greece and even more are planned to happen in the next years.

Another challenge is of course the issue of energy storage. We said that PV systems and wind energy are already a valuable part of Greece's energy mix but these technologies have a specific characteristic. They cannot provide a stable amount of energy every hour of the day and every day of the year because they are dependent from the weather conditions. So in order to be a bigger part of the country's energy mix, Greece will need to find also ways to store the excess energy that PV systems, for example, generate in the afternoon and to transpose it later during the evening. These energy storage systems will help also the national electrical grid to be more resilient and to let the further penetration of renewable systems to be included in the energy system of the country more easily. Also, they will make the Greek energy system more efficient.

Until a few years ago the energy storage was not possible or financially feasible in a commercial scale. However, this has changed in the last few years and there are some available options and technologies in the field of energy storage. At this moment energy storage projects have started to take the momentum in Greece and some state policies are helping in this direction through the shape of subsidies.

Some other aspects that create difficulties in the energy transition process in Greece are the issues of licensing and also the issue of recycling. To begin with the issue of licensing, it has been observed that in Greece the licensing process in order to start generating renewable energy and to provide the grid takes a long time. This phenomenon creates problems in the potential generators because they don't have profits in the first years, until everything is properly managed. As a result, the long and complicated licensing process discourages massive investments in the renewable sector and leads to results that are opposite to the pursed targets. Greek governments are trying to make licensing process simpler and easier in order to avoid discouragement of the much-needed investments in the renewable sector.

As far as recycling is concerned, this is an issue that poses challenges to every country. Energy transition will require large penetration of PV systems and wind turbines to generate more clean energy. However, after some decades the old systems and their equipment must be replaced. So we have to create a resilient recycling system for old PV systems and wind turbines that will dispose sustainably this equipment and will reuse everything that can be reused. Greece has not faced this challenge yet because most of the country's renewable systems are relatively new but in the next decade it will start to face it so it needs a stable and reliable recycling system in order to be prepared and to not let this issue be an obstacle in the country's energy transition.

Another aspect of the energy transition in Greece is the issue of energy democracy that we have already mentioned before. We said that energy democracy is related to the concept of self-generation of electricity. Energy democracy will help the Greek society to be more invested in the country's energy transition and every family could see through self-generation its electricity bill to be reduced. The reduced electricity bills through self-generation and generally through massive penetration of renewable energy sources will help the state to alleviate the energy poverty that is intense in Greece. Greece has one of the biggest percentages of energy poverty in European Union. According to the International Energy Agency (IEA), in 2021 "17.5% of the total population and 36.7% of economically vulnerable consumers were unable to adequately heat their homes; these figures are higher than the 8% average for the European Union” (IEA, 2023).

Therefore, energy democracy will lead to multiple benefits to the Greek society and state. First of all, it will help in the alleviation of energy poverty through self-generation. Secondly, it will make the Greek citizens more positive to the energy transition process and the penetration of renewables because they will start being invested and enjoy the positive effects. Last but not least, it will help the country to meet its climate targets and to achieve green energy transition. In the last years, the Greek governments have started to promote the concept of energy democracy through promotion of the energy communities that are developed gradually in Greece and through subsidies that promote self-generation, through home photovoltaic systems. These policies should be present even more in the future if we want to meet our goals and to achieve energy transition as a country.

2.3. Photovoltaic Systems and their Presence Globally

Photovoltaic systems are technologies which convert solar radiation to electricity. In the last fifteen years the presence of photovoltaics has increased significantly in the energy mix of many countries due to the dramatic reduction in their cost. The industry of photovoltaic systems that used to be a subsidized energy sector has started to become gradually very profitable. In this part of the thesis we will present some characteristics of this technology.

Sovacool in his paper titled “Environmental issues, climate changes and energy security in developing Asia” assesses each technology that is used to produce energy based on its environmental impact. It seems that photovoltaic systems are, along with wind energy, the cleanest technologies for energy production. Their impact to climate change, air pollution and water are minimal and only their impact to land use is characterized as moderate.

Table 2.1.Impacts of Energy Systems on Climate Change, Air Pollution, Water Availability and Quality, and Land-Use Change (Sovacool, 2014)

Energy System	Climate Change	Air Pollution	Water	Land Use
Energy efficiency	Minimal	Minimal	Minimal	Minimal
Nuclear power	Moderate	Minimal	Severe	Severe
Shale gas	Severe	Severe	Severe	Severe
Conventional coal	Severe	Severe	Severe	Severe
Clean coal	Moderate	Severe	Severe	Severe
Oil and gas	Severe	Severe	Severe	Severe
Hydroelectricity	Minimal	Minimal	Severe	Moderate
Wind energy	Minimal	Minimal	Minimal	Moderate
Solar photovoltaics	Minimal	Minimal	Minimal	Moderate
Solar thermal	Minimal	Minimal	Moderate	Moderate
Geothermal	Minimal	Minimal	Moderate	Moderate
Biomass	Minimal	Moderate	Moderate	Moderate
Biofuels	Minimal	Moderate	Severe	Severe

According to Sovacool, *"the land-use impacts center on the use of hazardous materials such as silicon, which must be mined and can contaminate land when systems break down or are destroyed during hurricane and tornados"*. Also, he adds that *"chemical pollution has also occurred manufacturing solar cells and modules and when not integrated into buildings, solar power plants need comparatively larger amounts of land than conventional energy sources"* (Sovacool, 2014).

The abovementioned show that solar photovoltaics are a quite clean technology that in comparison with other energy production technologies are very friendly for the environment. Therefore, solar photovoltaics, along with wind energy, would be very helpful in efforts to reduce greenhouse gas emissions and in the energy transition process. It seems that there are no energy sources or technologies that are absolutely free from environmental impacts. However, there are some technologies that are more eco-friendly than others. Solar photovoltaics are probably on the top of this list.

As for the cost of solar photovoltaics, it has a continuing reduction. According to IRENA's data from 2021, *"the global weighted average levelized cost of electricity (LCOE) of new utility-scale solar PV projects commissioned in 2021 fell by 13% year-on-year, from USD 0.055/kwh to USD 0.048/kwh"* (IRENA, 2022).

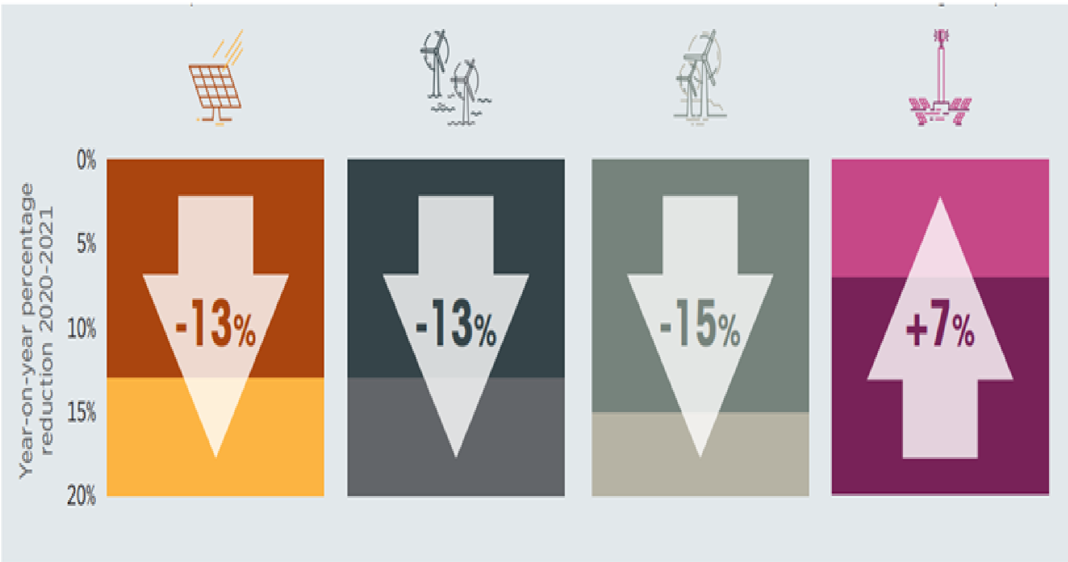

Figure 2.1.Change in global weighted levelized cost of electricity by technology, 2020 – 2021 (IRENA, 2022)

Even more impressive is the reduction in their LCOE since 2010. Again according to IRENA, *"this renewable power source was 710% more expensive than the cheapest fossil fuel-fired solution in 2010; however, driven by a spectacular decline in costs, it cost 29% less than the cheapest fossil fuel-fired solution in 2022"* (IRENA, 2023).

