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Statistical analysis of electricity production from Photovoltaics in Greece

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SCHOOL OF SCIENCE & TECHNOLOGY

A thesis submitted for the degree of

Master of Science (MSc) in Energy Systems

DECEMBER 2013

THESSALONIKI – GREECE

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Abstract

This dissertation was written as a part of the MSc in Energy Systems at the International Hellenic University and it was supervised by Dr. George Giannakidis.

The Green-House-Effect and its main consequences, such as the increase of the average Earth's temperature and the ice melt, are part of the bigger environmental problem that next generations will have to deal with. Oil and gas play the key role in the energy production globally, but due to their heedless use and the pollution they cause to the environment, schemes like the "20-20-20" are promoted by the European Union, for the utilization of the renewable energy sources (e.g. sun or wind). Greece is a very shiny country and lots of photovoltaic installations, which convert the solar energy into electricity, have become recently.

At this study a statistical analysis of the hourly electricity production of the residential photovoltaics (≤10kWp installed capacity) in Greece was performed. For each of the fifty one Greek Prefectures, the theoretical energy yields were examined through a simulation program and the results were then compared to those obtained by existing installations. Eventually by calculating the average of the two measurements, the Prefectures of Greece were presented in a descending order, according to their solar potentials.

A great thank to my supervisor, Dr. George Giannakidis, for the trust he showed to me, giving me the opportunity to enter into such an interesting study field. During the two years of my master program, he was the person who encouraged me to admire the solar energy direction and for that reason I would like to express my thankfulness.

Eleftheria Tsiarapa

20/12/2013

Contents

1 Introduction

The pollution of the environment, which affects the quality of people's lives and is mainly, caused by the excessive use of fossil fuels leads to the need of finding alternative energy sources, such as renewables (solar energy, wind, geothermal etc.). This study's main object was the statistical analysis of the electricity production at an hourly level of the energy supplied to the national grid by residential photovoltaic systems in Greece. More specifically a predefined photovoltaic installation, which installed capacity, could not exceed the 10kWp was checked across the fifty one Greek Prefectures and its energy yields were next compared to data from real installations found in each prefecture. Finally, from the theoretical and the practical results, the average was obtained, to present the hourly production at a prefecture level.

In chapter 2, a review on the literature has been done. Initially a few information, regarding to the sun, as the center of our solar system, are provided to the reader. The journey of the solar radiation, and the reasons explaining how much of this energy is finally absorbed, are fully described. The Green-House effect and its negative impact to the environment consists a basic reason, of why should people change their habits and gain a green conscience. On the other hand the Photovoltaic effect is the phenomenon that explains how photovoltaics panels produce electricity from the solar radiation, as an answer to the reduction of the green house gases for securing the future of the next generations.

In this chapter, the reader gets familiar to the different categories of solar cells found in the energy market e.g. monocrystalline, polycrystalline, thin film etc. and also learns the basic pros and cons of each class. A very quick glance at the renewable energy sources available today is also part of this chapter, to continue with information regarding to the electricity production in Greece, data about the country's energy mix and the contribution of the renewable energy sources of today, and how is this planned to increase by the ambitious European Union's scheme, the "20-20-20".

The basic legislation framework on which the residential photovoltaic systems are applied in Greece is provided to the reader, whereas apart from those ≤10kWp systems, the rest available applications of photovoltaics (stand alone systems & devices, commercial photovoltaic systems etc.) are also given at the end of the Chapter

Following, at Chapter 3, a flashback in the energy sector has been done, starting from the surprising expansion of the Public Power Corporation System, which during the period 1956-1963, bought the 300 private electric companies that used to supply with energy, within small local networks, the oil crisis and it was during the 70's when the first ideas about energy saving and sustainable use of energy, appeared for first time. This global search for new, alternative energy sources had as a scope to move the common and finite energy sources. A short description of oil and gas, as energy sources, is also presented in this Chapter.

The Chernobyl accident, in Russia, in the April of 1986 and the new type of poverty that people will face during the 21st century, the energy poverty which will prevent some people to fulfill their energy needs e.g. cooking or heating, enhances the necessity at an organized level by the societies to make a green turn and base at renewable energy sources for the electricity production, especially in areas with high potentials.

At this Study an effort was made check on how much could the national grid of the country rely on the energy production from residential photovoltaics.

About the potential of the energy yields in Greece, a lot of studies has been published, but in this Study the country is examined at a prefecture level (for the 51 prefectures of Greece) for the average hourly production (kWh), as close to reality, with comparison, between numbers gathered by theoretical simulations and those one from samples of existing installations, found from as many as possible Greek prefectures.

The final results, the hourly data per prefecture, bring out a new map of the country, on which next or suggesting studies could examine if the national grid could rely on the production from the residential photovoltaics, to use or at least cover the amount of the energy that is need to be produced, especially during the peak hours.

The methodology that was followed is analytically described in Chapter 4. The methodology consists of two main parts: the Theoretical and the Practical one, and from the comparison of their results, the findings are concluded. Three main tools were used in the whole process: The PVSyst Simulation Program, the Sunny Portal, a website powered by SMA, the German Inverter Manufacturer Company and finally the Microsoft Office Excel 2007, for the statistical analysis.

The first step was, for each of the fifty one (51) prefectures of Greece, to calculate the theoretical annually produced energy by a 10 kWp residential photovoltaic system, and more specifically check during summer solstice and winter's, in an hourly level, the produced energy (KWh).

Next, from already existing installations, in each prefecture, check for the same two days (21^{st} of June, 21^{st} of December), the hourly produced energy. Finally, comparison of the results and findings for each prefecture.

PVSyst, also gives the opportunity to watch the hourly graph, of the energy that is injected into the grid, for each day.

Summer solstice (21st June) and winter solstice (21st December), are the longest and shortest days of the whole year. As the earth is closer and farer to the sun, respectively. So these days, could be theoretical, the best and the worst days for the production of a PV system.

Following the theoretical part, at this part of the Study, an effort was made to look for as more as possible, existing, residential installations, across the whole country. In some prefectures, with high population, such as Thessaloniki, it was easier to find installations for the reasons of this study. Finally in the most prefectures, at least one residential installation was found to be compared to the theoretical model.

In a table of Chapter 4, the results between the theoretical part and from those derived from the average of the existing installations found, are presented for comparison The prefectures of Crete (Rethimno, Chania, Lasithi and Hrakleio) are in the higher positions of the list, although Voiotia is on the top. Athens, the capital of prefecture of Attiki, has an average of 38,57 kWh which is slight higher than Thessaloniki's, 37,80kWh. Achaia and Evros, on the other hand, are at the last positions of the list. For the non-interconnected islands, Samos and Lesvos are on top.

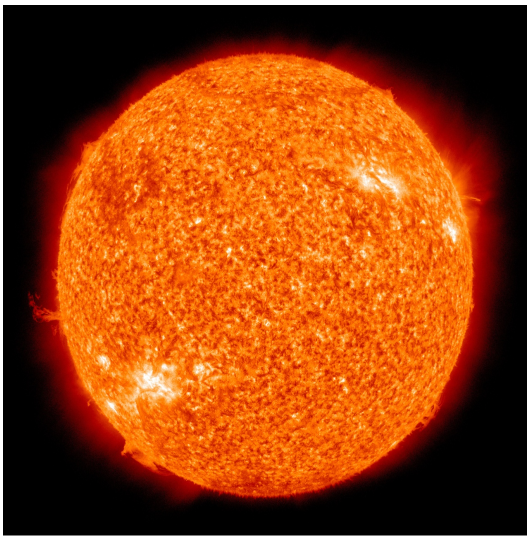
The tables for each of the 51 prefectures, showing the hourly production are available in the appendixes.

2 Literature review

In this Chapter a review to the relevant literature has been done. It is divided into two parts. In the first part, some specific terms regarding to solar radiation, is necessary to be explained, whereas at the second part, the basic framework on which the residential photovoltaic systems are applied in Greece, is presented.

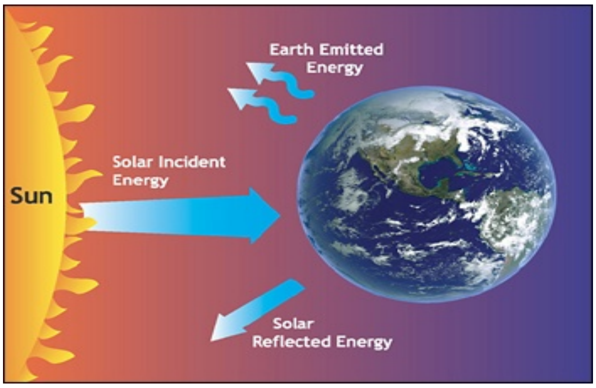
2.1 Solar radiation

The sun, the center of our solar system, has a radius of 700.000km. It weights 300 times more than earth. The sun is beaming huge amounts of energy, to the space. This energy, of different wave lengths, consists of light and energy. The power of the sun's energy is about hundred millions billions kilowatts (kW) and its derived to the nuclear fission of hydrogen (H_2), as in one second, 600 millions tones of this element are transformed to 596 million tones of helium (He). The rest 4 millions are turned into beam radiation. This fission is so strong that every single square meter of Sun, eventually beams 70.000Hp. In order to achieve the amounts of energy in that level, the whole production of Earth, from coal, per year, should be multiplied by 11 billion times, in time of one second.



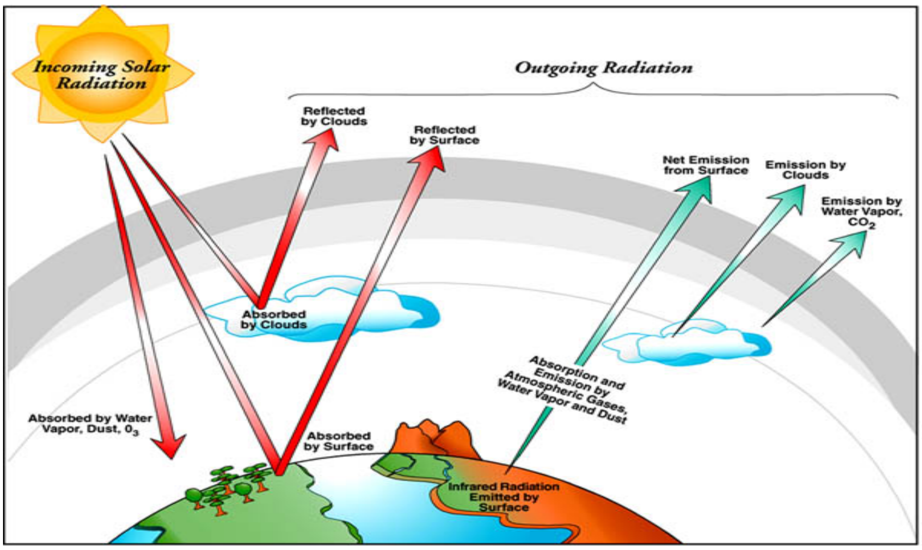
Picture 1: The Sun by the Atmospheric Imaging Assembly of NASA's Solar Dynamics Observatory

To the Earth, only the half of the billion hundredth of this radiation, eventually comes, as many layers of the atmosphere do absorb amounts of it. But this is considered as a not only a positive effect but also important for the continue of life on our planet. It has been measured that from 4000Q (whereas, 1Q= energy equivalent to 25.000t of oil) of the beam radiation that are directed to the Earth, the 1000Q are reflected to the external layers of the atmosphere, the 1000Q are absorbed, and finally the rest, do heat the surface of our planet.



Picture 2: Earth System Research Laboratory

The average intensity of the radiation that falls in a vertical surface, inside the limits of the atmosphere is 1353W/m². The decrease of this amount of energy, as the radiation passes through the atmosphere levels, depends on the conditions found. Meaning the possibility of clouds, the flying particles etc. This decrease happens because of the absorption of the solar radiation by the molecules of the air, the steam and the dirt and is not constant, as it may differs according to spectrum's levels.



Picture 3: Incoming and Outgoing Radiation (Credit - Steve Ackerman and Tom Whittaker)

The spectrum of the solar radiation, upon the limits of the atmosphere, equals to the emission of a black body, of 5762K. This spectrum is constant from the 200nm to the 3000nm, with a peak the 4800nm.

The atmosphere does not only have an effect on the amount of the solar radiation that eventually passes, but also changes the spectrum composition of it. For example, during the noon of a typical day, when the sun is at its zenith angle, the intensity of solar radiation, at a horizontal surface is $1kW/m^2$, from which the 20-25% is due to the diffuse radiation. The intensity is not constant, and because of the revolution of Erath round its axis, there is a big time difference, between the maximum value during the day, and the lowest, during the night, and also in accordance to the geographical location of a place, and the year's season. [13]

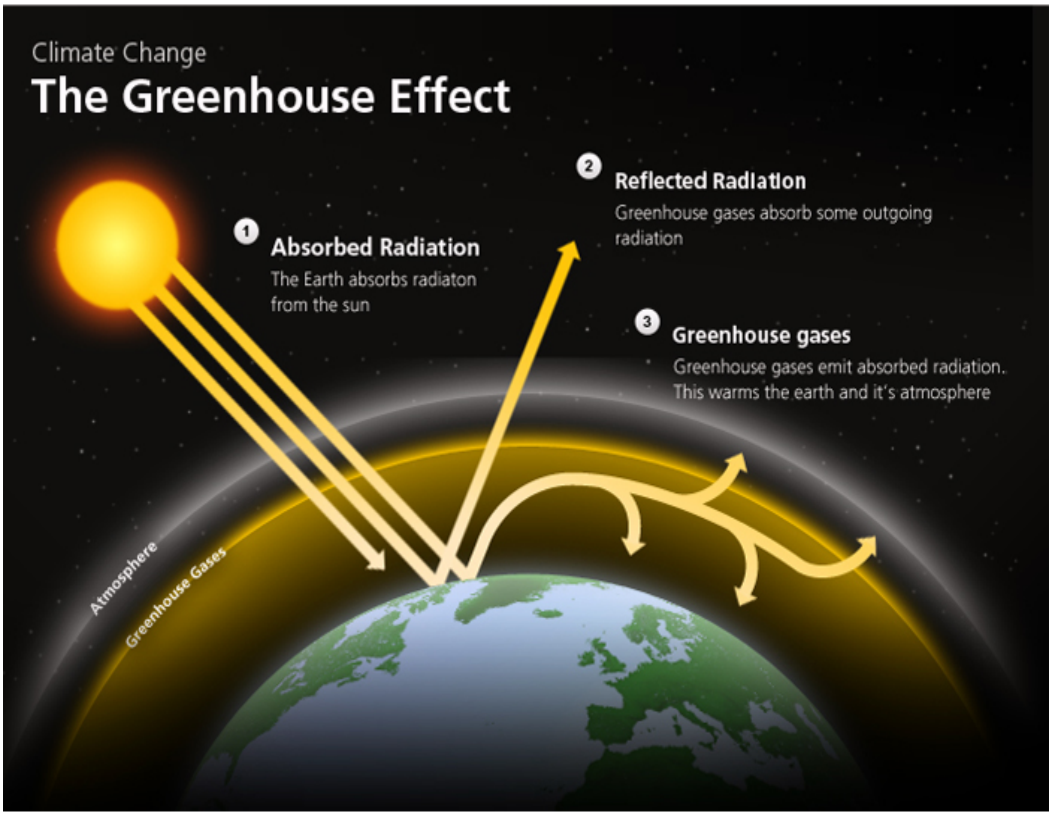
2.2 The Green-House-Effect

The Green House Effect is a natural phenomenon. It is of paramount importance and desirable. But what is considered as a severe threat for our planet is the excessive existence of this phenomenon, basically due to gases from human procedures.