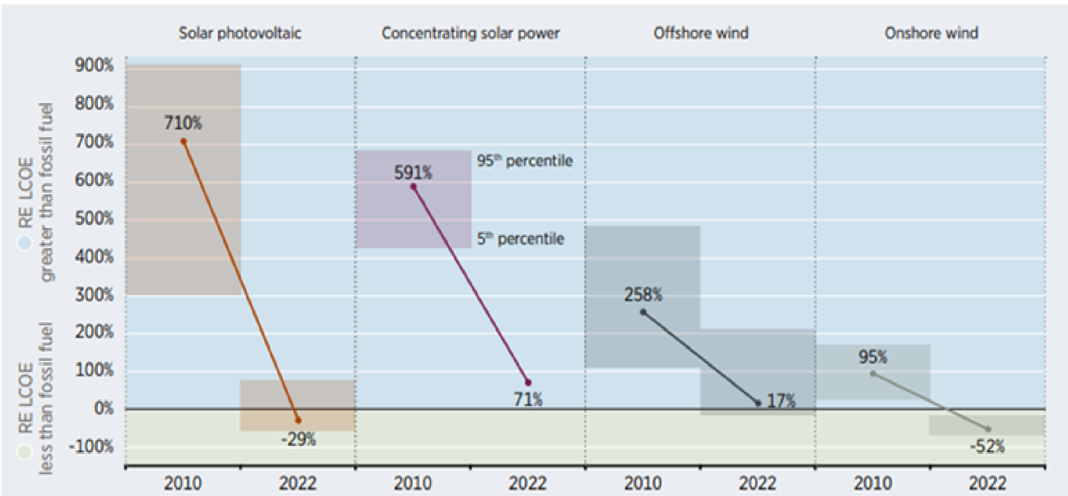

Figure 2.2.Change in competitiveness of solar and wind by country based on global weighted average LCOE, 2010 – 2022 (IRENA, 2023)

Furthermore, it seems that *"the global weighted-average LCOE of newly commissioned utility-scale solar PV projects declined from USD 0.445/kWh to USD 0.049/kWh between 2010 and 2022 – a decrease of 89%"*.

Table 2.2.Total installed cost, capacity factor and LCOE trends by technology, 2010 and 2022 (IRENA, 2023)

	Total installed costs (2022 USD/kW)			Capacity factor (%)			Levelised cost of electricity (2022 USD/kWh)		
	2010	2022	Percent change	2010	2022	Percent change	2010	2022	Percent change
Bioenergy	2 904	2 162	-26%	72	72	1%	0.082	0.061	-25%
Geothermal	2 904	3 478	20%	87	85	-2%	0.053	0.056	6%
Hydropower	1 407	2 881	105%	44	46	4%	0.042	0.061	47%
Solar PV	5 124	876	-83%	14	17	23%	0.445	0.049	-89%
CSP	10 082	4 274	-58%	30	36	19%	0.380	0.118	-69%
Onshore wind	2 179	1 274	-42%	27	37	35%	0.107	0.033	-69%
Offshore wind	5 217	3 461	-34%	38	42	10%	0.197	0.081	-59%

This information shows that the reduction in the cost of solar photovoltaic systems since 2010 has been dramatic and this can explain the rise in their popularity. Additionally, it underlines the role that solar photovoltaics can play in the global energy transition, given their low LCOE and their minimal environmental impact.

The efficiency of a solar photovoltaic system depends on various factors. For example, it depends on the weather, if there is enough sunlight or there are clouds, from the temperature, the inverter efficiency, the cabling losses, the terrain shading, the terrain slope etc. There is also a distinction between theoretical, practical and economic potential when we assess a country's ability to install photovoltaic systems and their potential yield.

According to Energy Sector Management Assistance Program (ESMAP), *"theoretical potential for PV generation is characterized by the amount of energy physically available, without considering any constraints of a particular PV system"*. Practical potential is characterized *"by the annual average of PV power production, taking into account the theoretical potential, real-world PV system performance and configuration, as well as, topographic and land-use constraints"*. Finally, when we assess the costs of PV power generation, *"we assess the costs of PV power generation at the country level based on the practical potential and the concept of LCOE"* (ESMAP, 2020).

Therefore, it is very important for a country to have a good theoretical potential but also practical potential in order to have a cheap and efficient PV power production. It is possible for a region to have a good theoretical potential but a not so good practical potential. This could be the case for a country with plenty of sunlight that at the same time has important landscape restrictions.

Except for the very low environmental harm, the fact that they provide renewable energy so it will be never depleted, and also the low levelized cost of energy (LCOE), photovoltaic systems have some other advantages too. In LCOE we should include the fact that their life expectancy is over twenty five years and their maintenance costs are very low, so a PV system is an investment that will provide investor with energy for a very long time. Also, their installation is a quite easy process.

But beside these, photovoltaics are mature renewable technologies that enable a country have more energy autonomy and they reduce a state's energy dependency for foreign fossil fuels that are usually expensive because they are linked to geopolitical developments. In opposition, the cost of energy that is produced from photovoltaics is predictable and this energy is local.

Furthermore, we have already analyzed the concept of energy democracy and its benefits in the energy transition process. Photovoltaics are probably the most democratic technology for energy production because everyone can install a small photovoltaic system in his roof or field and sell the excess energy that he produces injecting it into the grid through a process called "net-metering". "Net-metering" and similarly "net-billing" give people some abilities that there weren't available in the past. Therefore, through photovoltaics everyone can be involved in the process of energy production. This development can have only positive effects in the global energy transition.

Of course, photovoltaics have their disadvantages too. They are totally dependent on the weather conditions. This means that they don't provide the same stable amount of energy during the day because they are dependent on the sunlight. In a cloudy day, photovoltaics produce less energy. Furthermore, during the night they don't produce energy at all. The fact that they don't produce stable energy constantly is a disadvantage of photovoltaic systems in comparison with fossil fuels for example.

However, in the recent years this tends to be changing a little. Until some years ago, it was known that electricity cannot be stored so it should be consumed at the moment of its production. This was a big problem for photovoltaics. But in the last few years energy storage became commercially available through some technologies like batteries or pumped-storage projects. These technologies can store electricity for some hours or more and they allocate in a more efficient way the energy that photovoltaics produce during the day. Also, energy storage technologies have positive effects to the electrical grid too. Some other disadvantages are the high initial cost of the investment and the fact that photovoltaics need some space. These could discourage a potential investor. However, if energy storage continues to become cheaper, photovoltaics will be even more popular.

To avoid creating tones of waste after the end of the lifetime of solar panels, there is a need for creation of a recycling industry that will reuse some minerals of them. There are appropriate methods that can recycle and reuse the biggest part of a PV system but it has to be done in a bigger scale and certainly there will be this need in the future when much more gigawats of installed PV systems will participate in the global energy mix. Overall, this clean technology has both advantages and disadvantages but advantages are much more important. Its contribution to energy transition is totally necessary and will be crucial.

The fact that solar photovoltaic systems have low levelized cost of energy (LCOE) and short project construction times could be crucial factors to support developing countries include them more in their energy mix and to help in this way global energy transition. Many developing countries have very good theoretical and practical potential for electricity production from PV systems. Therefore, these systems could be perhaps a good option for several developing countries. Also, self-generation through autonomous off-grid photovoltaic systems could be a decent option too. Energy transition requires large investments in electricity grids and this could be a challenge for many developing countries. Off-grid solutions like autonomous photovoltaic systems provide people with clean energy without requirements for large grid investments. So this could be a helpful tool for some regions.

Conclusively, PV systems present an opportunity for many developing countries to combine the expected increase in energy demand with the increased use of renewable energy sources. This will help them not only come closer to energy transition, but also to stop being so dependent from foreign fossil fuels. They will be more energy independent and they will have some environmental benefits too.

Photovoltaics are very important for Europe too in order to achieve energy transition. Therefore, European Union makes efforts to create its own industry that produces PV systems, so as to not be dependent from China that is the world leader in their production. However, the European industry of photovoltaics faces significant difficulties in its attempt to develop and to be profitable. The reason behind these is the fact that in China the cost of production is very low and, as a consequence, Chinese photovoltaics are very competitive because they are cheap.

So we observe that there are specific geopolitical and geoeconomical conditions that are linked to solar photovoltaics and energy transition. Europe faces the fear that it will be dependent for its energy transition from China, in the same way that it used to be dependent from Russia for natural gas. This is happening because it imports the biggest part of its PV equipment from China, as well as, important for its energy transition metals. Therefore, European Union is trying to create its own supply chain and PV industry in order to be more independent.