There are some gases, also known as Green-House gases, that allow the passage of the solar radiation, through the atmosphere, to the Earth. At the same time, the benefit that they offer is the absorption of the infrared radiation, that is reflected back from the Earth's surface and is accused of negative effects to live beings, in general. But, this trapping of the infrared radiation is what is called the Green-House Effect.

It is important for the existence and the continue of life. Without this mechanism there will be no life in our planet, because the average temperature of Earth would be 35°C lower, meaning -20°C, from +15°C that is today and no form of life, in the meaning that we, as humanity, now understand, would exist.

The global society's worry is the enhancement of this effect, due to the air pollution. All the daily activities that people do, increase the emission of the Green-House-Gases (GHG), and this results to the increase of infrared radiation trapped in the atmosphere of Earth. The most severe result, is the increase of the average temperature, about 3°C per year, threatening with ice melting, vanish of some areas that are in danger (also Greece), health problems etc.



Picture 4: The Greenhouse Effect (www.edfenergy.com)

So, is more now needed than before, for humans to change their habits, and turn to green ways of producing energy, in a manner that the GHG would at least be eliminated. [19]

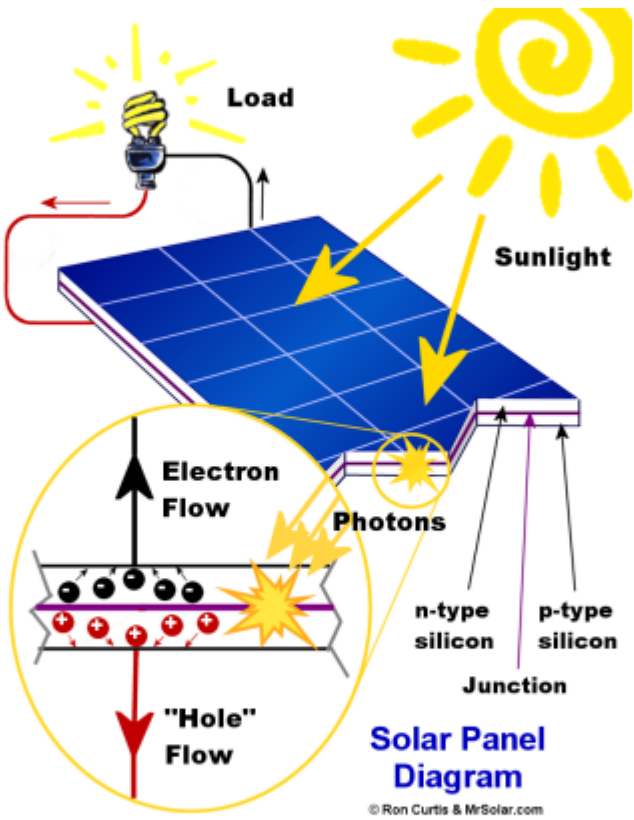
2.3 The Photovoltaic effect

Renewable Energy Sources (the sun, the water, the wind etc.) are the best way to produce pure energy. These sources were the first type of sources that man used to use until the start of the 20^{th} century, when in the next, he turned to the intense exploitation of coal and hydrocarbon.

Photovoltaic solar radiation is a type of Renewable Energy that does match green production and economic advantages. The solar radiation is captured through solar or photovoltaic panels, which is converted eventually to electric, thanks to the Photovoltaic effect.

The photovoltaic panels that mentioned before, are constructed by semiconductors. They are four-valence elements, with crystal structure in four sides, like the silicon (Si). In those elements there are no free carriers of electric current and that is why they have no electric conductivity, at the ideal hypothetical condition that the semiconductor is at the fundamental energy condition, meaning that is totally energy downgraded. But when semiconductors absorb a significant amount of energy, in a form of heat or radiation, a total change occurs.

Solar cells are semi conductors with a form of a disc, meaning that the positive-negative joint is across the whole length of their length. When they receive an amount of solar radiation, a number of photons come in contact with the semiconductor. If the photon's energy is equal or higher of the energy gap of the semiconductor's, it can be absorbed in a chemical bond and let an electron free. So, as long there is a continuous flow of radiation, many free electrons can be created, more than in case of balance conditions. Now, when these electrons are moving inside the solid, and as long as they do not match again with opposite carriers, they can be found in an area of p-n joint, where they will be affected by the electrostatic field.



Picture 5: The Photovoltaic Effect (www.mrsolar.com)

As shown in the previous picture, the photons of the sunlight, that come in contact with the front side of the n-type of the solar cells, result to the production of carriers couples (free electrons and holes). A part of these carriers is separated, by the affect of the diode's incorporated field and are diverted to the front (the free electrons, e-), or to the back (the holes h+), creating simultaneously a voltage difference between the two sides of the element. The rest of the carriers are reconnected and finally disappear.

It is important to notice that a part of the sunlight is reflected back from the photovoltaic's panel surface, whereas another part of it, passes through until the time, that it will meet the back electrode.

So, with this procedure, the free electrons are diverted to the n type, and the holes to the p type. This results to the creation of voltage between the terminals of the two parts of the diode.

This whole configuration can be the source of electric current, which duration will last as long as the sunlight hits the surface of the photovoltaic panel.

The creation of voltage between the two sides of the solar cell, which results to the normal polarization of the diode, is called Photovoltaic Effect. The operation of photovoltaic panels and the exploitation of the solar energy are based on this effect. [17, 18]

2.4 Type of photovoltaic panels

There are (4) four main categories of photovoltaic panels, classified according to the type of the solar cell used. They will be presented in the ascending order, based on the relation of price – quality, they gain in the global energy market. [20, 30]

2.4.1 Thin-Film Solar Cells

Depositing one or several thin layers of photovoltaic material on a substrate is the basic gist of how thin-film solar cells, of thin film panels, are manufactured. The different types of thin-film solar cells can be categorized by which photovoltaic material is deposited on the substrate:

Amorphous silicon (a-Si)

Cadmium telluride (CdTe)

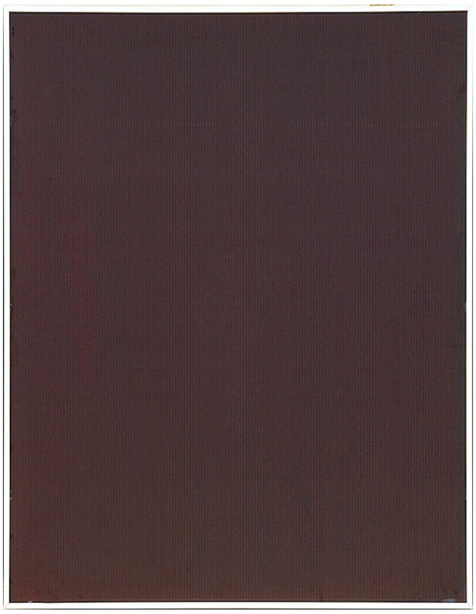
Copper indium gallium selenide (CIS/CIGS)

Organic photovoltaic cells (OPC)

Depending on the technology, thin-film module prototypes have reached efficiencies between 7–13% and photovoltaic panels operate at about 9%. Future module efficiencies are expected to climb close to the about 10–16%.

Advantages

- They are mass-producted. This makes them and potentially cheaper to manufacture than crystalline-based solar panels.
- Their homogenous appearance makes them look more appealing.
- Can be made flexible, which opens many new potential applications.
- High temperatures and shading have less impact on solar panel performance.
- In situations where space is not an issue, thin-film solar panels can make sense.



Picture 6: Thin film panel.

Disadvantages

- Thin-film solar panels are in general not very useful in most residential situations. They are cheap, but they also require a lot of space.
- Thin-film solar panels tend to degrade faster than mono- and polycrystalline solar panels, which is why they typically come with a shorter warranty.

2.4.2 Polycrystalline Silicon Solar Cells

The first solar panels were based on polycrystalline silicon, which also is known as polysilicon (p-Si) and multi-crystalline silicon (mc-Si), and were introduced to the market in 1981. Polycrystalline solar panels do not require the Czochralski process, as raw silicon is melted and poured into a square mold, which is then cooled and cut into perfectly square wafers.

Picture 7: Polycrystalline panel.

Advantages

- The process used to make polycrystalline silicon is simpler and cost less.
- Polycrystalline solar panels tend to have slightly lower heat tolerance than monocrystalline solar panels (which will be the next category presented). This technically means that they perform slightly worse than monocrystalline solar panels in high temperatures. Heat can affect the performance of solar panels and shorten their life. However, this effect is slight, and the majority of owners do not pay attention to it.

Disadvantages

- The efficiency of polycrystalline-based solar panels is typically 13-15%. Because of lower silicon purity, polycrystalline solar panels are not quite as efficient as monocrystalline solar panels.

- Lower space-efficiency.
- Monocrystalline and thin-film solar panels tend to be more aesthetically approved since they have a more uniform image compared to the speckled blue color of polycrystalline silicon panels.

2.4.3 Monocrystalline Silicon Solar Cells

Solar cells made by monocrystalline silicon (mono-Si), also called single-crystalline silicon (single-crystal-Si), are recognizable by an external smooth colored and uniform image, indicating high-purity silicon, as it can be seen in the picture below:

Picture 8: Monocrystalline panel

Monocrystalline solar cells are made by silicon ingots, which have cylindrical shape. To optimize performance and lower costs of a single monocrystalline solar cell, four sides are cut out of the cylindrical ingots to make silicon wafers, which is what gives monocrystalline solar panels their characteristic look.

The easiest way to recognize mono from poly crystalline solar panels is that polycrystalline solar cells look perfectly rectangular with no rounded edges.

Advantages

- Monocrystalline solar panels have higher efficiencies, since they are made by the highest-grade silicon. The efficiency rates of monocrystalline solar panels are typically 16-17%.
- Monocrystalline silicon solar panels match an excellent combination of space needed, during the installation and efficiency. Since these solar panels yield the highest power outputs, they also require the least amount of space compared to any other types. Finally monocrystalline solar panels do produce four times more the amount of electricity than from thin-films.
- Monocrystalline solar panels do live the longest. Although there have not been enough time for those state-to-the-art products to be checked through the passing years, most solar panel manufacturers promise a 25-year warranty on their monocrystalline solar panels.
- Tend to perform better than similarly rated polycrystalline solar panels at low-light conditions.

Disadvantages

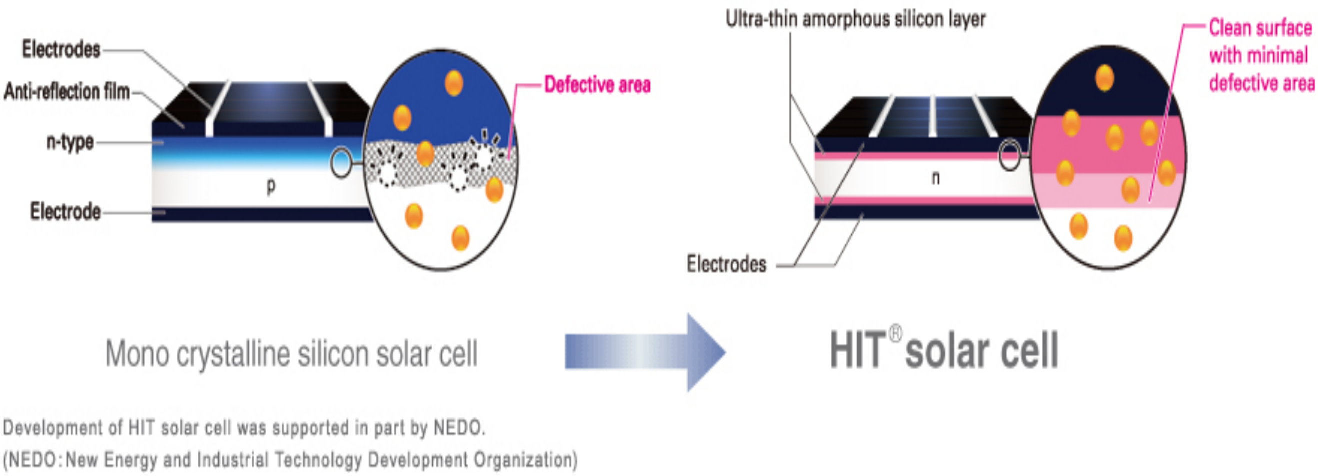
- Monocrystalline solar panels are more expensive. From a financial point of view, a solar panel that is made of polycrystalline silicon (and in some cases thin-film) can be a better choice for some people.
- The Czochralski process is used to produce monocrystalline silicon. It results in large cylindrical ingots and unfortunately a significant amount of the original silicon ends up as waste.
- Monocrystalline solar panels tend to be more efficient in warm weather. The performance decreases as temperature goes up, but less so than polycrystalline solar panels.

2.4.4 Heterojunction with Intrinsic Thin layer Solar Cells

HIT cells are made by a thin monocrystalline silicon wafer surrounded by ultra-thin amorphous silicon layers. This product provides the leading performance and value using state-of-the-art manufacturing techniques. The development of the HIT solar cell was supported in part by the New Energy and Industrial Technology Development Organization (NEDO).

Picture 9: HIT panel.

HIT solar cells improve boundary characteristics and reduce power generation losses by forming impurity-free i-type amorphous silicon layers between the crystalline base and p- and n-type amorphous silicon layers.



Picture 10: From monocrystalline to HIT panel (source: http://panasonic.net/ecosolutions/solar/).

- HIT solar panels have the highest efficiencies, 17-20%.
- They are 100% emission free, and have no moving parts and do not produce any noise.
- Their significant small dimensions, compared to the previous technologies enable a space saving installation and the achievement of the maximum output power possible on a given area.

Disadvantages

- They are very expensive and unfortunately the cost of an installation, with such a type of panels has not dropped at all. So, they are preferable, to cases where there is no enough space, and by taking advantage of their small dimensions the owner can increase the installed capacity of his installation, which would be significant low with any from the previous described technologies.

2.5 Renewable Energy Sources

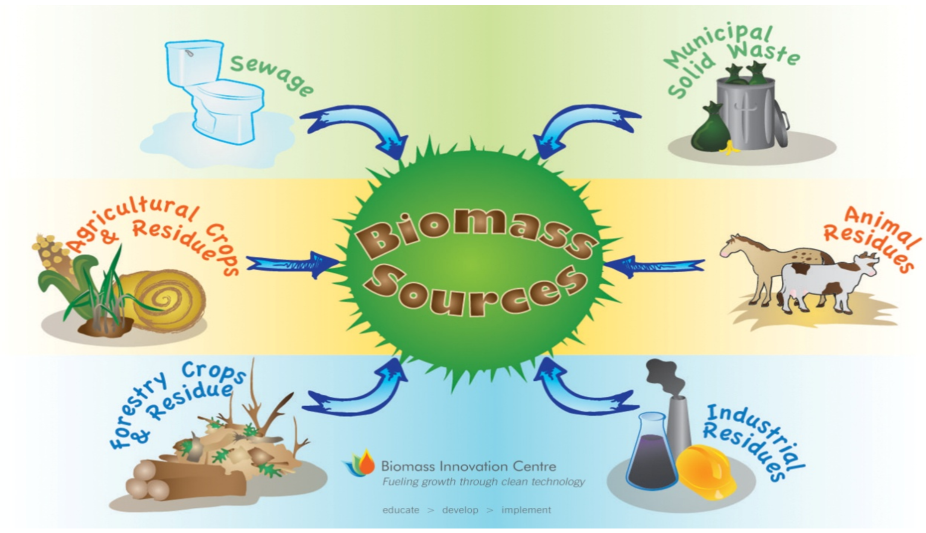
Apart from the solar energy that was described before, there some other forms of renewable energy, which can be exploited economically, but in a sustainable way:

Biomass

Today from biomass the 14% of the energy needs, are covered, globally. Biomass is the result of the photosynthesis procedure, during which vegetable micro organisms from land or aquatic origin, through a series of procedures, convert the solar radiation.

The combustion of biomass is the most typical process, from which the Bioenergy is produced. From a sustainable point of view, the combustion is a neutral process, meaning that it has no negative effect on the Green House Effect, and that is why it is considered among the clean forms of energy, but as long as the slight equilibrium of the environment is not affected.

The biomass sources appear on the next picture:



Picture 11: Biomass sources (Biomass Innovation Centre)

In Greece, there are facilities in where biomass is converted to Bioenergy and are found in Thessaloniki, Hrakleio, Chania and Psitalleia of Attiki. Their total installed capacity is 8000kW.

Wind

Picture 12: A wind farm in the Panachaiko.

Wind turbines utilize the wind and turn the kinetic energy to mechanic energy or electric. Globally the installed capacity of wind turbines from the 7,6GW in 1997, it reached the 120,8GW in 2008.

In Europe, the respective installed capacity is about 66GW.

Geothermal

Geothermy is the thermal energy that comes from inside the Earth and is found in natural steams, to superficial or below the ground hot water paths and in hot, dry rocks. When the temperature of the geothermal liquids is low, their energy is used for the heating of buildings, green houses etc. In cases when the steam temperature is high (>150°C), they can be used for the production of electricity.

In Greece there are many geothermal fields, of low temperature, in where hundreds of drilling processes are about to start working, with excellent energy potentials. From these potential, only a small part, about 3/20 is used today for space heating, or greenhouse heating etc.

The installed capacity of Greece, in geothermal applications, at 2005 was 74,8MWth.

Picture 13: Large Geothermal application.

Wave

Picture 14: Wave energy exploitation in Netherlands.

The wave energy, meaning the energy that is derived from the strength of the waves in the ocean, can provide to humanity vast amounts of energy.

The wave energy is converted to kinetic, through ocean turbines, below the sea level. The energy that is carried through the waves, spins the turbine. The elevating movement of the waves pushes the air to the top and inside the tube, this moves the turbine and as long as the turbine is spinning, the generator supplies with current.

The produced energy from the waves could even support the basic needs of a small house.

The sea flows also hide a vast energy potential and could be a great answer to the energy poverty that world will face in the next years, but require very high technology, a lot of research and study.

To this point, only theoretical schemes have occurred, for the exploitation of the sea flows, with the installation of huge, low speed, turbines at the sea bottom.

To sum up, the benefits of the use of Renewable Energy Sources are:

- They infinite. They are endless and at the same time they help in reducing the dependency on other type of finite sources, as oil or gas.
- They enable the domestic use of them, at a country level or even closer. So, in that way they also increase the energy independency of countries, by ensuring at the same time the energy supplies of countries.
- Since they are natural (sun, wind etc.) they can be found in everywhere, not as oil or gas, which would be found only in specific areas on Earth. So, the energy is created and consumed at local level, which this leads to fewer transmission losses and simultaneously coverage of the local needs by their domestic resources,
- The operations costs are usually low and this provides independency of the costs of other finite fuels, like oil or gas.
- As mentioned before, the installations using renewable energy sources are designed to exploit the sources found at the specific areas, and not transfer them from others. So, they can cover the needs of a few users around, or of more, analogous to the installations' design, enabling the quick response between demand and offer.

- With these type of installations, even the most remote areas or not very rich, like in Africa, can now be used as a base for investments, providing at the same time, jobs at the local community.
- Eventually, they are environmental friendly, and in general the society does approve them. [7,8]

Picture 15: Green world by WWF campaign.

2.6 Electricity Production in Greece

The energy production in Greece is dominated by the state owned Public Power Corporation, PPC (known mostly by its acronym in English DEI).

In 2004, the consumption of primitive energy in Greece, reached the 32,7 millions of toe. In the energy mix of the country, the oil gains the biggest percentage, with about 20 millions of toe (61,2%), whereas the lignite follows with 9,3 millions of toe (28,5%), next is natural gas, with 2,2 millions of toe (6,8%) and finally come the hydro applications and the rest renewables with 1,1 millions of toe (3,5%).

Table 1: The Energy in Greece.

Energy in Greece [7]						
	Capita	Prim. energy	Production	Import	Electricity	CO_2-emission
	Million	TWh	TWh	TWh	TWh	Mt
2004	11.06	354	120	284	57.0	93.9
2007	11.19	374	141	284	63.0	97.8
2008	11.24	354	115	293	64.3	93.4
2009	11.28	342	117	258	62.5	90.2
Change 2004-09	2.0%	-3.4 %	-2.0 %	-9.1 %	9.8%	-3.9 %
Mtoe = 11.63 TWh . Prim. energy includes energy losses						

These data, among the years stayed a little bit constant, since the fossil fuels do have the strongest contribution in the coverage of needs of the primitive energy, as this percentage is about 93%. This explains why the carbon dioxide emissions have arisen dramatically, overcoming the limit that was set, at a country level, during the period of 1990-2011.

In 2008, the contribution of the renewable to the country's total energy consumption was 8%, and although it raised from the 7.2% that was in 2006, it was still below the EU average of 10% that was in 2008. The 10% of the Greece renewable energy comes from solar power, while most is also derived from biomass and waste recycling.

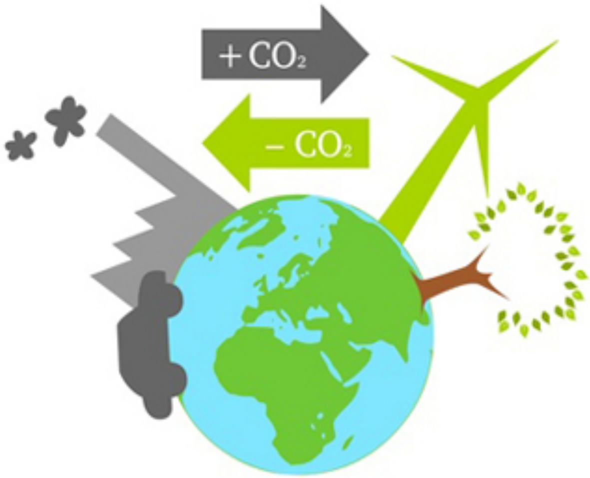
The European Union, especially during the last years, seems to have understood the significance of the renewable energy sources, and by incentives given, tends to push the communities to adopt sustainable, green habits, starting by each person individually (through recycling etc.) and at a more organized level with green investments on top of people's roofs, for large businesses to use green energy to cover their needs, etc.

The "20-20-20" is an ambitious scheme that the Union is promoting. It means that by the year 2020, the 20% of the energy production must be derived from renewable form of energy and at the same time, reduction of the GHG and other CO2 emissions at 20%.

Greece has achieved the first target, meaning that more than 20% of the energy production is derived from renewables and especially the photovoltaics which had a dramatic increase in the last 3years, but without organized plans about reducing the gases emissions, it is measured that they will increase by 57,6% till 2020. Not even stay constant. Decrease of this percentage, without change of habits and ecological conscience in Greece, is something impossible.

More specifically, concerning the CO2 emissions, they mostly come from the combustion of fossil fuels (about 95% of the total emissions at the energy sector), and the second places, with smaller percentages, the methane and the hypoxide of nitrogen are found, with 1,5% and 3,5% respectively.

Talking exclusively about the CO2 emissions, according to studies, the percentage have arisen to 47,6% in 2010 and are about to reach the 67,8 terrifying percentage by 2020. So it is of paramount importance from societies to cultivate the green way of thinking for the next generations and give incentives to change their minds, the olders. [1, 2, 3, 9]



Picture 16: The climate trend in Europe (WWF Campaign).

2.7 Legislative framework

According to data from the Ministry of Environment (in April 2013) the total nominal power of Residential Photovoltaics that have been installed in Greece, reach 341 MWp, corresponding to approximately 38,000 facilities.

It all started in July of 2009, when a totally new, program for Residential Photovoltaics ≤10 kWp eventually approved and set into action. To this Special Development Program, could be applied premises used either for housing or for small businesses.

At the beginning it ran for the mainland and the interconnected islands, while for the non-interconnected islands after an investigation made to check the available power margins in the electric field of each island, the implementation of the Project also began at 10th January 2011 in order to implement the 1251/2010 Decision of RAE.

The program is planned to run until 31st December, 2019.

A limit was set from the beginning, for the total installed capacity that could be found in those facilities.

So, the maximum capacity of the Residential PV system per facility according to the Program is:

- 10kWp for the mainland, the grid-system islands and Crete and,
- 5kWp for the rest, non-interconnected islands.

Picture 17: Installation of a residential photovoltaic station.

The Program corresponds to PV systems whose energy is totally injected into the Grid, and can be installed on top of houses roofs or buildings roofs, including terraces, facades and shadings, and complementary areas of the building such as warehouses and parking, as defined in the GBR (General Building Regulation).

Right to admit to the program have individuals and not companies or legal entities classified as small business, who have under their own property the place where the photovoltaic system will be installed. In cases of shared or jointly-owned buildings space, only a single system can be installed, and after getting the consent of the rest of the co-owners.

Right to admit to the program do also have legal entities of public law (Public Entities) and private legal entities (private law) non-profit, who have under their property the space where the system will be installed. The right for the installation of the PV system in a building owned by Legal Entity of Public Law (Public Entity), the use of which has been undertaken by a manager (eg. school board), is provided to him, under the written agreement of the owner of the building.

The Prerequisites for PV systems under this Program are:

1. the existence of active connection of electricity consumption in the name of the owner of the PV, in the building where the system will be installed,
2. part of the heating needs for hot water, of the owner of the PV must be covered by renewable energy, including solar thermal, solar water heaters etc.,
3. lack of public support.

The licensing procedure according to the Greek Legislation is not part of this study.

The Offsetting Contract will be signed between the owner of the PV and the Public Power Corporation (PPC) or any other supplier who electrifies the consumption of the building.

This Contract:

- has a twenty five (25 years) duration, starting from the date of activation of the connection of the PV system.
- is concluded with a constant reference value (Feed-in-Tariff), which corresponds to the price at the time it (the contract) is signed.

If the owner of the PV decides to change the supplier who will supply with power the consumption of the building, then the Contract will automatically be cancelled and a new Offsetting Contract must be signed with the new supplier for the rest of the years remaining.

The tax treatment and the obligations the owners of the PV systems ≤10 kWp have, as defined in the "Special Development Program for Photovoltaic Systems in buildings and especially in lofts and rooftops" (Official Gazette B 1079 04/06/2009) are specified in the Circular of Ministry of Finance (POL 1101/6.08.2009).

More specifically:

- The owner of the PV system is not described as a trader for this activity and therefore is not obliged to the provisions of the Code of Books and Records. (p.d.186/1992 - Government Gazette 84 A)
- The injection of the produced energy (electricity) into the Grid is not a taxable event, where a good is delivered, in accordance to the provisions of Articles 2 and 5 of the VAT Code (n.2859/2000) and so, no VAT is applied.
- The earnings of the individuals (non-trades) and small businesses (sole proprietorships, partnerships, etc.), which are totally derived from the sale of the produced electric energy according to the Program, are exempt from any taxation. [1]

2.8 Applications

Photovoltaics do have many applications apart from the residential facilities that are connected to the grid. Stand-alone, or autonomous systems are another type of installations in where the photovoltaics play a significant role. [10, 11]

2.8.1 Stand alone systems

In Greece, the photovoltaic panels and the rest of the equipment (e.g. the inverters etc.) first appear at the market, 10 years ago, as a solution to supply with electricity all the remote houses, usually summer-season ones, which were either build without civil licenses, illegally, and that was why their owners could not be connected to the national Grid, or those houses were really far away from the communities' center, leading to extreme high cost for them to pay, in order to bring the grid close to their premises.