Germany was the first country that created a PV market in the decades 1990-2000 and 2000-2010. China started gradually to produce solar panels at a large scale and to export them in Europe. Germany and also Spain and Italy were very interested in these solar panels and they were subsidized the development of these technologies in their territory. Until 2010 there were 123 producers of solar panels in China. Between 2010 and 2018 China's production of solar panels was increased impressively, as well as the producing companies. As a result, global supply was higher than global demand. Therefore, the prices of PV systems were decreasing and many China's producing companies were hardly survived. China in order to deal with this problem, as well as to satisfy its increased energy consumption and to reduce its pollution, decided to create a local market of solar energy. In 2013, China was the biggest market of installed solar panels, having surpassed Germany. Until 2017, China was alone half of the global market of installed photovoltaic systems. Right now, it produces almost 70% of PV systems globally (Yergin, The New Map: Energy, Climate and the Clash of Nations, 2020).

The cost reduction of PV systems since 2010 is impressive. This development is crucial for this technology in order to be even more popular in the future in many countries' energy mix and to play a significant role in the global energy transition. It is obvious that the further development of electricity storage technologies will be decisive for the abovementioned. The cost reduction of PV systems at this scale is mainly a result of China's massive increase in the production of these systems and its installed capacity since 2010, as well as a result of technological developments. Apart from these, another factor for this cost reduction is the increased demand for renewable energy from many countries in the last few years. This demand is supported by international agreements, public policies and subsidies, which are a consequence of the developments linked to the climate crisis and the environment protection.

Photovoltaic systems have a very rapid expand. According to Yergin, "*global installed capacity in 2019 was 642 gigawatts, fourteen times what it had been little more than a decade earlier*". Also, he adds that "*over half of total capacity installed between 2010 and 2019 is utility scale…solar parks that feed into the grid*". We have analyzed previously the basic characteristics of PV systems and also some politics that are present behind their development. Now we will examine the development of Greece's solar market and the role that photovoltaic systems play in the energy transition process of this country.

CHAPTER 3

THE CASE STUDY OF GREECE

3.1. Introduction

The first important legislative effort to promote energy production from PV systems in Greece started in 2006 with the adoption of the “feed-in-tariffs” system for the first time[1]. With “feed-in-tariffs” a specific price was defined, in which the renewable energy produced by PV systems in Greece would be sold. This price would ensure that producers would have profits and thus it promoted the establishment and development of the Greek photovoltaic market. Basically, “feed-in-tariffs” was a scheme that was offering long-term purchase agreements to renewable energy producers. The price in which they would sell their energy was independent from the price of the market. In this way, the risk for producers was reduced and their confidence was increased.

Another legislative effort in 2010 simplified the licensing process and promoted even more the birth of photovoltaic market in Greece. In fact, PV systems in Greece started having serious development since 2010. From 2010 to 2013, there was an important expansion of investments in photovoltaics in Greece. However, in 2014 some new legislative initiatives stopped this momentum that had been created. An important reason for this development was the deep economic crisis that was going on in Greece at that point. In the next years, there is no significant expansion of the Greek photovoltaic market. A crucial legislative initiative for PV systems in Greece

[1] For the needs of this chapter, the following Laws and Decisions of Greek governments have been examined: (LAW No. 3468: Production of Electric Energy from Renewable Energy Sources and Combined Production of Electricity and High-Efficiency Heat, and other provisions, 2006), (LAW No. 3851: Acceleration of the development of Renewable Energy Sources to address climate change and other provisions in matters falling under the jurisdiction of the Ministry of Environment, Energy, and Climate Change, 2010), (LAW No. 4414: New support scheme for electricity production stations from Renewable Energy Sources and Combined Heat and Power with High Efficiency, 2016), (LAW No. 4513: Energy Communities and other provisions, 2018), (LAW No. 4685: Modernization of environmental legislation, transposition into Greek law of Directives 2018/844 and 2019/692 of the European Parliament and of the Council, and other provisions, 2020), (DECISIONS: Special Program for the Development of Photovoltaic Systems in building installations, especially on rooftops and building roofs, 2009), (DECISIONS No. ΑΠΕΗΛ/Α/F1/econ. 24461: Installation of RES units by self-producers with energy self-consumption, in accordance with Article 14A of Law 3468/2006, 2014), (DECISIONS No. 4: Ratification of the National Energy and Climate Plan (NECP), 2019), (DECISIONS No. ΥΠΕΝ/ΥΔΕΝ/47129/720: Announcement of the "Photovoltaic on Rooftops" Program, 2023)

was the change of the type of subsidizing in 2016. The new kind of subsidizing was called “feed-in-premiums” and tenders were introduced.

Through “feed-in-premiums” there was a sliding premium that was added on top of the average spot electricity market price. In other words, renewable energy producers would earn an extra income on top of the income that they were receiving from the market. Also, there was determined a specific Reference Value. When the price of the market was lower than the Reference Value, then the state had to give a specific amount of money to the producer in order to reach the Reference Value. On the other hand, when the price of the market was higher than the Reference Value, the producer had to give money to the state in order to earn only the income derived from the Reference Value. This mechanism would ensure that producers will have a remarkable amount of profits and thus promote further investments in new renewable projects. Also, it would ensure that producers would not earn excessive profits and would return these to the State (Regulatory Authority for Energy (RAE), 2020).

We have already stated that tenders were introduced, in which renewable energy producers were competing in order to get a subsidy of this kind. The “feed-in-premiums” scheme, which is open until 2025, promoted even more the market of PV systems in Greece. In the last five years, PV systems have gained again a great momentum in Greece and have become a mature technology. Tenders and “feed-in-premiums” are suitable as a mean of subsidy for a mature technology like photovoltaics in Greece. Since 2017, tenders for subsidizing renewable projects are mandatory in Greece.

3.2. Development of PV Systems in Greece

As we mentioned before, in the last years, PV systems have gained again great momentum. In 2023, photovoltaic installed capacity in Greece was over 7 GW. According to Hellenic Association of Photovoltaic Companies (HELAPCO), in 2023 the Greek photovoltaic market installed more MWp than any other technology. This development shows the great interest that there is for investments in PV systems in Greece. In fact, photovoltaics represented 74% of the capacity from renewable energy sources that were installed in the country in 2023 (HELAPCO, 2024).

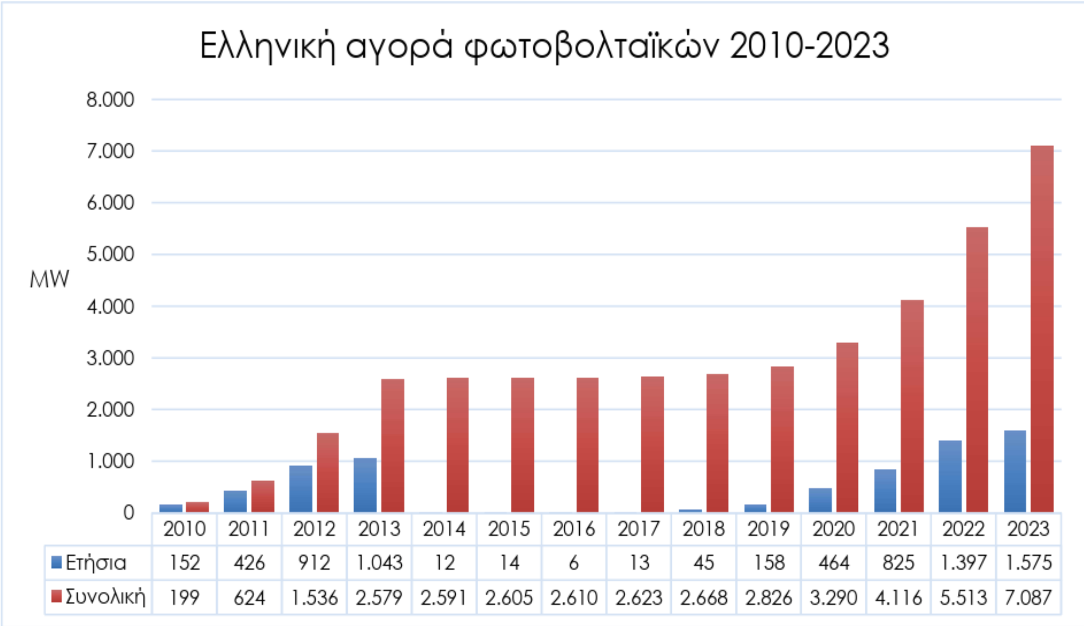

Figure 3.1.Evolution of the Greek PV market, 2010 – 2023 (HELAPCO, 2024)

In the figure above, we observe that from 2010 to 2013 there was a significant increase in the installed capacity of PV systems in Greece. Similarly, from 2019 to 2023, there was also a significant increase in the installed capacity. Furthermore, from 2013 to 2018 there was an obvious stagnation. This information is consistent with the information mentioned in the beginning of the chapter about the development of the Greek photovoltaic market.