Many people, used to use diesel or petrol generators in order to cover their basic needs. Because since talking about summer houses, there were no laundry machines or ovens. But just the fridges or some television appliances.

In 2004 the first photovoltaic panels entered the local market, and the electrical engineers of those days, were able to support their clients with another, more sufficient way of covering the needs for their houses.

By purchasing some photovoltaic panels, according to the energy needs at each case, a solar inverter, and the rest equipment (cables, batteries, charge controller), an autonomous system could stand, able to cover the needs of its user by this simple way.

Picture 18: A Stand-alone System.

The two or three panels were installed usually on top of the house's roof, at a south orientation, which would create electricity in the manner that described in the Photovoltaic Effect chapter.

That electricity could be used to cover the direct loads of the house, during the day, meaning the energy needed for cooking at noon, and the rest energy could be saved in the batteries, in order to be consumed during the night.

The growth of these type of installations was significant and as year passed and the photovoltaic technology got more mature, the cost of this type of equipment also dropped (half per year), allowing the first users to add more panels or batteries to their initial systems. [14]

2.8.2 Stand alone devices

Stand alone devices are the type of systems that described before, but at a smaller level, meaning that are designed to cover one type of need, whereas the most common, and of low cost, is the need for light.

In the next picture a standalone street lamp, appears. The logic is the same, the pv panel converts the solar radiation to electric energy, which is saved in the battery at the back side of the device and when the sun sets, the lamp is automatically turned one. It will be shine as long as its battery can supply with energy.

Picture 19: Stand alone Street lamp.

This means that during the summer period, the duration of the lamp being turned on is longer than, during the winter.

This type of standalone devices, is gaining a significant part at the energy markets, since many good products like this can be found from countries like China, meaning that they may do no cost expensive, but offer a good quality to the user.

Stand alone street lamps are recognized in many Greek Streets and usually are financed by the local municipalities. So, the benefit is double, and green way of thinking for locals and money save from the electricity bills, that common street lamps would increase.

Stand alone devices can also be found in parking meters, emergency calls, water pumps, even toys for kids etc. and is for sure a market that continuously increase. [27]

2.8.3 Commercial Photovoltaic Stations

Apart from the residential photovoltaic systems that are referred to the Special Program of the maximum 10kWp installed capacity, in Greece also used to exist the commercial photovoltaic stations (above 10kWp)

Picture 20: Commercial Photovoltaic Station with one-axis tracking system.

For these type of investments, a completely different type of agreement was signed between the owner and the Public Power Corporation Company. Firstly, the duration of the contract was for 20-years period and the feed-in tariffs were at the half of the ones that Residential photovoltaic owners could achieve.

But in these case, the owner would earn from the quantity. In a few years, across the whole country more and more photovoltaic stations were growing like mushrooms. Because of the high initial cost of such investments, the majority had applied to the bank for loans. Also, cause of the easy way that their owners were earning money, even Greek farmers by profession, stopped from the agriculture sector and preferred to sign 20-year contracts with the PPC and install photovoltaic stations in their lands.

Unfortunately, the lack of organized plans, from the society and the high taxation that was set to the profits of the owners, and with the banks demanding their money at the same time, lead to the majority of such investors to bankruptcy, closing of companies which were among the renewable energy sector, and thousands of people without work eventually. [25]

2.8.4 Integrated Systems

Photovoltaic panels can also be integrated into buildings' facades, or mounted on them. Panels are most often retrofitted into existing buildings, usually mounted on top of the existing roof structure or on the existing walls. Alternatively, they can be located separately from the building but connected by cable to supply power for the building.

Building-integrated photovoltaics (BIPV) are increasingly incorporated into new domestic and industrial buildings as a principal or ancillary source of electrical power. Typically, photovoltaic panels are incorporated into the roof or walls of a building. [15, 26]

Picture 21: Photovoltaic wall at MNACTEC Terrassa in Spain.

3 Problem Definition

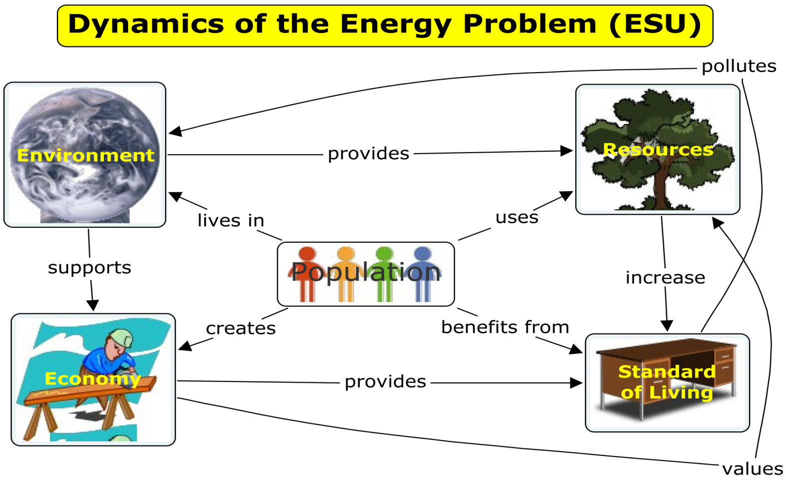
At this Chapter a flashback in the energy sector is done, whereas the necessity for organized societies to make a green turn to renewable energy sources for electricity production, is highlighted.

3.1 Energy flashback

From the beginning of the last century, when the first applications of electricity appeared and till the beginning of the 70's, there was a global trend in constructing bigger and bigger Electricity Production Stations and at the same time a continuous growth of large Transmission and Distribution Networks. The main reason behind this fact was the dramatically increase for electric energy, able to cover the needs of the population.

The same effect also happened and in Greece, with the surprising expansion of the Public Power Corporation System, which during the period 1956-1963, bought the 300 private electric companies that used to supply with energy, within small local networks.

However, due to the oil crisis at 70's, it became to the common sense obvious the need of the better, at least at that time the word sustainable was unknown, exploitation and usage of the energy sources. The effects of the pollution of the environment were even from that time obvious and more and more people start at that time to adopt more green habits.



Picture 1: Dynamics of the Energy Problem (by Emporia State University)

At a more organized level, the global search for new, alternative energy sources began, with higher target to avoid even at all the finite fossil fuels, like coal and oil, or even better the nuclear power plants, with all the commonly known negative effects that had to humanity.

During the 70's it was when the first ideas about energy saving and sustainable use of energy, also appear for the first time. [4, 16, 24]

3.2 Forms of energy

The energy sources that man has available to choose, are classified into two main categories:

- To the non-renewable resources, which are derived from the Earth's crust and are finite.
- And to the renewable resources, which are natural and have a sustainable yield.

In the first category, belong the fossil fuels and also the nuclear energy. In the second category, the sources that are originated by the sun, are found.

The sun is the main reason of the existence of life on Earth. Because of the sun's radiation that reaches our planet, life is created and developed every day. The sun provides energy, without stop, in different forms, from which many can be exploited by man, for the coverage of his needs (energy).

The sun also provides the necessary heat to Earth, keeping its average temperature possible for living. From the heat, large amounts of sea water are evaporated and the natural circle of the water is going on. To this effect the lakes and the rivers owe their existence. The sun also moves the air masses and creates the waves on the ocean and also to the sun's radiation, the sea flows are existing.

When the sun is absorbed by combined materials, the Photovoltaic effect that was described in a previous chapter occurs. Finally, solar radiation helps to the growing of the plants, from which combustion, also energy can be revealed.

In contrast to the benefits that whole community gain, free, from the sun, societies use, until today, unfortunately, other type of forms to produce energy, like:

3.2.1 Coal

For many years and even for today, coal is the main substitute for the energy production. To coal, at the biggest part, the industrial revolution was based. Until now, at a global level, the industrial production is based on the production of energy through the combustion of coal.

3.2.2 Oil

At the first half of the 20th century the use of oil, for the energy production had dramatically increased.

Today, after two oil crisis that knocked the world is more necessary than ever, by looking all the negative effects on the environment, for people to understand the need for change to our way of living and turn to renewable energy sources.

In developed societies, oil covers the needs for the production of energy at 85%, where as in developing countries this percentage is 55%, with tend to steadily increase.

On the other hand however, at the developed countries the above percentage seems to be decreasing, and at the same time, the percentage of the renewables increases.

As described in Section 2.2, the combustion of the oil hydrocarbons and its others derivatives, produces CO2 and the other dangerous gases which are accused for the negative effect they do at the atmosphere's ozone layer.

It is of paramount importance for people to understand the tremendous impacts to our health, from the existence of these gases at the atmosphere, which do not only change the climatic conditions but also cause a significant drop from the standard conditions of our planet (e.g. the average increase of the planet's temperature).

From recent studies, is calculated that the oil sources will be available for exploitation only for the next 50 years, and for the coal sources for the next 200 years.

Then, there will be none. [6, 29]

3.2.3 Nuclear energy

From 1945 and later on, when the nuclear energy firstly appeared, a lot of hope was set in its use.

Today, people feel fear in front of the weakness of governments to deal with all these nuclear wastes or even worst, against the challenge of a nuclear war. Needless to mention the terrifying results of accidents that occurred at nuclear plants.

It should be needed many more years to pass, for humanity to forget the Tsernobil accident, in Russia, in the April of 1986.

But why nuclear energy is so appealing, is because it provides energy without any gaps or upside downs. Energy is being produced in a steady way, without any differences in demand.

The 6,5% of the global energy demand is covered by nuclear energy, and the 17% of the global energy production is base on that form of energy. The total installed capacity globally is 370GW, whereas in Europe this percentage overcomes the 158,4GW. [6, 28]

3. 3 Energy poverty

The poverty of energy is the new type of poverty that people face during the 21st century. This modern poverty explains the lack of some people to fulfill their energy needs. Meaning that they cannot find energy to cover the need for cooking, space heating etc.

The coverage of these type of needs is mandatory for the civilized way of lives and is also an indicator between developed and developing countries, in terms of economic empowerment. Unfortunately 1,3 billion people have no access to electricity, from which the 95% are found in Africa or Asia.

Energy plays a crucial role in a country's development and the lack of access to modern energy services can be a serious obstacle. [12, 21]

3. 4 Need for a green turn

This Study's main object, apart from promoting the benefits that society gains through the use of renewable energy sources, economically speaking and also for quality of life reasons, an effort was made to check on how much could the national grid of the country rely on the energy production from residential photovoltaics.

Greece gained the 4th place in Europe and the 7th globally, regarding to the new installed capacity in 2012. More specifically, 912MW, were added in 2012 and the largest percentage of 19,4% was coming from residential photovoltaic installations on top of roofs of the Greek houses, across all over the country.

About the potential of the energy yields in Greece, a lot of studies has been published, showing the average solar radiation in W/m^2, but those studies are more general and in theoretical level. [22]

What in this Study is tried to be done, is to check the country at a prefecture level (for the 51 prefectures of Greece) for the average hourly production (kWh), as close to reality, with comparison, between numbers gathered by theoretical simulations and those one from samples of existing installations, found from as many as possible Greek prefectures.

The final results, the hourly data per prefecture, bring out a table of the country, on which next or suggesting studies could examine if the national grid could rely on the production from the residential photovoltaics, to use or at least cover the amount of the energy that is needed to be produced, especially during the peak hours (even in Summer or Winter).

For that reason, the existing installations were checked specifically, on a hourly level (kWh), during the longest day of the year, the Summer Solstice, and the shortest, the Winter Solstice.

Producing energy from lignite or coal apart from the environmental impact, which is very serious and mentioned a lot of times before, in the Study, also requires a lot of money. So the question is if the Greek Residential Photovoltaics, could supply to the national grid the extra energy that is needed especially during the hours that the demand reaches its peak.

If the amount of energy that is eventually produced, would be enough to rely on, many unpleasant events, like break down of the system, in particular areas (black out), in Summer, would at least be reduced. [4, 5, 11]

4 Contribution

4.1 Methodology

In this Chapter, the methodology is described.

4.1.1 Methodological approach

The methodology of this study consists of two main parts: the Theoretical and the Practical one, and from the comparison of their results, the findings are concluded.

Three main tools were used in the whole process: The PVSyst Simulation Program, the most reliable and accurate tool, specified in simulation procedures with photovoltaics systems (stand alone, grid connected etc.), the Sunny Portal, a website powered by SMA, the German Inverter Manufacturer Company, in which, results of existing PV installations, are in public view, and finally the Microsoft Office Excel 2007, for the statistical analysis.

An important point for the Theoretical Part of the Study, and for the accuracy of the results, was to define equipment (PV panels, inverter) that would have common characteristics (efficiency, performance guarantee etc.) with the equipment in the majority of the existing installations. For this reason, the mono-crystalline PV panel BOSCH c-Si M 60 (245Wp) and the SMA Sunny Tripower 10000 TL (10 KW) inverter, were chosen.

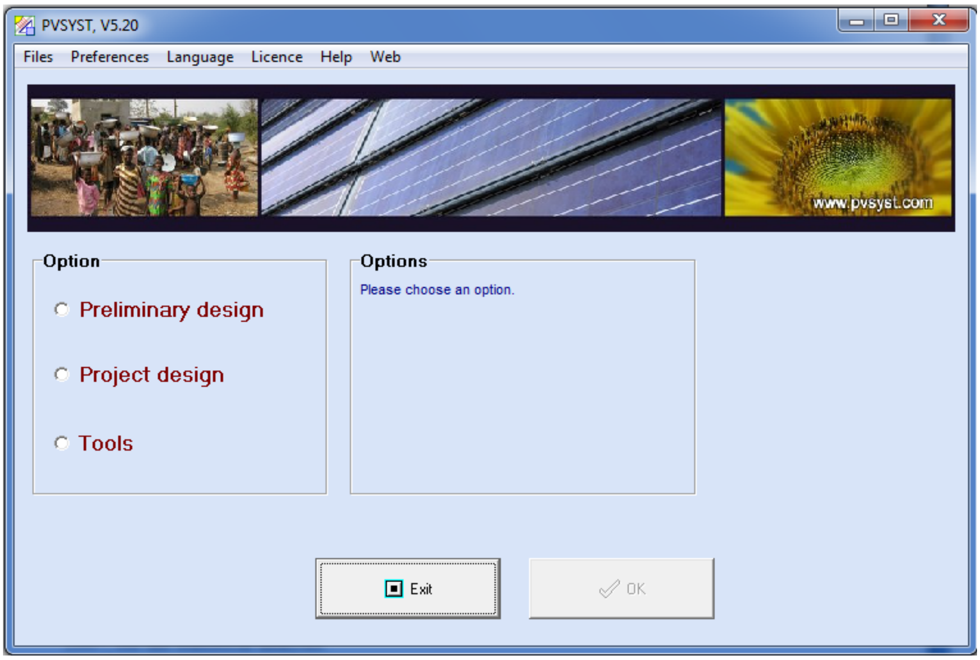
The first step was, for each of the fifty one (51) prefectures of Greece, to calculate the theoretical annually produced energy by a 10 KWp residential photovoltaic system, and more specifically check during summer solstice and winter's, in an hourly level, the produced energy (KWh).

Next, from already existing installations, in each prefecture, check for the same two days (21st of June, 21st of December), the hourly produced energy.

Finally, comparison of the results and findings for each prefecture.

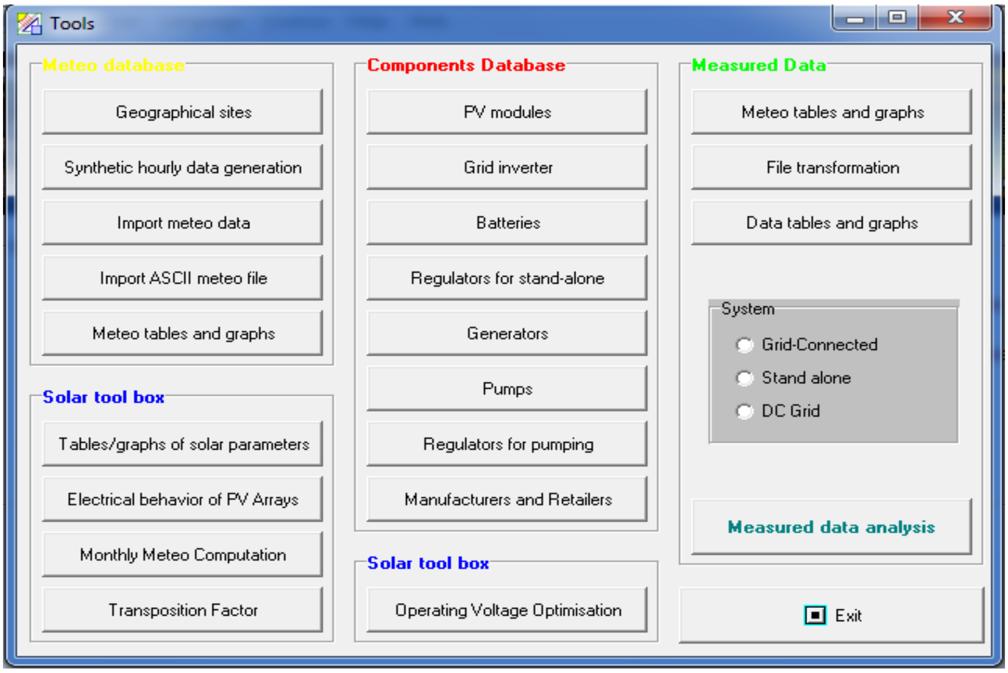
4.2 Theoretical Part

In this Part of the Study, the PVSyst Simulation Program was thoroughly used.



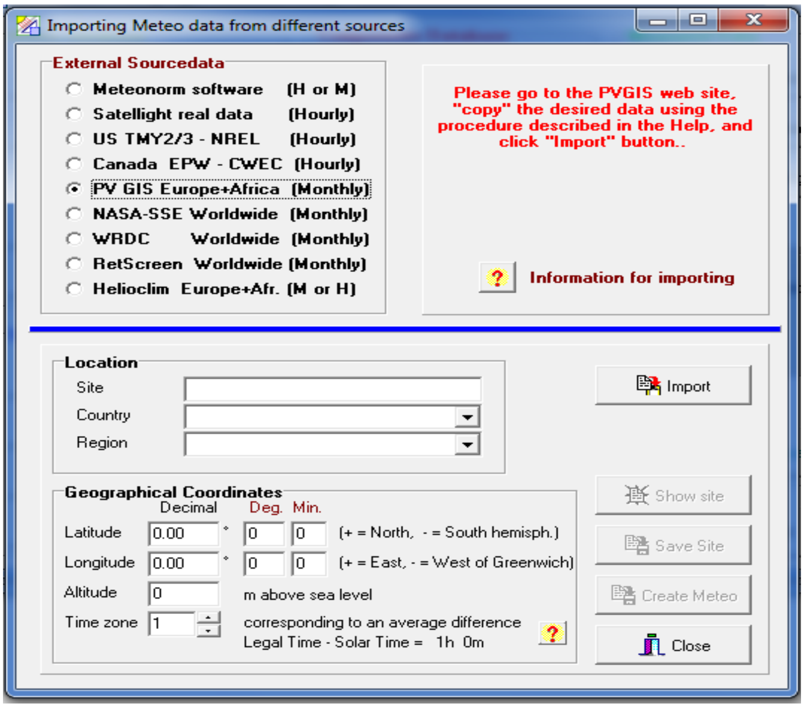
Picture 1: First image when open the program.

The program, has a large database of Meteo and Geographical data for different locations around the world. But it also allows the user to import specific data, for any desirable for calculation, location. For example, for Greece, only Athens, Kythira, Rhodos, Ioannina and Andravida meteo data exist in the database. For the rest prefectures, from the option **Tools**, the user can import the data from an external source database.



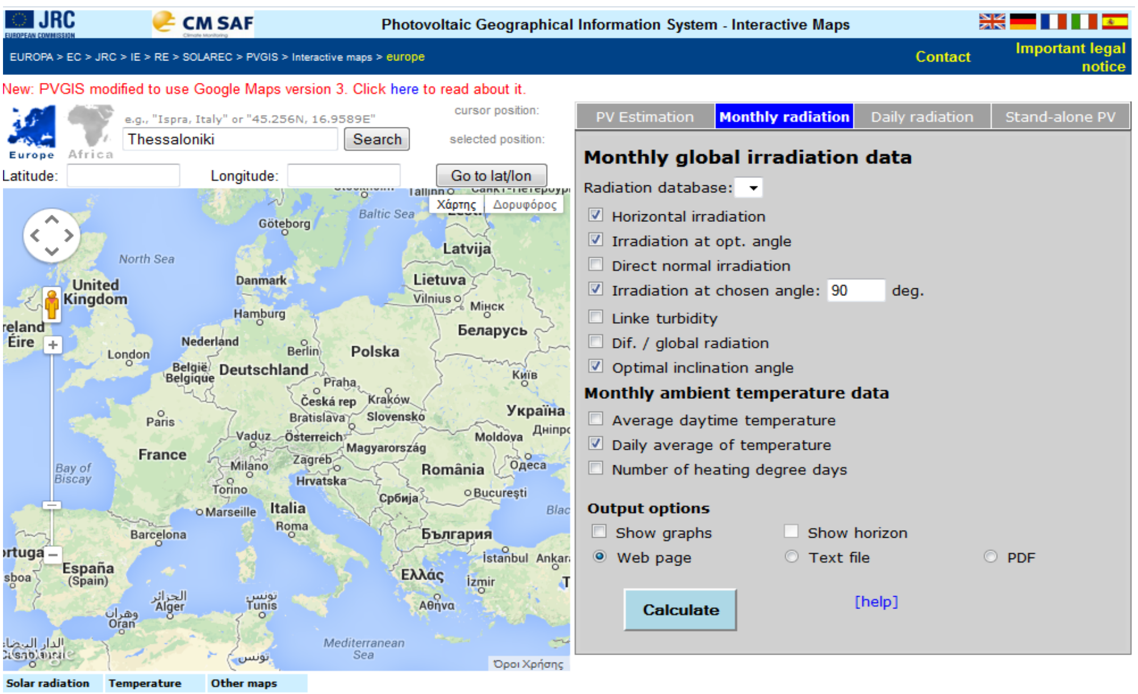
Picture 2: Tools' options.

In this Study, the **PVGIS** website, was chosen for importing the meteo data.



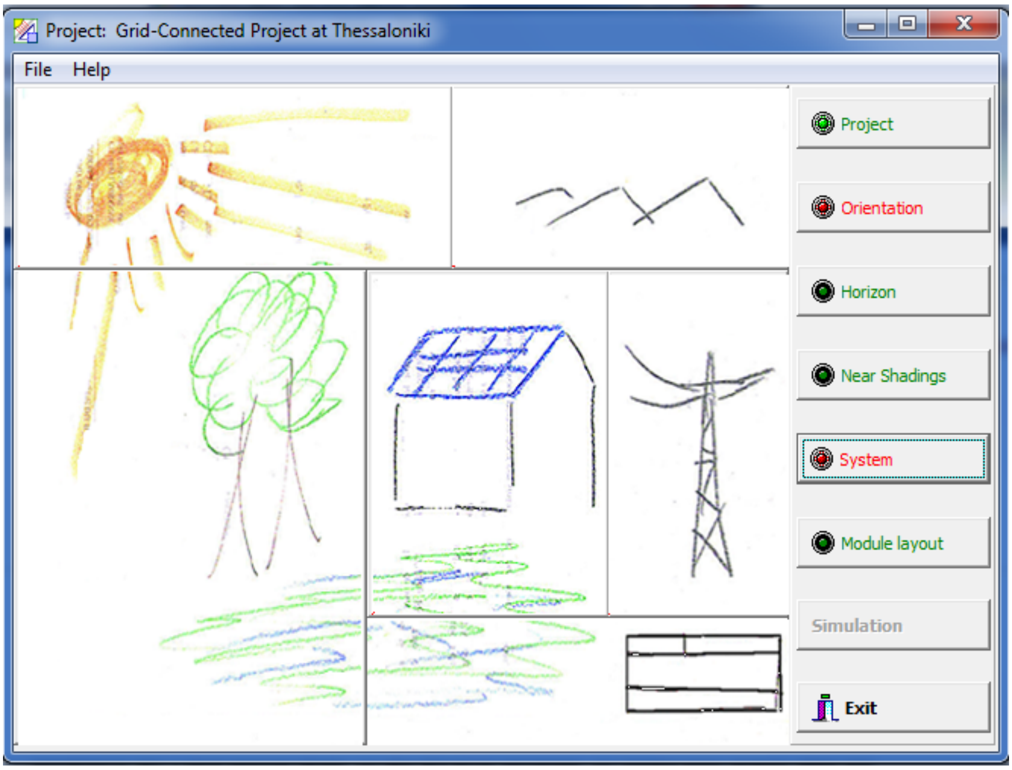
Picture 3: Importing data from PVGIS.

The procedure followed in each case, was the same. Visit to the PVGIS web site, give the name of the location (e.g. Thessaloniki etc.), copy the meteo data (radiation, irradiance etc.) and import them, to the PVSyst program, to create new meteo data for every Greek prefecture.



Picture 4: PVGIS website.

After having this part done, the project design of a residential grid connected system begins.



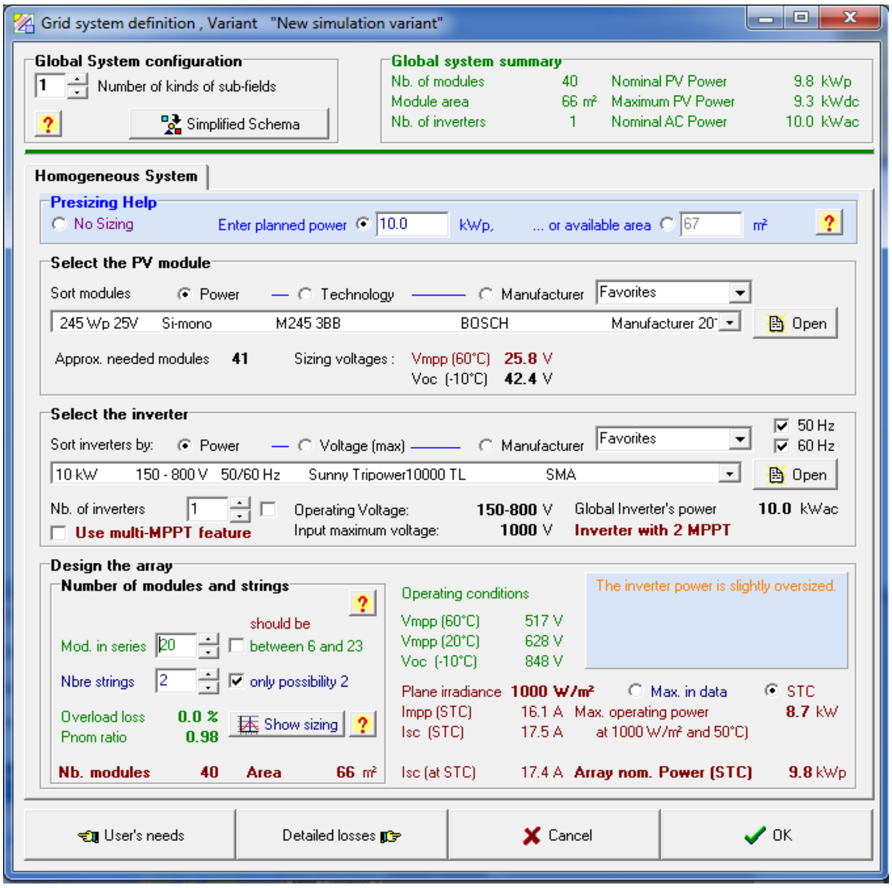
Picture 5: Project Design.

The program allows the user to define several parameters: the location of the project, the orientation, the horizon, the possibility of near shadings, the system (installed capacity, chose equipment etc.) and the module layout. And finally proceed to the simulation.

For the scope of this study, and in order to have a more general view for every prefecture, south orientation was set, with 30o angle of the PV panels, no near shadings and as far for the equipment, BOSCH PV panels and SMA Inverter were chosen.