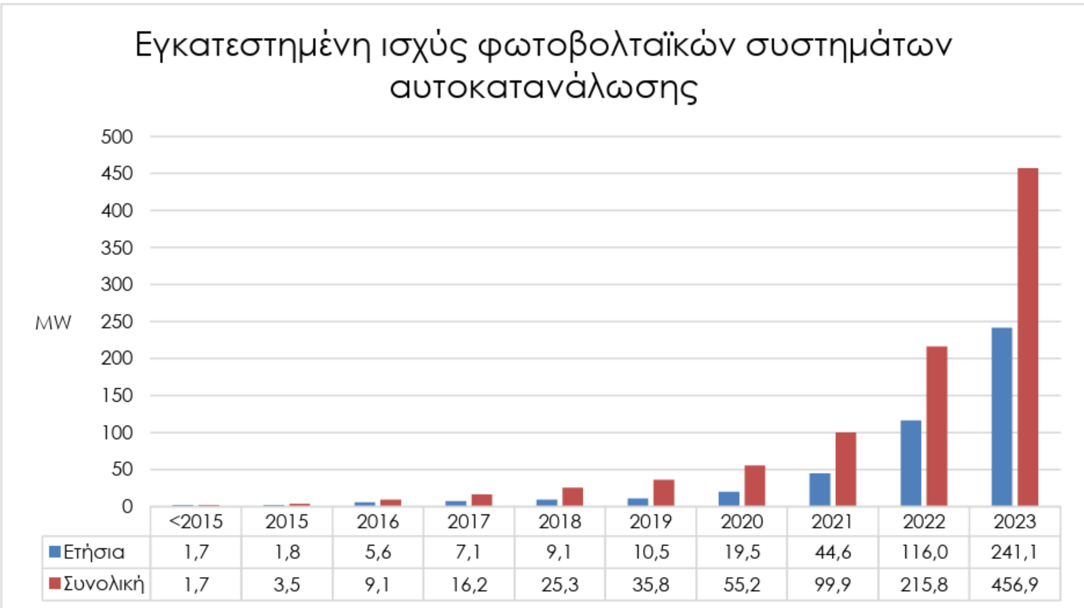

Figure 3.2.Installed capacity of PV systems for self-consumption in Greece, 2015 – 2023 (HELAPCO, 2024)

We can also observe that in the last years there is a remarkable increase in the installed capacity of photovoltaics for self consumption. In the year 2023, new installed capacity for self consumption reached 241 MW and the total installed capacity for self consumption surpassed 456 MW.

The biggest part of the Greek photovoltaic market, basically 67.6%, consists of projects of 10-1000 kWp. Projects bigger than 1 MWp represent the 26% of the total installed capacity of the Greek photovoltaic market. Similarly, projects smaller or equal to 10 kWp represent the 6.3% of the total installed capacity. Thus, we observe that the biggest part of the PV market in Greece consists of medium-sized projects.

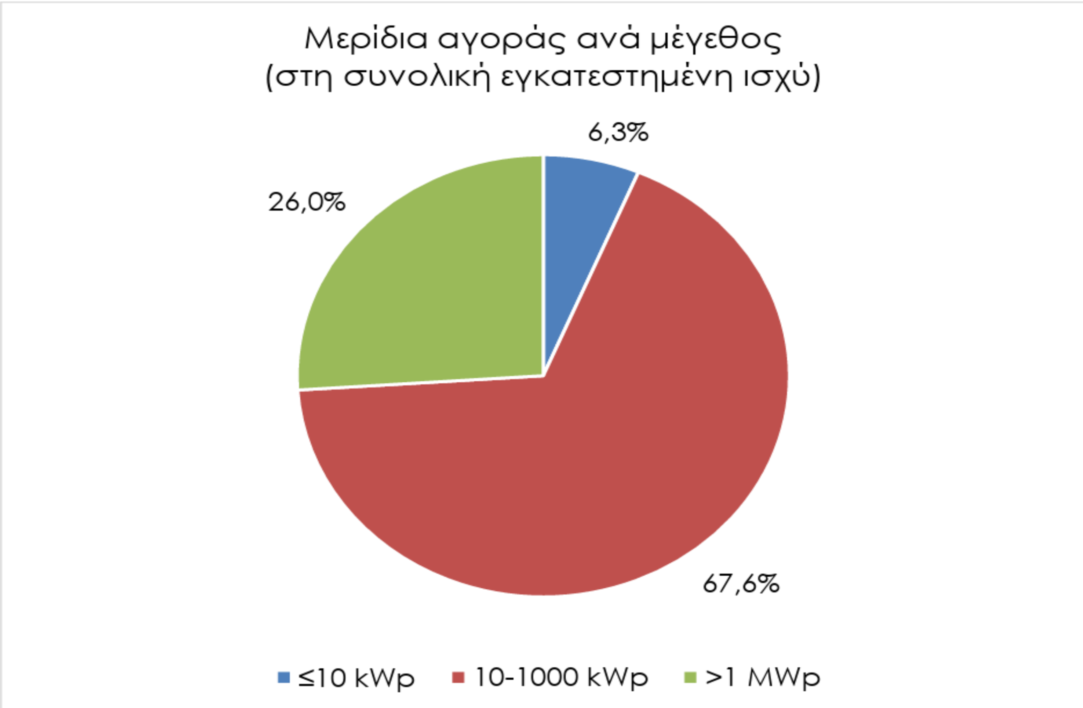

Figure 3.3.Market share by size (total installed capacity of PV systems in Greece) (HELAPCO, 2024)

If we examine the market share for the projects that completed in 2023, we can come to similar conclusions. Medium-sized projects (10-1000 kWp) represent 56.6% of the total. Also, projects over 1 MWp represent 40.2% and projects equal to or smaller than 10 kWp represent only 3.2% of the total.

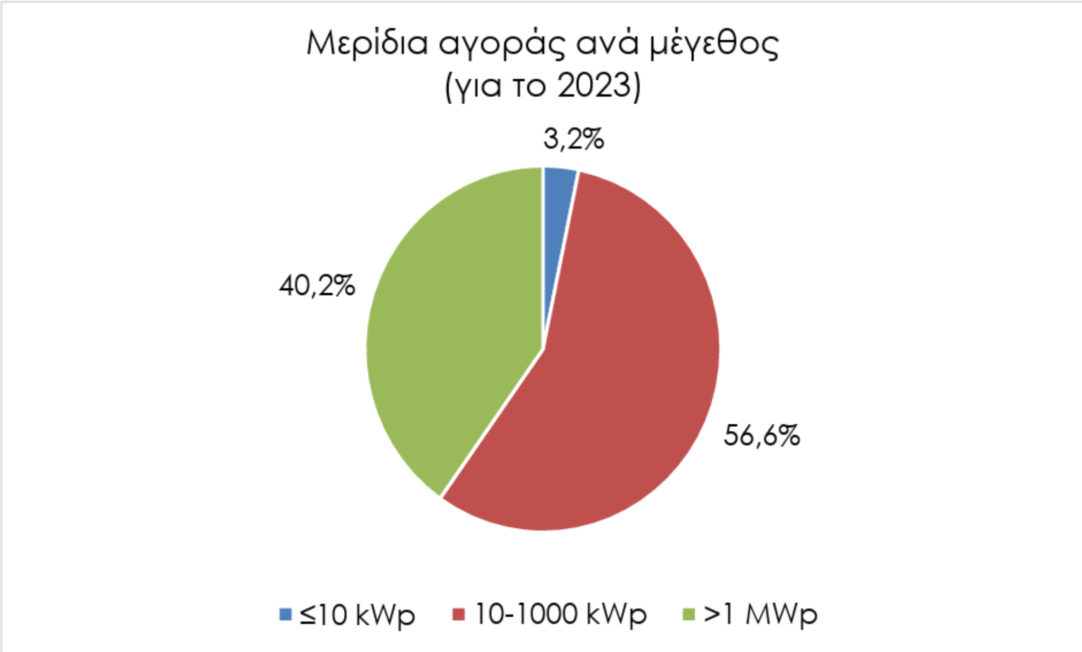

Figure 3.4.Market share by size (for PV projects in Greece finished in 2023) (HELAPCO, 2024)

Continuing our research, we can conclude that photovoltaics have a remarkable increase in Greece in the last fourteen years if we examine the data about the share of PV systems in Greece's electricity generation since 2010. In 2010, the percentage of the Greek electricity that was generated from PV systems was only 0.3%. In 2023, this percentage was 18.4%. To use HELAPCO's words: *"Greece ranked first in Europe in 2023 in terms of the percentage of domestic electricity production generated from photovoltaics, with a rate more than double the European average (8.6%) and more than triple the global average (5.4%)"*.

Figure 3.5.Share of PV systems in the total electricity production of Greece (HELAPCO, 2024)

In the Greek National Energy and Climate Plan (NECP) of 2019 there was a target for solar energy to reach 7.7 GW of installed capacity in 2030. The reformed NECP of 2023 raises this goal to 13.4 GW of installed capacity. Furthermore, the reformed NECP sets as target for solar energy, so basically PV systems, to reach 25.4 GW of installed capacity in 2040 and 40.3 GW of installed capacity in 2050 (Greece - Draft Updated NECP 2021-2030, 2023).

Table 3.1.Targets of the revised Greek NECP for solar energy in the next years and comparison with the NECP of 2019 (Greek NECP – Preliminary Draft Revised Version, 2023)

NECP (Apr 2023)	2021 (estimate)	NECP 2019 for 2030	2025	2030	2035	2040	2045	2050
Electricity sector								
RES power other than-hydroelectric (GW)	9.3	15.5	14.8	23.5	34.7	46.2	64.4	71.7
Wind	4.7	7.1	6	9.5	14.7	19	27.2	29.2
— of which sea				1.9	6.2	9.8	15.4	17.3
Solar	4.3	7.7	8.2	13.4	18.7	25.4	35.2	40.3
Other RES[28]	0.4	0.7	0.5	0.6	1.3	1.8	2	2.1
Hydroelectric (W) (GW)	3.1	3.7	3.1	3.8	3.8	3.8	3.8	3.9
Electricity storage capacity (GW)	0.7	2.7	3.3	5.3	5.7	11	21.3	24.8
— batteries	0	1.25	1.9	3.1	3.6	8.8	19.1	22.6
— pumped storage	0.7	1.4	1.4	2.2	2.2	2.2	2.2	2.2
Capacity of units with burntgas (GW)	5.3	6.9	6.9	7.7	5.7	5.2	2.8	4.2
Power of solid burntunits (GW)	2.3	0.3	1.5	0	0	0	0	0
Power of units with liquidburnt (GW)	1.7	0.3	1.3	0.7	0.6	0.4	0.4	0.1

This information shows clearly that the Greek government sees a great potential in PV systems to carry, along with wind parks, the country's electricity consumption in the future. In other words, PV systems have a solid presence at this moment in Greece's electricity mix but their future is even brighter.

However, the situation for further investments in PV systems in Greece is not ideal right now. Despite the willingness of the government to promote solar energy in the country, there is a serious issue, which is the lack of capacity as for the electrical grids. Due to the high number of applications for new renewable projects, the grid in Greece is congested and Hellenic Electricity Distribution Network Operator (HEDNO) has stopped accepting new applications for photovoltaic parks since the end of 2022. Applications can be accepted only for self-consumption PV systems and for projects located in specific Greek regions. On the other hand, Independent Power Transmission Operator (IPTO) continues to accept applications for big PV projects or combined small projects that are related to high voltage. Nevertheless, IPTO could stop accepting new applications for six months if there was a congestion problem. As we can easily understand, the willingness to promote PV systems and renewable technologies is not enough. Large investments in the electrical grid are necessary in order to continue connecting new projects.

3.3. The Role of Photovoltaics in the Energy System of Greece

PV systems will be very beneficial in the improvement of Greece's energy security in the future as the percentage of their deployment in the Greek energy mix grows. This will happen because due to the further deployment of solar energy, that will be produced domestically, Greece will be able to reduce the amount of energy that imports. This energy is basically natural gas and oil. The price of hydrocarbons like gas and oil is highly dependent from geopolitics. The most recent examples are the war in Ukraine and the geopolitical situation in Middle East. The dependence on hydrocarbons can easily create energy crisis and worsen energy poverty in the Greek society. Therefore, if Greece continues to increase PV systems' deployment, its needs for energy imports of hydrocarbons will be reduced and its energy security will be enhanced because it will produce energy domestically and with a very low cost.

Also, Greece will have financial benefits too. It will spend less money in imports and this can enable the country to invest more in its production capabilities. Furthermore, Greece can become renewable energy exporter and provide neighboring countries, or other countries, with domestically produced clean energy. In fact, the Greek government promotes this vision through the construction of electrical interconnections with other countries. A very important project of interconnections will connect Greece with Cyprus and Israel. Greece will be thus able to export renewable energy to Cyprus and Israel and it will connect these countries with the rest of Europe. Also, there is a plan to connect Greece with Germany. We will examine in depth the existing and planned interconnections of Greece with other countries in the next chapter of this thesis.

In general, Greece wants to have a very active role in the energy transition process and it sees energy transition as an opportunity for economic development. Therefore, the further deployment of photovoltaic systems will facilitate Greece make this vision a reality in the not so distant future. PV systems will provide Greece with cheap, clean and abundant energy that the country can use in the most optimal way. Greece has a comparative advantage in solar energy in comparison with other European countries because of its weather conditions. This means that it can use this comparative advantage to have profits. Finally, as we also mentioned before, PV systems will enhance Greece's energy security because they will make it more energy independent. Greece will reduce its energy imports, will not be dependent from hydrocarbons and its energy system will be more stable. It will also save money that will be able to use for other purposes.

In the recent years, the Greek society has experienced very hot summers. Climate crisis will make this situation a constant phenomenon. As a result, the energy consumption in Greece during the hot months of the summer is seriously increased because of the massive use of air conditioners. This could have caused serious problems to the electrical grid and blackouts. However, the contribution of photovoltaic systems is crucial. PV systems produce the most of their energy during the hours that the daylight is more. During the summer, people use massively air conditioners in the afternoon, when the temperature is higher. At that point, PV systems produce big amounts of energy and ensure, with their contribution, that no blackouts will happen due to high electricity demand. Thus, during heat waves in Greece, PV systems will help the electrical grid be more resilient and the energy system more stable.

As we have mentioned earlier in this thesis, PV systems face some significant challenges that prevent them from being even more popular. They are highly dependent on the sunlight to produce energy. This means that they produce sometimes excessive energy in the afternoon and much less in the next hours. Electricity storage can mitigate this problem though storing electricity for some hours in order to be consumed in the evening.

In the last few years, electricity storage has been deployed in Greece too. During the summer of 2023 there was the first tender in Greece for subsidies in the electricity storage. The demand for investments in the storage sector in

Greece has been growing fast. This will be very beneficial for the further deployment of the PV systems in the country. There are two main kinds of electricity storage. These are storage with the use of batteries and pumped-hydro storage. In Greece there are storage projects of both kinds ready or under construction.

In their paper titled “Photovoltaic Systems and Net Metering in Greece”, Mavromatakis, Viskadouros, Haritaki and Xanthos are explaining the Net Metering Scheme. As they say: *“One of the support mechanisms to promote photovoltaic (PV) technology and reduce the energy costs for residential and commercial customers is related to the local production of renewable energy (self-production). The net metering scheme involves grid connected systems and is available in many countries worldwide”* (Mavromatakis, Viskadouros, Hara, & Xanthos, 2018).

The net metering scheme besides promoting photovoltaic technology and clean energy production provides some other benefits too. Explaining the benefits of net metering, they continue in the same paper saying that: *“Utilities can better manage peak loads since PV systems generate most of their power around noon time. Local production allows reducing the strain in the electrical distribution systems and the transmission and distribution losses”*. With the implementation of net metering scheme, part of the energy that is produced from a photovoltaic system will be used to cover the loads of its owner. In other words, it will be used for self-consumption. The rest of the energy that is produced from the same PV system will be exported to the grid. The PV system’s owner will be billed for the net energy. Net energy is *“equal to the energy retrieved from the grid minus the energy injected to the grid”*.

The law related to the implementation of net metering was introduced in Greece in 2014. Also, in 2017 Greece introduced virtual net metering. Using the words of the paper “Photovoltaic Systems and Net Metering in Greece”, “*under this scheme the points of energy production and consumption may well differ electrically or spatially. In addition, it is foreseen that a customer may incorporate more points of consumption into the energy balance agreement*”. The Greek government is actively trying to promote the installation of PV systems in thousands of Greek households. In accordance with this, the government launched in the spring of 2023 a subsidy program for rooftop PV systems with batteries called “Photovoltaics on the Roof”. According to the related legislation, this program, which is funded by Recovery and Resilience Facility, “*subsidizes households for the installation of PV systems with storage system and farmers for the installation of PV systems with or without storage system for self- consumption with application of net metering”*.

This program will give multiple benefits to the country. First of all, it will reduce CO2 emissions that are produced from the buildings due to the usage of hydrocarbons for covering electricity needs. With the implementation of the program, thousands of households will use their own PV system covering their needs in electricity with clean energy. This development is in line with the goal of the Greek government for more energy efficient buildings that in the distant future will emit much less or even zero CO2. Secondly, the extended investments in PV systems for households will mitigate energy poverty in the Greek society. This will happen because, in the long run, people that will be participants of the program will have financial benefits with lower electricity bills. Thirdly, this program will promote the participation of citizens in the developments of the energy sector and of the Greek green energy transition. This active participation is in line with the promotion of the concept of energy democracy.