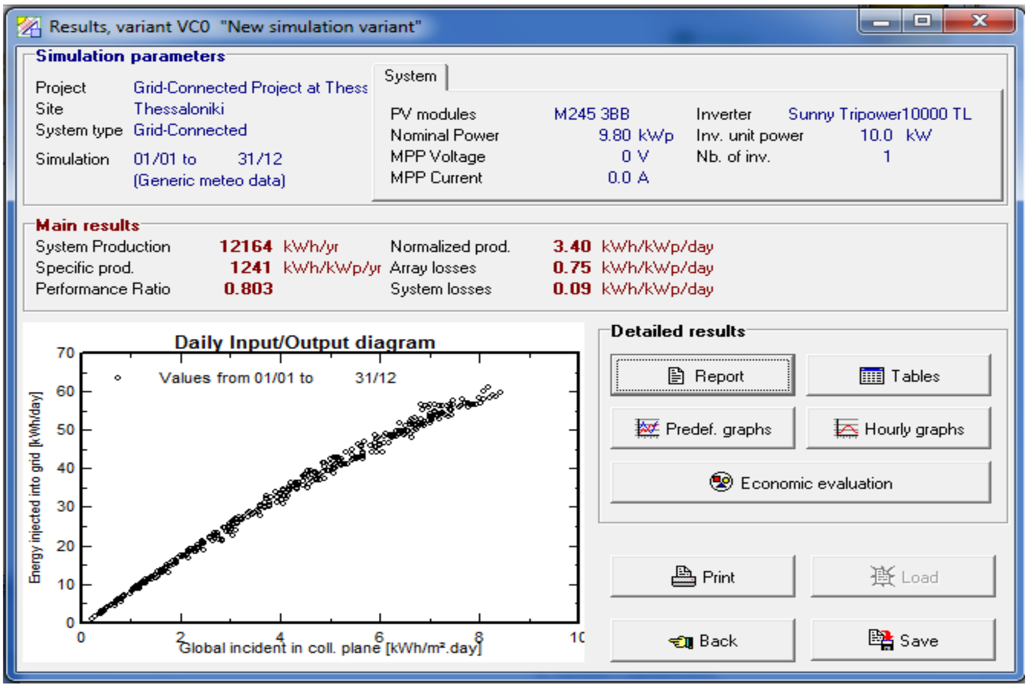
It is important to mention at this part, that the PVSyst program, apart from the meteo data base, it also provides the ability to the user to choose among a variety of Manufacturers, the equipment that will be used.

BOSCH and SMA Companies' products are very popular in Greece, and besides that, their PV panels and Inverters, respectively, do have common features to the majority of the equipment found in Greek residential PV systems.



Picture 6: System's parameters.

Finally, the simulation is executed. The main results are the system's production, whereas in a more detailed level a three-page report is given.



Picture 7: Simulation results.

As the prefecture of Thessaloniki was taken as an example to show the procedure followed, its report will also be described.

In the 1st page of the report, appears the specific meteo data for Thessaloniki, and a short description of the equipment used.

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Grid-Connected System: Simulation parameters

Project : **Grid-Connected Project at Thessaloniki**

Geographical Site	**Thessaloniki**		**Country**	**Greece**
Situation	Latitude	40.6°N	Longitude	22.9°E
Time defined as	Legal Time	Time zone UT+1	Altitude	30 m
	Albedo	0.20		
Meteo data :	Thessaloniki from PVGIS, Synthetic Hourly data			

Simulation variant : **No shading effects**

Simulation date 01/08/13 13h45

Simulation parameters

Collector Plane Orientation	Tilt	30°	Azimuth	0°
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module Si-mono	Model	**M245 3BB**		
	Manufacturer	BOSCH		
Number of PV modules	In series	20 modules	In parallel	2 strings
Total number of PV modules	Nb. modules	40	Unit Nom. Power	245 Wp
Array global power	Nominal (STC)	**9.8 kWp**	At operating cond.	8.7 kWp (50°C)
Array operating characteristics (50°C)	U mpp	544 V	I mpp	16 A
Total area	Module area	**65.7 m²**		
Inverter	Model	**Sunny Tripower10000 TL**		
	Manufacturer	SMA		
Characteristics	Operating Voltage	150-800 V	Unit Nom. Power	10.0 kW AC

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
=> Nominal Oper. Coll. Temp. (G=800 W/m², Tamb=20°C, Wind velocity = 1m/s)			NOCT	56 °C
Wiring Ohmic Loss	Global array res.	571 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	1.0 %
Module Mismatch Losses			Loss Fraction	2.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Parameter	0.05

User's needs : Unlimited load (grid)

Picture 8: PVSyst Report: 1st page.

In the 2nd page of the report, the main results, such as the Performance ratio and the Energy that is injected into the grid, per month, appear.

For Thessaloniki, the theoretical calculated Energy Production is **12.164kWh/y.**

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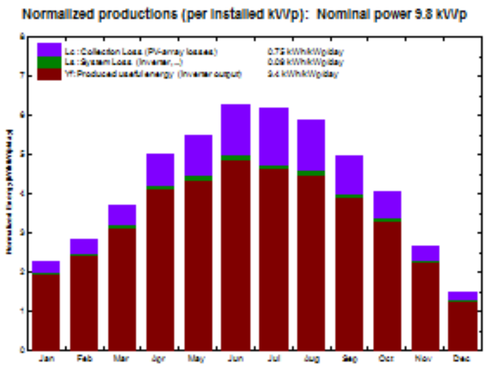
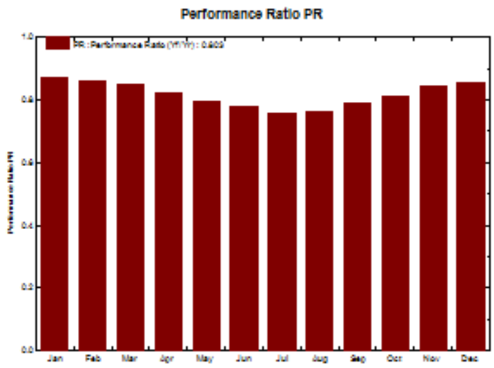
Grid-Connected System: Main results

Project : **Grid-Connected Project at Thessaloniki**
Simulation variant : **No shading effects**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	M245 3BB	Pnom	245 Wp
PV Array	Nb. of modules	40	Pnom total	**9.8 kWp**
Inverter	Model	Sunny Tripower10000 TL	Pnom	10 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**12.16 MWh/year**	Specific prod.	1241 kWh/kWp/year
	Performance Ratio PR	80.3 %		





New simulation variant

Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	49.9	4.70	70.0	67.8	614	596	13.34	12.96
February	62.4	6.30	79.0	76.3	685	666	13.20	12.83
March	100.4	9.30	114.2	110.6	975	950	12.98	12.65
April	141.3	13.50	150.2	145.5	1245	1213	12.60	12.28
May	173.0	19.10	170.5	165.0	1359	1325	12.13	11.83
June	199.2	23.80	188.1	181.8	1467	1430	11.87	11.57
July	199.9	26.10	191.1	184.8	1448	1411	11.53	11.24
August	175.5	25.80	182.1	176.5	1397	1363	11.67	11.38
September	130.8	21.10	148.7	144.3	1181	1152	12.08	11.78
October	96.4	16.30	126.2	122.6	1031	1005	12.42	12.11
November	57.0	10.50	80.4	77.9	685	666	12.96	12.61
December	36.6	6.10	46.3	44.7	401	386	13.19	12.69
Year	1422.5	15.27	1546.7	1497.8	12487	12164	12.28	11.96

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

Picture 9: PVSyst Report: 2nd page.

In the 3rd page, a very detailed loss diagram appears, showing from the array nominal energy (14.833 kWh), how this is lost, because of the equipment's losses, to end up to the final energy that is injected into the grid.

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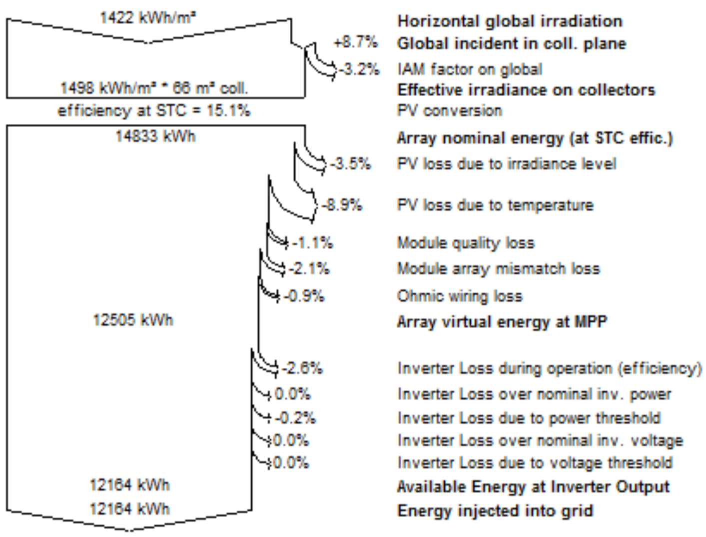
Grid-Connected System: Loss diagram

Project : **Grid-Connected Project at Thessaloniki**

Simulation variant : **No shading effects**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	M245 3BB	Pnom	245 Wp
PV Array	Nb. of modules	40	Pnom total	**9.8 kWp**
Inverter	Model	Sunny Tripower10000 TL	Pnom	10 kW ac
User's needs	Unlimited load (grid)			

Loss diagram over the whole year

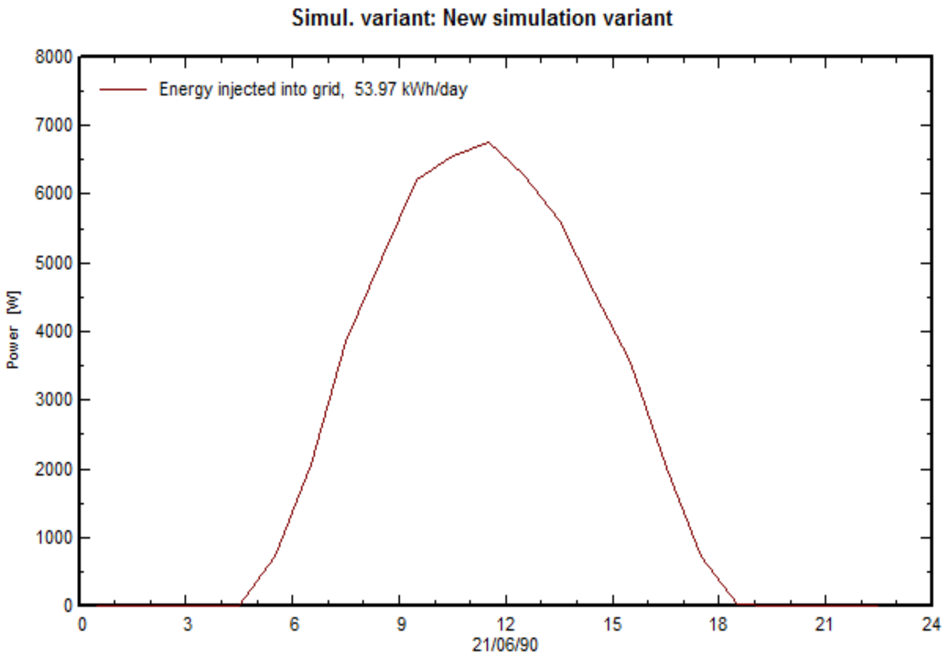


Picture 10: PVSyst Report: 3rd page.

The program, also gives the opportunity to watch the hourly graph, of the energy that is injected into the grid, for each day.

Summer solstice (21st June) and winter's (21st December), are the longest and shortest days of the whole year. As the earth is closer and farer to the sun, respectively. So these days, could be theoretical, the best and the worst days for the production of a PV system. [23]

For Thessaloniki, at 21st of June, the energy that injected into the grid per hour appears at the following graph:



Graph 1: Hourly graph for 21st of June.

By exporting the values to the Excel, the next table, concerning the hourly production appears.

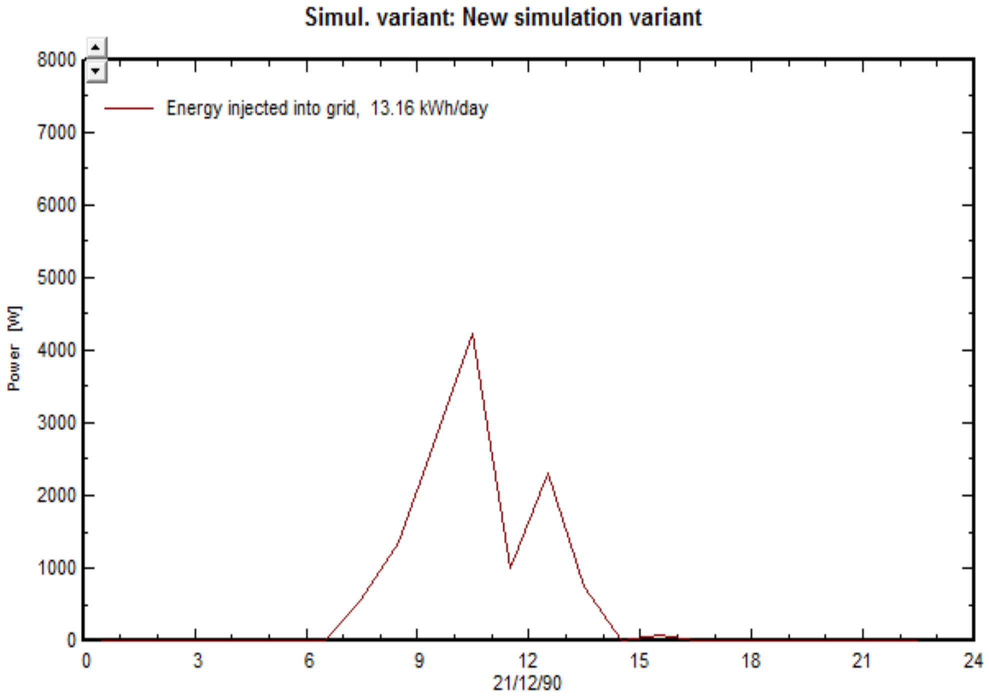
Table 1: Summer hourly values.

HOUR	21st JUNE
0	0
1	0
2	0
3	0
4	0

5	0
6	7.232.795
7	20.554.404
8	38.414.683
9	50.712.476
10	62.075.381
11	65.632.295
12	67.514.097
13	62.715.864
14	56.170.420
15	45.616.235
16	35.465.808
17	20.020.865
18	7.321.718
19	210.291
20	0
21	0
22	0
23	0
FINAL	**539657332 kWh**

.

For the same theoretically examined installation, for the 21st of December the energy that is injected into the grid per hour is:



Graph 2: Hourly graph for 21st of December.