Speaking of active participation, in the recent years, more and more energy communities have been created in Greece. The expansion of PV systems in the country has given a great boost in the creation of energy communities, that are, basically, collective forms of self consumption. Energy communities promote the idea of energy democracy and urge citizens to be involved in issues that are connected with energy production. As a result, citizens will be more informed, engaged, they will embrace easier the green energy transition that is underway in Greece and they will enjoy financial benefits from the clean energy production process.

Finally, there have been increased concerns recently about the concept of the decreased crops or the obstruction of agricultural work and livestock farming because of the installation of PV systems in fields. However, it seems that photovoltaic systems in Greece cover much less arable land in comparison with activities related to lignite for example. As far as livestock farming and apiculture are concerned, it seems that they are also not interrupted due to solar panels (HELAPCO, 2023). Furthermore, the dilemma "solar panels or crops" in a field has started to abate. The idea of a combination of energy production from PV systems and cultivating in the same field has started to gain ground gradually. This kind of PV systems is also called "agrivoltaics" (HELAPCO, 2023). In the next years, is probable that more and more countries will start to implement this idea. Additionally, maybe there will be subsidy programs that will promote this activity.

3.4. International Interconnections of Greece

The further development of Greece's international grid interconnections is a very important goal of the Greek government. Responsible body for the promotion of the development of Greece's international grid interconnections is the Independent Power Transmission Operator (IPTO) or ADMIE in the Greek language, which is the operator of the Greek electricity transmission system. Until now, the Greek electricity transmission system is connected with the electricity transmission systems of Italy, Bulgaria, Albania, North Macedonia and Turkey. In the last few years, Greece has been examining with the abovementioned countries the possibility of further development of their existing interconnections (ADMIE, 2021).

During the December's 2023 visit of the President of Turkey, Recep Tayyip Erdogan in Athens, one of the issues that there was a positive result in the conversations between Greece and Turkey, was the promotion of the enhancement of the grid interconnection between Greece and Turkey. In this diplomatic visit, IPTO signed a Memorandum of Understanding (MoU) with the Turkish Electricity Transmission Corporation (TEIAS), related to the construction of a new electric interconnection between Greece and Turkey and the increase in the volume of bi-directional energy flow by 600 MW. This project will be completed at the end of this decade. Therefore, the development of the international grid interconnections can operate as an enhancement factor in the relations of Greece with neighboring countries, as a result of cooperation in issues of "soft politics", on the basis of mutual benefit.

As for the grid interconnection of Greece with Bulgaria, in the summer of 2023 the two countries activated the second electricity transmission line that connects them. This development will result in significant benefits for both sides, as well as for the broader region overall. The development of grid interconnection between Greece and Bulgaria will contribute to the enhancement of cross-border trade and of the energy security in South-East Europe and Balkans. At the same time, Greece will be able to deploy more efficiently the amounts of renewable energy that will produce, while the European electricity market will enjoy benefits too. This project will increase the energy transmission capacity from Greece to Bulgaria to 1400 MW and from Bulgaria to Greece to 1700 MW (Kolonas, ADMIE: Projects for 7 international electric interconnections of Greece are underway, 2023).

We could say that the development of the Greece's international grid interconnections with other countries features a new kind of diplomacy, the "electrical cable diplomacy" or just "cable diplomacy" (Kolonas, From pipeline diplomacy to electrical cable diplomacy, 2021). Through this kind of diplomacy, Greece can enhance its relations with neighboring countries, while its deeper goal is to become an important energy hub and clean energy exporter, taking advantage of its geography and the big amounts of renewable energy that will be able to produce in the future.

As for the grid interconnection between Greece and Italy, in the IPTO's Ten -Year Development Plan is included its development, which will lead to increase in electricity exchanges between the two countries. More specifically, a second interconnection, the so-called "GRITA 2" project, will be constructed in the next few years between the two countries that will increase their electricity exchange capacity from 500 MW to 1500 MW. This second interconnection is considered as necessary for Greece and Italy. The project is estimated to be completed by 2031 and will cost a little more than 600 million euro (ADMIE, 2023).

The updated IPTO's Ten-Year Development Plan also includes a new electricity transmission interconnection between Greece and Albania, completed until 2030. The goal of this interconnection is the connection of the Greek Electric Transmission System with the new Fier's power substation, in South Albania. This new interconnection between Greece and Albania will increase by at least 200 MW the electricity transmission capacity in both directions. The construction of the project will be probably finished until 2030. Speaking of interconnections in the Balkan region, the update of interconnection between Greece and North Macedonia is also under consideration.

As for Egypt, it is estimated that in the next years the interconnection between Greece and Egypt will be completed. This project, which is known as "GREGY Green Energy Interconnector", or "GREGY", is a very important and crucial project, the budget of which surpasses 3.5 billion euro. This interconnection will provide great benefits for all stakeholders (Grimanis, 2022). On the one hand, Egypt will be able to export the large quantities of clean energy that will produce in the future towards Europe's market. On the other hand, the European Union will receive large quantities of clean energy from Egypt, which will use to various sectors of its economy. Furthermore, it will enhance its energy security through the differentiation of its sources for energy imports, the increase in the percentage of clean energy in its energy mix and the consequent decrease in its dependence on fossil fuels.

As far as Greece is concerned, the interconnection with Egypt will help it to achieve its goal to become an important clean energy hub, which in the future will connect Africa and Asia with Europe for the transmission of clean energy. This will increase Greece's geopolitical significance too. Finally, except for the project "GREGY Interconnector", there is also the so-called "GAP Interconnector", which is another project being considered as a second interconnector that will connect Greece with Egypt.

At this point, it is worth mentioning that Greece beside its goal to become a clean energy hub, it wants to become also an important clean energy exporter. According to the governmental plans, Greece will probably produce big quantities of clean energy until 2035. Also, a major part of this energy will be produced from offshore wind energy. In the coming years, Greece intends to deploy its great offshore wind capacity. Therefore, the development of its infrastructure and of grid interconnections with other countries is of great importance for the achievement of Greece's goal to become clean energy exporter. This achievement will, consequently, give multiple benefits to the country. It will make its national economy more competitive, improving its trade balance and its fiscal conditions.

Maybe the most emblematic project of international grid interconnection that Greece promotes is the interconnection with Cyprus and Israel. This project is known as "Great Sea Interconnector", formerly known as "Euro Asia Interconnector". IPTO is the main player that is responsible for the promotion and completion of this project (ADMIE, 2023). The first step needed was the connection of the Greek island of Crete with Attica and mainland Greece. This will be probably completed in 2024. The next steps are the connection of Crete with Cyprus and Cyprus with Israel. Cyprus is the last Member State in EU that is not connected in the European energy system. The interconnection with Greece will end this situation and will improve the energy security of Cyprus. Also, this interconnection will enhance the energy security of Israel and will increase the use of renewable energy sources in its energy system. As for Greece, it will underline even more the importance of the country as renewable energy hub and it will enable it to increase even more its clean energy exports through the interconnection with two more countries in its neighborhood.

The emblematic project of grid interconnection of Greece, Cyprus and Israel is considered as very important for European Union and is a Project of Common Interest. It has secured European funding of more than 700 million euro. Also, there is an increased international investing interest for it. The whole interconnection will cost over 2 billion euro and will be finished probably in 2027.

Moreover, Greece and Saudi Arabia are examining the commercial feasibility of constructing an electric interconnection between them. In fact, it could be possible for Saudi Arabia to join the Great Sea Interconnector project and to be interconnected through Israel and Cyprus with Greece and the rest of Europe. However, this development is uncertain and will be probably influenced by the geopolitical developments in the Middle East after the start of the war between Israel and Hamas in October 2023. In September 2023, IPTO on behalf of Greece and National Grid S.A. – Saudi Electricity Company on behalf of Saudi Arabia signed an agreement, in which they decided to form a company of a special purpose, the so-called "Saudi-Greek Interconnection". The object of this company is to examine the commercial viability of the interconnection project. This is the first important step for the realization of the interconnection (Liaggou, 2023).

The government of Greece has planned another ambitious and interesting project, which will promote the Greek strategic goals in the field of energy.

The project is called “Green Aegean Interconnector” (Deligiannis, 2023). According to the website of the Hellenic Ministry of Foreign Affairs, *“the Green Aegean Interconnector (GAI) is a project initiated and promoted by the Hellenic Electricity Transmission System Operator, ADMIE, aiming to create a new Energy Corridor from Greece to Southern Germany (initial capacity of 3 GW, potentially increasing to 6 GW and later to 9 GW). This project will link the markets of Southeastern and Central Europe”*. The text continues saying that *“during the European Council meeting in March 2023, the Prime Minister emphasized the necessity of establishing a Green Energy Corridor from the South to the North to assist the EU in addressing its two energy policy priorities, “Fit for 55” and “REPowerEU”*.