By exporting the values to the Excel, the next table, concerning the hourly production appears.

Table 2: Winter hourly values.

HOUR	21st DECEM.
0	0
1	0
2	0
3	0
4	0
5	0
6	0
7	5.767.971
8	13.684.510

9	28.276.274
10	42.413.809
11	9.947.346
12	23.059.866
13	7.530.806
14	0
15	912.060
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
FINAL	**131592642 kWh**

So, from the theoretical study, for the Prefecture of Thessaloniki, for a 10kW residential installation, during the "best day" **53.97kWh/day** can be injected to the grid and during the "worst day", **13.16kWh/day** can be injected to the grid.

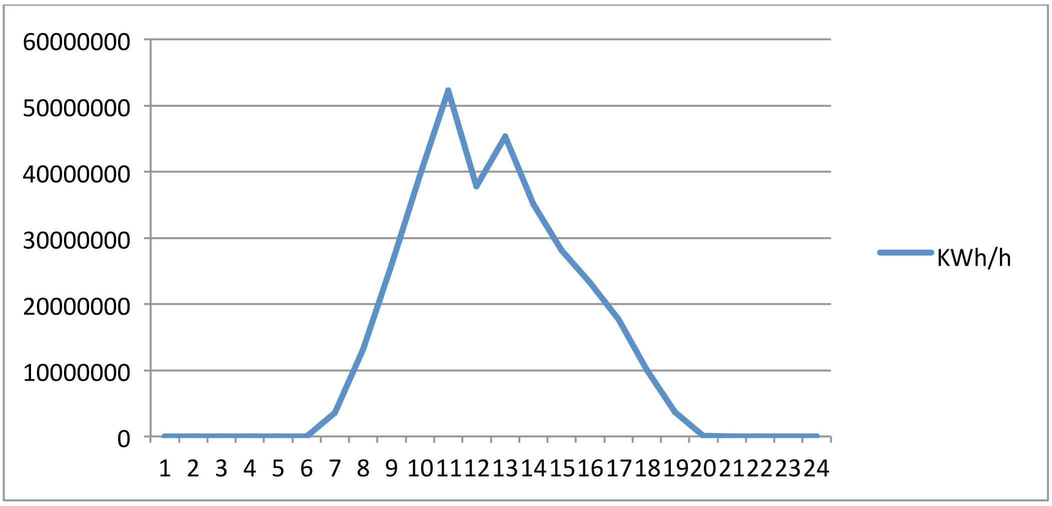
By taking its average, per hour:

Table 3: Average values.

HOUR	AVERAGE
0	0
1	0
2	0
3	0
4	0

5	0
6	3616397,5
7	13161188
8	26049597
9	39494375
10	52244595
11	37789821
12	45286982
13	35123335
14	28085210
15	23264148
16	17732904
17	10010433
18	3660859
19	105145,5
20	0
21	0
22	0
23	0
FINAL	**335624987 kWh**

33.56KWh/day could enhance the National Grid, from an average residential photovoltaic installation in Thessaloniki. Whereas its hourly graph is:



Graph 3: Average hourly graph.

The same analytical process was conducted for the rest 50 Greek prefectures. Their results are summarized in the next table.

Their three-page reports, their hourly tables and graphs are presented in the appendix.

Table 4: General Theoretical Results

	Pref.	Annually (KWh)	21st JUNE	21st DECEM.	AVERAGE (KWh)
1	**ATHENS**	**13702**	45,11	28,13	**36,62**
2	**THESSALONIKI**	**12164**	53,96	13,15	**33,555**
3	**ACHAIA**	**13323**	39,5	4,88	**22,19**
4	**HRAKLEIO**	**13540**	48,41	36,64	**42,525**
5	**LARISA**	**12107**	48,88	41,43	**45,155**
6	**AITOLOA/NIA**	**12305**	54,09	12,87	**33,48**
7	**EVOIA**	**13571**	48,45	13,93	**31,19**
8	**MAGNISIA**	**12447**	42,48	20,81	**31,645**
9	**SERRES**	**11764**	37,74	0,986	**19,363**
10	**HLEIA**	**12429**	56,77	13,97	**35,37**
11	**DODEKANISA**	**7402**	25,07	3,38	**14,225**
12	**FTHIOTIDA**	**13023**	54,61	4,65	**29,63**
13	**MESSINIA**	**12863**	51,24	16,3	**33,77**

14	**IOANNINA**	**12520**	55,4	5,32	**30,36**
15	**KOZANI**	**13092**	41,59	3,72	**22,655**
16	**KORINTHIA**	**13291**	44,35	19,5	**31,925**
17	**CHANIA**	**13816**	51,16	24,71	**37,935**
18	**EVROS**	**11879**	18,7	35,55	**27,125**
19	**PELLA**	**12177**	42,26	20,47	**31,365**
20	**KAVALA**	**11734**	13,44	14,14	**13,79**
21	**IMATHIA**	**12554**	46,18	13,02	**29,6**
22	**TRIKALA**	**12200**	49,08	21,47	**35,275**
23	**VOIOTIA**	**13117**	52,63	27,62	**40,125**
24	**PIERIA**	**13531**	56,02	26,03	**41,025**
25	**KARDITSA**	**12073**	52,55	7,96	**30,255**
26	**KYKLADES**	**6866**	25,88	3,78	**14,83**
27	**KERKYRA**	**12491**	55,21	9,32	**32,265**
28	**RODOPI**	**11597**	59,83	7,43	**33,63**
29	**LESVOS**	**6567**	27,67	11,79	**19,73**
30	**ARGOLIDA**	**13018**	52,4	27,9	**40,15**
31	**CHALKIDIKI**	**12554**	55,09	9,74	**32,415**
32	**DRAMA**	**11595**	47,27	42,01	**44,64**
33	**ARKADIA**	**13362**	53,07	32,19	**42,63**
34	**XANTHI**	**11630**	54,73	38,85	**46,79**
35	**LAKONIA**	**13138**	53,47	29,26	**41,365**
36	**KILKIS**	**12188**	47,3	23,92	**35,61**
37	**RETHIMNO**	**13420**	52,95	29,6	**41,275**
38	**ARTA**	**11867**	47,73	34,35	**41,04**
39	**LASITHI**	**14132**	51,71	22,21	**36,96**
40	**PREVEZA**	**11844**	52,37	23,85	**38,11**
41	**FLORINA**	**13489**	55,65	35,75	**45,7**
42	**KASTORIA**	**13459**	56,06	26,38	**41,22**

43	**CHIOS**	**6807**	28,12	15,36	**21,74**
44	**FOKIDA**	**12602**	34,58	23,05	**28,815**
45	**THESPROTIA**	**12454**	48,28	1,09	**24,685**
46	**SAMOS**	**7085**	26,15	17,34	**21,745**
47	**KEFALONIA**	**12870**	57,46	15,01	**36,235**
48	**ZAKINTHOS**	**12364**	51,71	6,26	**28,985**
49	**GREVENA**	**12934**	48,23	27,7	**37,965**
50	**EVRITANIA**	**11695**	39,86	23,6	**31,73**
51	**LEFKADA**	**11889**	22,12	23,68	**22,9**

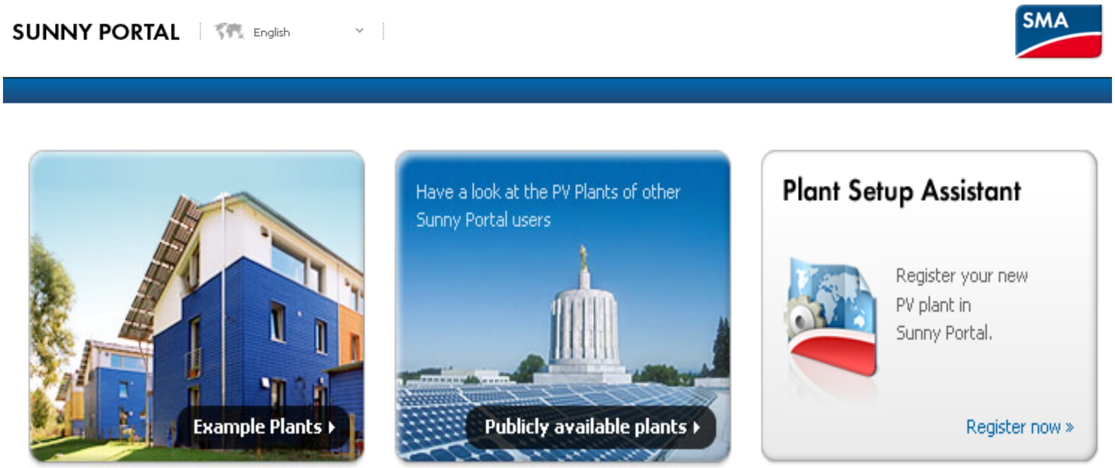
At this point it is important to notice that according to the Greek Legislation, only in the mainland and in Crete (in which the prefectures of Chania, Rethimno and Lasithi are found), 10kWp PV systems can be installed, whereas in the rest of the islands, which are not interconnected to the National Grid, at Dodekanisa, Kyklades, Chios, and Samos, the higher limit of the installed capacity is the 5kWp. (this explains the low numbers of the annually produced energy in these prefectures.)

4.3 Practical Part

Following the theoretical part, at this part of the Study, an effort was made to look for as more as possible, existing, residential installations, across the whole country.

SMA is a major German Company, that produces inverters for renewable installations (solar, wind, stand-alone systems etc.), Sunny Portal is the website powered by the firm, in where owners of such facilities do use it to watch the performance of their installations, through monitor systems (this helps especially the owners of installations, who live far away from the building, in which the PV system is installed), and also in many cases, they allow the data to be in public view.

In some prefectures, with high population, such as Thessaloniki, it was easier to find installations for the reasons of this study. An obstacle ahead of this research was that sometimes even a lot of systems could be found on the website, their data were locked and available only for the owner. Finally in the most prefectures, at least one residential installation was found to be compared to the theoretical model.



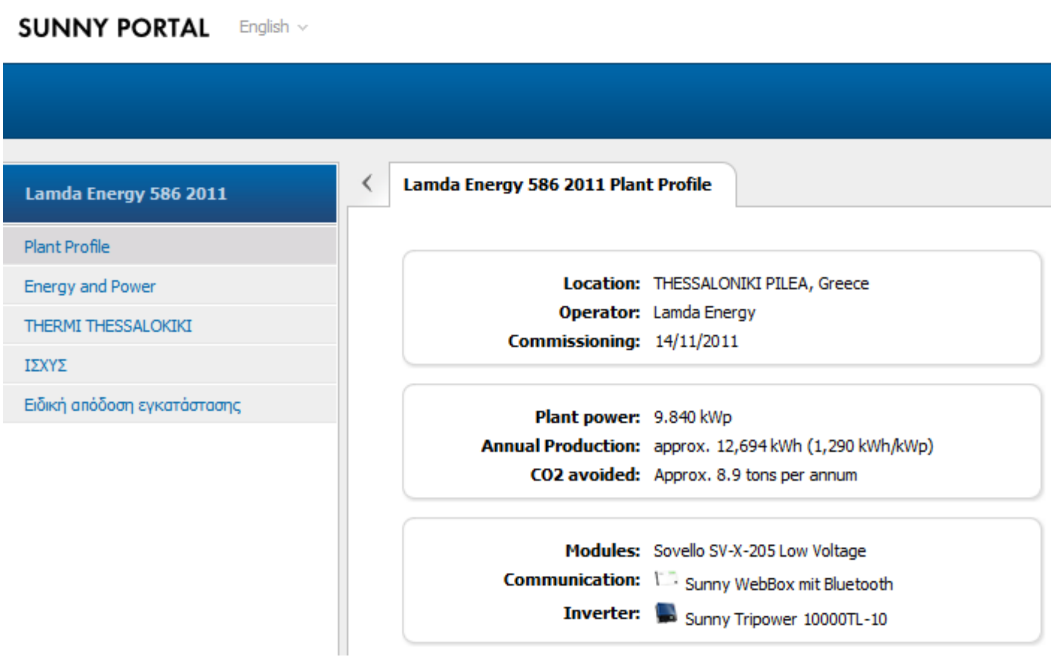
Picture 11: Sunny Portal website.

For the prefecture of Thessaloniki, four (4) residential PV systems were chosen, in accordance to their installed capacity and the used equipment and their location.

The installations: a 9,84kWp in Pylaia, a 9,89kWp in Oraiokastro, also a 9,89kWp in Kalamaria and a 9,64kWp in Retziki.

There were more systems, with features close to the pre-set, but either their hourly graphs, were not open to public view, or they were in operation for a few time only, so they were neglected.

The above systems were checked for the 21st of June and the 21st of December, at an hourly level.



Picture 12: Installation at Pylaia, Thessaloniki.