Finally, about the profits of the project is referred that *“the GAI electric interconnection will harness the vast potential of Greek energy production – solar and wind – to meet the increased demand in Central Europe, especially in Germany. It will contribute to Europe’s overall energy self-sufficiency and climate security, further promote the decarbonisation of our energy systems, and reduce the EU’s dependence on Russian fossil fuel imports”* (Hellenic Ministry of Foreign Affairs, n.d.).

The above information shows that the Green Aegean Interconnector will be very beneficial for Europe’s energy security. Also, it will be very beneficial for Greece enabling it to export massive amounts of clean energy to Central Europe and basically to Germany. As a result, this project is also promoted actively from the Greek government because it will help the country become “green” energy exporter. Conclusively, we see that international interconnections constitute a very useful tool for Greece in order to enhance its economy and its diplomatic image. Additionally, Greece has the opportunity to increase its geopolitical importance as energy hub, to become energy exporter and to introduce itself internationally as a model – country in the global energy transition process.

3.5. Comparison with Italy in Terms of Energy Transition

As for the energy transition process, Italy and Greece are showing some similarities and some differences. Both countries have committed to achieve carbon neutrality by 2050 and are pursuing their energy transition. Also, they have a good performance in this field in general. From 2010 to 2014, Italy and Greece presented a remarkable increase in renewable energy sources capacity. However, in the next years this development was slowed down significantly. There are different explanations for each country. In the case of Italy, the lack of incentives for further investments and the achievement of reaching its 2020 targets early in the decade led to this decrease. In the case of Greece, the reason was the deep economic crisis that the country was facing until a few years ago.

In their journey to become carbon neutral, we can observe some interesting things in the attempts of these countries. Since 2020, Greece has been trying vividly to achieve its energy transition through investments, auctions and other tools. Moreover, it is trying to solve the problems that the country faces in order to transform its energy mix and to make its economic development more sustainable. For example, Greece is trying to enhance and upgrade its grid transmission and distribution system to satisfy the enormous investing interest in renewable energy projects. Similarly, Italy is facing some challenges that remain unresolved at the time being, undermining its efforts and is trying to fix them to accelerate its energy transition process.

Some of Italy's problems are the long permitting procedures that make investors wait for years to be connected to the grid, high administration burden and increasing local oppositions. Also, Italy has to upgrade its grid in order to boost the deployment of renewable energy. Greece faces these problems too in a smaller or an equal degree but in the recent years it seems that its energy transition has taken a momentum. Maybe the bigger problem of Greece and Italy in this process is the urgent need for grid development. Without this, they will not be able to deploy more renewable energy. Beside this, more storage capacity will be necessary in the future for both countries.

Furthermore, Italy needs to find ways to incentivize its different regions to participate more actively in the government's plans to achieve its climate goals. Italy's different regions and autonomous provinces play a significant role to the implementation of meters related to energy transition. For example, in the early 2010's they had developed and adopted their own plans for energy and environment. However, after Italy's government developed and adopted the country's NECP in 2019, which set specific targets for the whole country, only a few regions updated their own plans to be consistent with the country's targets. Therefore, there is the phenomenon that many regions do not follow as fast as it is needed the government's plans in this field.

Speaking of NECP, Italy adopted, as we said, its own National Energy and Climate Plan in 2019. This plan became the main strategic document of the country that guides its national energy and climate targets for 2030. This document got updated in 2023. Specifically, in Italy's updated NECP it is written that *"Italy intends to pursue a target of covering 40.5 % of gross final consumption of energy from renewable sources in 2030, outlining an ambitious growth path for these sources with full integration into the national energy system"* (Italy - Draft Updated NECP 2021-2030, 2023). Also, Italy has adopted the EU's net emissions reduction target of at least 55% by 2030 compared to 1990. This target was adopted by European Council at the end of 2020. Finally, Italy's updated NECP points that the share of total national electricity consumption covered by renewable sources in 2030 will be 65%.

About the electricity sector, we should mention that the share of total national electricity consumption covered by renewable sources at the time being is 36%. This means that until 2030 there must be large investments to enable greater deployment of renewable technologies like photovoltaic systems and wind turbines. These technologies will be the key for the increase of the share of renewable energy. It is understood, though, that Italy has to try hard in order to achieve the target of 65% in 2030. As for the technology of photovoltaic systems, it is referred that their installation will be promoted in buildings, roofs, parking spaces, service spaces, etc. However, the NECP points that *“the deployment of large ground-based photovoltaic systems also remains important for the achievement of the 2030 targets, but priority is given to unproductive areas that are not intended for other uses, such as land that cannot be used for agricultural purposes”* (Italy - Draft Updated NECP 2021-2030, 2023).

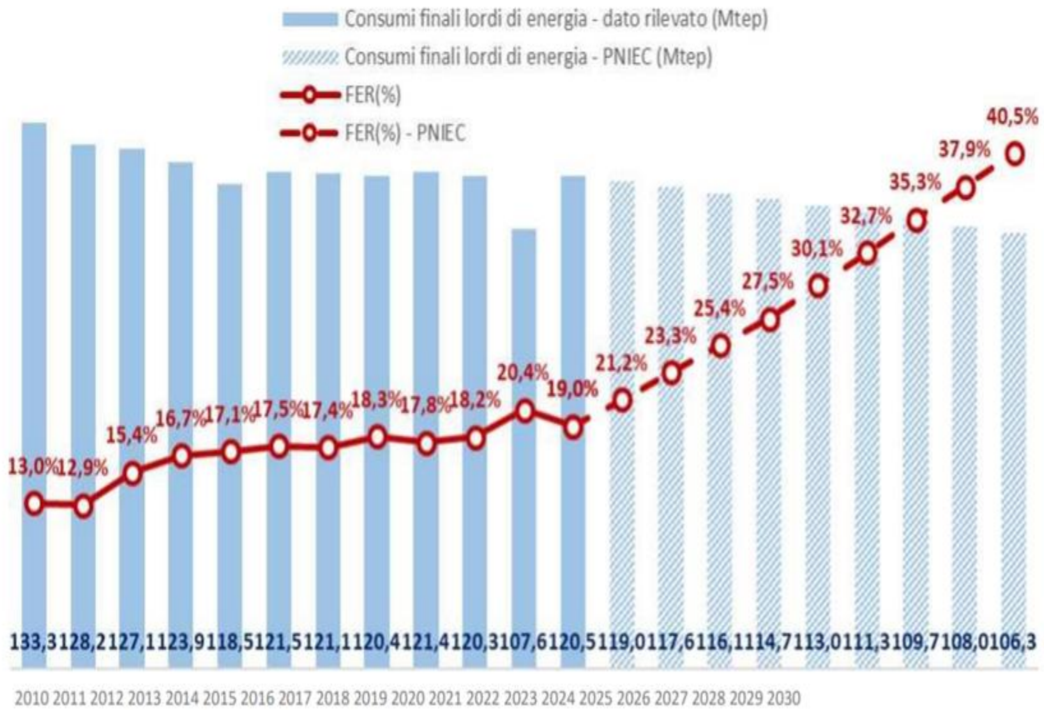

Figure 3.6.Overall RES share track in Italy’s energy system (ITALY – DRAFT UPDATED NECP 2021-2030, 2023)

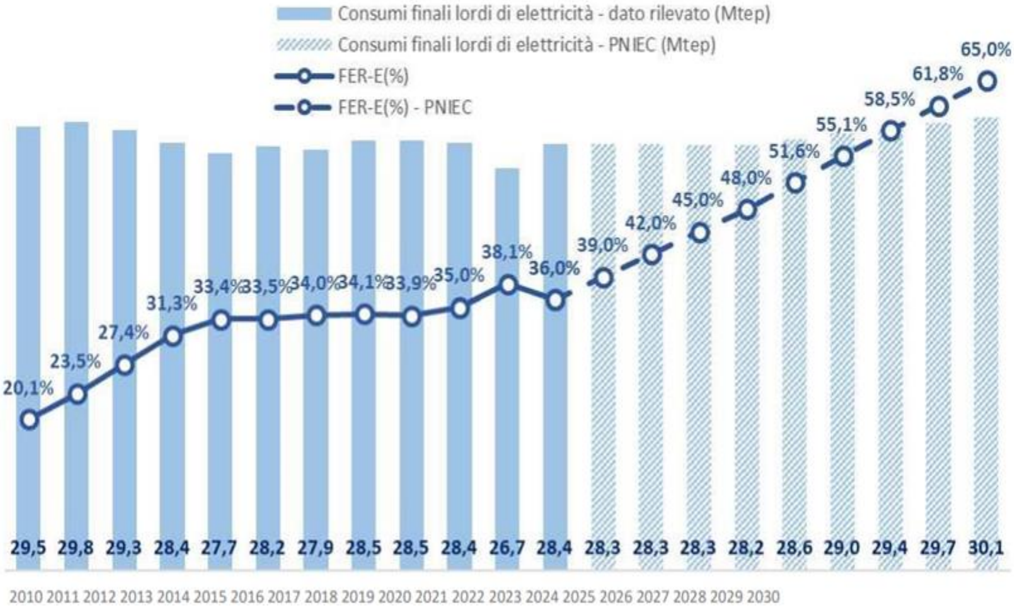

Figure 3.7.RES quota track in Italy's electricity sector (ITALY – DRAFT UPDATED NECP 2021-2030, 2023)

Italy's energy sector is still strongly reliant on Russia for fossil fuel imports. Natural gas plays a decisive role in Italy's energy mix and its electricity generation mix. In 2021, natural gas had a share of 50.2% in electricity generation (IEA, 2023). A large amount of Italy's gas imports comes from Russia. So we can understand that the further deployment of renewable energy sources will improve Italy's energy security. This has been shown especially after the invasion of Russia in Ukraine and the energy crisis that this invasion provoked. Most of Italy's energy supply is imported, mainly gas and oil. So the clean energy transition with domestic generation of electricity from renewable energy sources will benefit Italy greatly in terms of energy security. Additionally, it will help the country meet its emission reduction targets. These facts are same for Greece too. Italy is trying to stop the dependence on Russian gas and is expected to reduce drastically the gas imports from Russia in the next years.

In conclusion, Italy has a good performance in terms of energy transition. In the last fifteen years the country has made significant changes in order to decarbonize its economy. Also, Italy met its climate targets that had been set for 2020. However, it will need bigger efforts if it wants to achieve the new targets for 2030 that are derived from its updated NECP and the latest European Union's policy. These efforts will have to combine further deployment of renewable energy sources with energy efficiency goals in its economy.

It is true that after the first impressive steps until the middle of the previous decade, Italy's energy transition lost a degree of its momentum. Obstacles like long permitting procedures, high administration burden, local opposition, lack of new incentives and a need for grid development were the main reasons behind that. Furthermore, the different degree of implementation of government's plans across the country's regions and autonomous provinces contributed to this situation. Nevertheless, Italy has to find ways to overcome these obstacles and continue its efforts.

In the Green Future Index 2023, which is a research program by MIT Technology Review Insights and a comparative ranking of 76 countries on their ability to develop a sustainable and low-carbon future, Italy was ranked 13th and Greece 17th with score 5.70 and 5.56 respectively. However, in 2021 the score of Italy was 5.30 and the score of Greece was 4.82. This means that in the last years, Greece's performance has taken a momentum on its way to develop a sustainable and low-carbon future. Although Italy still has a better score than Greece, it seems that the gap between them is closing due to the enhanced efforts of Greece. Both countries, though, are in very good positions in this ranking, which means that their overall performance is quite adequate. The Green Future Index 2023 has five pillars that are translated to the final scores. These pillars are Carbon Emissions, Energy Transition, Green Society, Clean Innovation and Climate Policy. The final scores are the results of a country's performance in these five pillars (The Green Future Index, 2023).

CHAPTER 4

SUMMARY AND CONCLUSIONS

4.1. Summary of Thesis

Energy transition is an unavoidable process that the world, sooner or later, will have to accept and embrace. It is driven by the climate conditions that will lead to very intense phenomena in the future, unless the humanity changes the way it produces energy, it creates products, the ways of transportation, etc. The new climate conditions will make extreme weather phenomena more often, will affect crops, living species and of course will affect humanity. Some island states in the ocean will be extinct, other countries will become desert and millions of people will have to migrate in order to find a more friendly place to settle. Except for these examples, many things will probably change in different regions of the world. Phenomena like droughts, floods and wildfires will be more constant.

Faced with these developments, we have the opportunity, or the obligation, to prepare ourselves to be better adapted in the future and of course to keep the changes to a minimum level through changing our lifestyle. Energy transition is the most important change that we have to embrace with all of our hearts in this process. We have to abandon fossil fuels, which are the basic factor that increases the greenhouse gas emissions and to produce energy from clean and renewable energy sources. Other measures will be necessary too. Energy efficiency, electrification of the economy and electricity storage are only a few of them. Of course, it is easily understood that the amount of investments that are needed globally is enormous. Yet, it is necessary and can also lead to opportunities for economic development.

In this thesis the author dealt at first with the concept of energy transition in general and after that with the process of energy transition in Greece. Greek policies about this issue were mentioned, as well as, the challenges that must be addressed, like the need for investments in infrastructure or in energy storage. However, the goal of the thesis was not to describe the process of energy transition that is happening in Greece right now and will continue in the next years. Its main goal was to examine the role of photovoltaic systems in the country's energy transition. What role can photovoltaics play in the

Greek energy system and, why not, in the transformation of the Greek society's perception of energy?

To examine these we examined at first the basic features of this technology. After pointing out the advantages and disadvantages of PV systems, we analyzed the current and future probable situation in Greece as for their use. More specifically, we saw that PV systems are a greatly developing technology in Greece right now and there is huge interest for investments in solar energy production. Furthermore, there is a great interest for investments in the field of energy storage which is absolutely necessary for the future development of photovoltaics in Greece. However, the Greek government faces a significant problem that could halt investments in solar energy. This is the lack of grid capacity that leaves a large number of PV projects untapped and makes investors wait for months or years to see their investments yield. It is obvious that there is a need for large investments in the Greek grid infrastructure.

Therefore, we can conclude that, if there are the appropriate investments in the grid infrastructure, PV systems can play a great role in the Greek energy system. They can produce large amounts of energy during the day, amounts that will be vital especially in the summer that energy consumption is large because of frequent heatwaves. This amount of energy will also be transferred in the evening with the help of energy storage in the not so distant future. Beside these, Greece will export the rest of the energy that photovoltaics will produce, stabilizing in this way its energy prices in a satisfactory and fair point for everyone involved and earning at the same time income from the energy exports.

As far as society is concerned, through self-production like the net-metering scheme many families can be benefited. Every household will be able to produce its own energy, consume the energy that it needs and sell the rest to the grid, paying thus very low electricity bills with a small relatively initial investment. This development will make people more receptive to the Greek energy transition and will reduce energy poverty. Also, Greece will have environmental benefits, making its climate targets more feasible and will produce energy with the minimum environmental impact.

Except for a necessity, energy transition can be also an opportunity for a country. A good example of this can be Greece. Greece is actively trying to enhance its existing electrical interconnections with neighboring states and also to develop new ones with other countries. In this context, Greece is constructing interconnections with Egypt or Cyprus and Israel that will be emblematic for the energy supply of Europe. Furthermore, Greece is examining the feasibility of interconnections with Saudi Arabia or with Germany.

The goal of the country is twofold. On the one hand, through interconnections with Egypt and countries of Middle East, Greece will be able to transfer to Europe large necessary amounts of clean energy from Africa and Asia. In other words, it will be converted to a state – energy hub. On the other hand, Greece, through interconnections, will be able to export the excessive amounts of clean energy that will produce in the future, stabilizing in this way its energy system and becoming energy exporter. This purpose highlights the importance of a potential interconnection with Germany for example and Central Europe.

In the last part of the previous chapter, we examined the case study of Italy. Additionally, we attempted to compare Italy's performance in terms of energy transition with the performance of Greece. During this process, we found out that both countries have an adequate performance in general. However, they have to deal with some significant challenges, which are mainly related to the need for more investments in grid infrastructure, as well as, other bureaucratic challenges. Certainly, both countries need to try harder in order to achieve their climate targets. The truth is, though, that they have created a solid basis to work on.

4.2. Recommendations for Further Research

We have highlighted the great role that PV systems can play in Greece's energy transition and its energy system. We have also analyzed the challenges, as well as, the opportunities that energy transition creates for the country. But this field of research cannot be fully examined in a single thesis. There are many topics related to the above that would give many options for further research. For example, which other factors will influence Greece's energy transition? Which will be their contribution to the country's efforts? It is now known that Greece has a great offshore wind potential. Maybe in the future this field will determine the volume of the country's energy exports. Also, challenges like the grid infrastructure can be examined too. The field of infrastructure itself gives multiple options for research due to its importance for a country's economic development.

Of course, apart from the policies and challenges related to the infrastructure or energy storage, there are other topics that can be further examined too. One of them is the so-called "electrical cable diplomacy" or "cable diplomacy" that we mentioned earlier in the thesis. This issue has a geopolitical interest and concerns the field of International Relations. Questions like "how the diplomacy of cables can influence countries' relations?" or "how it can be an opportunity for cooperation between states?" could offer great options for a future thesis or papers. Finally, this kind of knowledge can be used as a tool from policy makers and can contribute to the country’s actions. Thus, the academic sector will be involved with the policy making sector for the benefit of the country and Greek society.

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