Their values, were then imported to the Excel. The table showing the results is as follows:

Table 5: Real-time hourly values (part A)

	PYLAIA		ORAIOKASTRO		KALAMARIA	
	9,84KW	winter	9,89KW	winter	9,89KW	winter
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	1.400.000	0	1.100.000	0	2.560.000	0
8	13.400.000	0	9.400.000	0	5.950.000	0
9	32.600.000	4.000.000	25.000.000	9.800.000	16.690.000	3.100.000
10	50.500.000	13.200.000	42.500.000	25.700.000	33.150.000	8.800.000
11	64.100.000	27.000.000	57.300.000	35.400.000	49.170.000	20.800.000
12	73.400.000	48.600.000	68.400.000	41.000.000	62.550.000	32.300.000
13	78.000.000	52.000.000	74.800.000	49.900.000	72.670.000	43.700.000
14	77.300.000	37.200.000	76.400.000	30.800.000	78.380.000	31.400.000
15	73.000.000	21.000.000	73.400.000	15.900.000	79.480.000	19.400.000
16	64.000.000	10.800.000	65.100.000	12.300.000	79.570.000	11.500.000
17	48.100.000	2.600.000	51.900.000	2.500.000	75.850.000	2.400.000
18	27.500.000	0	35.100.000	0	65.650.000	0
19	12.000.000	0	20.300.000	0	52.920.000	0
20	3.200.000	0	7.500.000	0	34.050.000	0
21	500.000	0	1.300.000	0	5.120.000	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0

TOTAL (kWh)	619000000	216400000	609500000	223300000	713760000	173400000

Table 6: Real-time hourly values (part B)

	RETZIKI		AVERAGE
	9,64KW	winter	
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	2.010.000	0	883750
8	4.800.000	0	4193750
9	8.260.000	3.300.000	12843750
10	34.220.000	7.700.000	26971250
11	50.410.000	18.700.000	40360000
12	60.980.000	31.300.000	52316250
13	69.000.000	40.600.000	60083750
14	72.050.000	29.500.000	54128750
15	73.390.000	15.300.000	46358750
16	72.770.000	12.600.000	41080000
17	66.720.000	2.200.000	31533750
18	58.450.000	0	23337500
19	45.870.000	0	16386250
20	27.320.000	0	9008750
21	2.400.000	0	1165000
22	0	0	0

23	0	0	0
TOTAL (kWh)	648650000	161200000	420651250

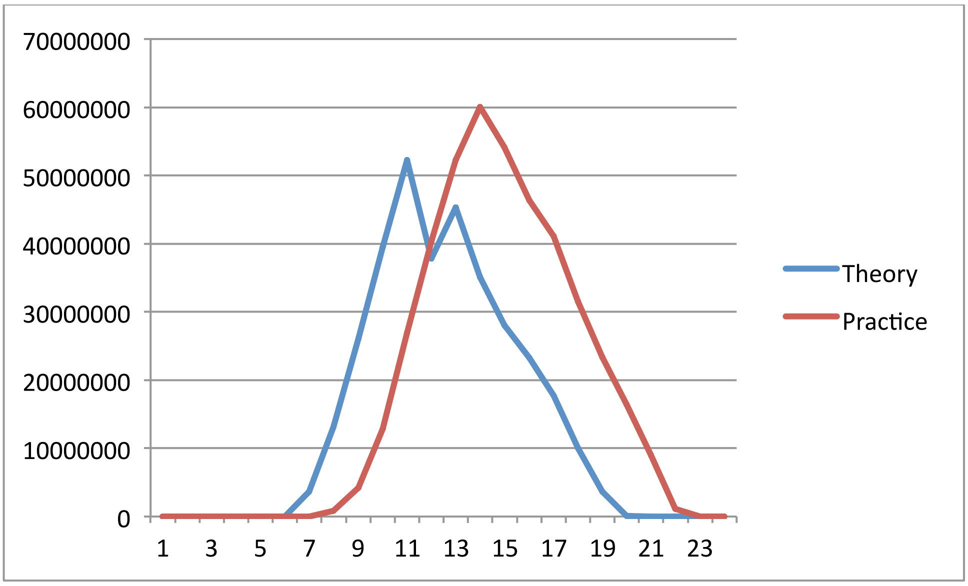
From a first glance, **up to 60KWh/day**, for the "best" day of the year, enhance the National Grid, and **at least 16,12KWh/day**, during the theoretical "worst" day of the year.

The analogous numbers from the theoretical part was **53,96KWh** and **13,15KWh** respectively.

By taking the average of these two days, for the four systems, **42.07KWh/day** could enhance the National Grid, from a residential photovoltaic installation in Thessaloniki.

So, from the Simulation Process, 33.56kWh/day was thought to be injected into the grid, whereas in practice, at a prefecture level the real number **is more than 20% higher**.

In the following graph, the blue line describes the average theoretical calculated energy (kWh), that would be injected into the grid, per hour, by a residential PV system in Thessaloniki, whereas the red line shows the average energy (kWh) per hour, that is actually injected into the grid, by an already existing installation in the same area.



Graph 4: Comparison for Thessaloniki.

Reality beats theory, but it is much better for a simulation programs to be conservative in promising results and then let practice, prove the difference.

At this point it is important to mention that, the PVSyst program, performs a simulation, using average meteo data of the last 100-year period, and on the other hand, the data from the Sunny Portal are from the last year, in the best case. This happens because of the little time that the PV installations grew up in Greece (since 2009). So, as it will be presented later on, not in every prefecture the real numbers are above the theory, but as it will be described in the Ethics Chapter, maybe the past year would be either very good or very bad for a location, and not representative enough.

But for the scope of this study, these facts are neglected.

The same process was followed for the rest 50 Greek Prefectures. Their results are summarized in the last Chapter. Their hourly tales are available in the appendix.

The next table shows how many existing installations were found across Greece.

In the best case, at the prefecture of Hleia, Greece, five existing installations, which features did matched to the pre-set requirements of the theoretical model, were found. At the majority of the prefectures, three to four installations were checked. As the list declines, to the less populated prefectures, the number of the installations found also decreases. Finally at some Greek Islands, line Samos or Kefalonia, no installations at all were found at the Portal.

Table 7: Installations found at Sunny Portal, per prefecture.

	Pref.	Installations
1	**ATHENS**	4
2	**THESSALONIKI**	4
3	**ACHAIA**	3
4	**HRAKLEIO**	3
5	**LARISA**	3
6	**AITOLOA/NIA**	3
7	**EVOIA**	2
8	**MAGNISIA**	2
9	**SERRES**	3
10	**HLEIA**	5
11	**DODEKANISA**	-

12	**FTHIOTIDA**	3
13	**MESSINIA**	4
14	**IOANNINA**	-
15	**KOZANI**	4
16	**KORINTHIA**	4
17	**CHANIA**	3
18	**EVROS**	3
19	**PELLA**	3
20	**KAVALA**	3
21	**IMATHIA**	3
22	**TRIKALA**	-
23	**VOIOTIA**	3
24	**PIERIA**	2
25	**KARDITSA**	-
26	**KYKLADES**	3
27	**KERKYRA**	1
28	**RODOPI**	3
29	**LESVOS**	-
30	**ARGOLIDA**	3
31	**CHALKIDIKI**	4
32	**DRAMA**	4
33	**ARKADIA**	2
34	**XANTHI**	3
35	**LAKONIA**	1
36	**KILKIS**	1
37	**RETHIMNO**	1
38	**ARTA**	-
39	**LASITHI**	1
40	**PREVEZA**	2

41	**FLORINA**	1
42	**KASTORIA**	1
43	**CHIOS**	1
44	**FOKIDA**	2
45	**THESPROTIA**	-
46	**SAMOS**	-
47	**KEFALONIA**	-
48	**ZAKINTHOS**	1
49	**GREVENA**	
50	**EVRITANIA**	3
51	**LEFKADA**	-

4.4 Validity and Reliability

For the implementation of this Study, two basic tools were used, during the writer's contribution part: the PVSyst simulation program and the database, powered by SMA Company, the Sunny Portal.

The version 5.20, of the PVSyst program (study of photovoltaic systems, www.pvsyst.com) was created in Agust 3rd, 2010, by the Institute for the Sciences of the Environment, of the University of Geneva, Switzerland.

The program requires license from the user, and for the scope of this study the original version was purchased.

PVSyst is recognized among other similar programs (e.g. RETScreen) as the most accurate for photovoltaic studies, globally approved and widespread used. Either for scientific reasons or for technical reports by Private Companies.

SMA is the leader Inverter Manufacturer Company in Germany. Its products (solar/ wind inverters, monitor systems etc.) have gained the largest "piece" of the European Market, also in Greece, because of the excellent combination of price and quality (value for money).

The Sunny Portal, the Company's website, provides the ability to users of SMA inverters, to register their photovoltaic systems on the website. It is on the users'/owners' choice, to just watch the performance of their installations, from wherever on Earth, they are, or also let those data be in public view. This is something that the Company encourages its clients to do so, through ads at the website.

The data, concerning the photovoltaic systems performance (daily, monthly etc.) or other indicators, cannot be touched by external factors and are derived directly from the inverter's measurements.

In Greece there are about 3.500 residential (maximum installed capacity 10kWp) photovoltaic installations (ypeka.gr.). From those, with criteria to be 9-10kWp installed capacity, only 210 were found at the Sunny Portal, meaning that their data could be available for the Study reasons. Eventually, 105 installations, across the whole Greece were checked.

Two main facts could affect the reliability of this Study's results.

The first is that in some small prefectures like Florina or Lasithi, the theoretical model was compared to only one found, existing installation. So the accuracy of the comparison between the results (of the theoretical and the practical part) increases as the number of the existing installations, checked is higher (e.g. 4 or 5) and decreases as that number is 1 or even none.

Finally, all the measurements from the Sunny Portal, for the 21^{st} of June and December, were derived from the years 2013 or 2012 or 2011. This happened because of the immaturity of this type of installations in Greece. So in every single case, data were taken from one of these three years. This means that if in 2011 for example the winter in Greece was very smooth, the hourly data of the winter solstice could be very high and not representative enough for a year's measurements. Or, on the other hand if in 2011 the summer in Greece was broiling hot, this could affect the performance of the photovoltaic systems, in the negative way and provide false sign.

Whereas in the PVSyst, the meteo data, in which the measurements are based during the simulation process, come from a statistical analysis of meteo data from the last 100-year period.

But the scope of this Study was to get a picture of the potential hourly production (kWh) for the 51 prefectures of Greece and that is why those facts were neglected.

4.5 Findings

In the next table, the results between the theoretical part and from those derived from the average of the existing installations found are presented for comparison.

Table 8: General Practical Results & Comparison.

	Pref.	THEORY (kWh)	PRACTICE (kWh)
1	**ATHENS**	**36,62**	**40,52**
2	**THESSALONIKI**	**33,555**	**42,06**
3	**ACHAIA**	**22,19**	**36,47**
4	**HRAKLEIO**	**42,525**	40,53
5	**LARISA**	**45,155**	38,77
6	**AITOLOA/NIA**	**33,48**	32,29
7	**EVOIA**	**31,19**	**37,79**
8	**MAGNISIA**	**31,645**	**41,49**
9	**SERRES**	**19,363**	**42,88**
10	**HLEIA**	**35,37**	**42,02**
11	**DODEKANISA**	**14,225**	-
12	**FTHIOTIDA**	**29,63**	**43,67**
13	**MESSINIA**	**33,77**	**39,03**
14	**IOANNINA**	**30,36**	-
15	**KOZANI**	**22,655**	**36,67**
16	**KORINTHIA**	**31,925**	**39,38**
17	**CHANIA**	**37,935**	**46,98**
18	**EVROS**	**27,125**	**40,84**
19	**PELLA**	**31,365**	**38,56**
20	**KAVALA**	**13,79**	**32,6**
21	**IMATHIA**	**29,6**	**38,15**
22	**TRIKALA**	**35,275**	-
23	**VOIOTIA**	**40,125**	**45,84**
24	**PIERIA**	**41,025**	40,93

25	**KARDITSA**	**30,255**	-
26	**KYKLADES**	**14,83**	**21,27**
27	**KERKYRA**	**32,265**	**32,71**
28	**RODOPI**	**33,63**	**36,55**
29	**LESVOS**	**19,73**	-
30	**ARGOLIDA**	**40,15**	39,06
31	**CHALKIDIKI**	**32,415**	**38,91**
32	**DRAMA**	**44,64**	38,55
33	**ARKADIA**	**42,63**	42,22
34	**XANTHI**	**46,79**	34,7
35	**LAKONIA**	**41,365**	34,27
36	**KILKIS**	**35,61**	**43,26**
37	**RETHIMNO**	**41,275**	**44,04**
38	**ARTA**	**41,04**	-
39	**LASITHI**	**36,96**	**46,8**
40	**PREVEZA**	**38,11**	30,32
41	**FLORINA**	**45,7**	28,78
42	**KASTORIA**	**41,22**	30,11
43	**CHIOS**	**21,74**	**29,26**
44	**FOKIDA**	**28,815**	**43,53**
45	**THESPROTIA**	**24,685**	-
46	**SAMOS**	**21,745**	-
47	**KEFALONIA**	**36,235**	-
48	**ZAKINTHOS**	**28,985**	**40,56**
49	**GREVENA**	**37,965**	-
50	**EVRITANIA**	**31,73**	**37,96**
51	**LEFKADA**	**22,9**	-

In the cells that there is no number, it means that no existing installation was found, and for those prefectures, only theoretical information exists for the energy production. Hopefully for the 40 out of 51, Greek prefectures, at least one installation was found.

With bold letters, appear the installations in which the real number, showing the produced energy is higher than the one expected. But even in cases where this did not happen, the difference is minor.

Finally, by calculating the average of the two measurements, the last table shows in a descending order the 51 Greek prefectures.

It is important to notice that the prefectures colored in orange, are the non-interconnected islands and the maximum installed capacity is 5kWp.

Table 9: Average per prefecture in descending order.

	Pref.	AVERAGE
23	VOIOTIA	42,9825
37	RETHIMNO	42,6575
17	CHANIA	42,4575
33	ARKADIA	42,425
5	LARISA	41,9625
39	LASITHI	41,88
32	DRAMA	41,595
4	HRAKLEIO	41,5275
38	ARTA	41,04
24	PIERIA	40,9775
34	XANTHI	40,745
30	ARGOLIDA	39,605
36	KILKIS	39,435
10	HLEIA	38,695
1	ATHENS	38,57
49	GREVENA	37,965
35	LAKONIA	37,8175
2	THESSALONIKI	37,8075

41	**FLORINA**	37,24
12	**FTHIOTIDA**	36,65
8	**MAGNISIA**	36,5675
13	**MESSINIA**	36,4
47	**KEFALONIA**	36,235
44	**FOKIDA**	36,1725
42	**KASTORIA**	35,665
31	**CHALKIDIKI**	35,6625
16	**KORINTHIA**	35,6525
22	**TRIKALA**	35,275
28	**RODOPI**	35,09
19	**PELLA**	34,9625
50	**EVRITANIA**	34,845
48	**ZAKINTHOS**	34,7725
7	**EVOIA**	34,49
40	**PREVEZA**	34,215
18	**EVROS**	33,9825
21	**IMATHIA**	33,875
6	**AITOLOA/NIA**	32,885
27	**KERKYRA**	32,4875
9	**SERRES**	31,1215
14	**IOANNINA**	30,36
25	**KARDITSA**	30,255
15	**KOZANI**	29,6625
3	**ACHAIA**	29,33
43	**CHIOS**	25,5
45	**THESPROTIA**	24,685
20	**KAVALA**	23,195
51	**LEFKADA**	22,9

46	**SAMOS**	21,745
29	**LESVOS**	19,73
26	**KYKLADES**	18,05
11	**DODEKANISA**	14,225

In conclusion, the average energy production (kWh), per prefecture is between 42,99-22,90 kWh. This average is derived from the 21^{st} of June and December of installations checked with a simulation program and in real-time.

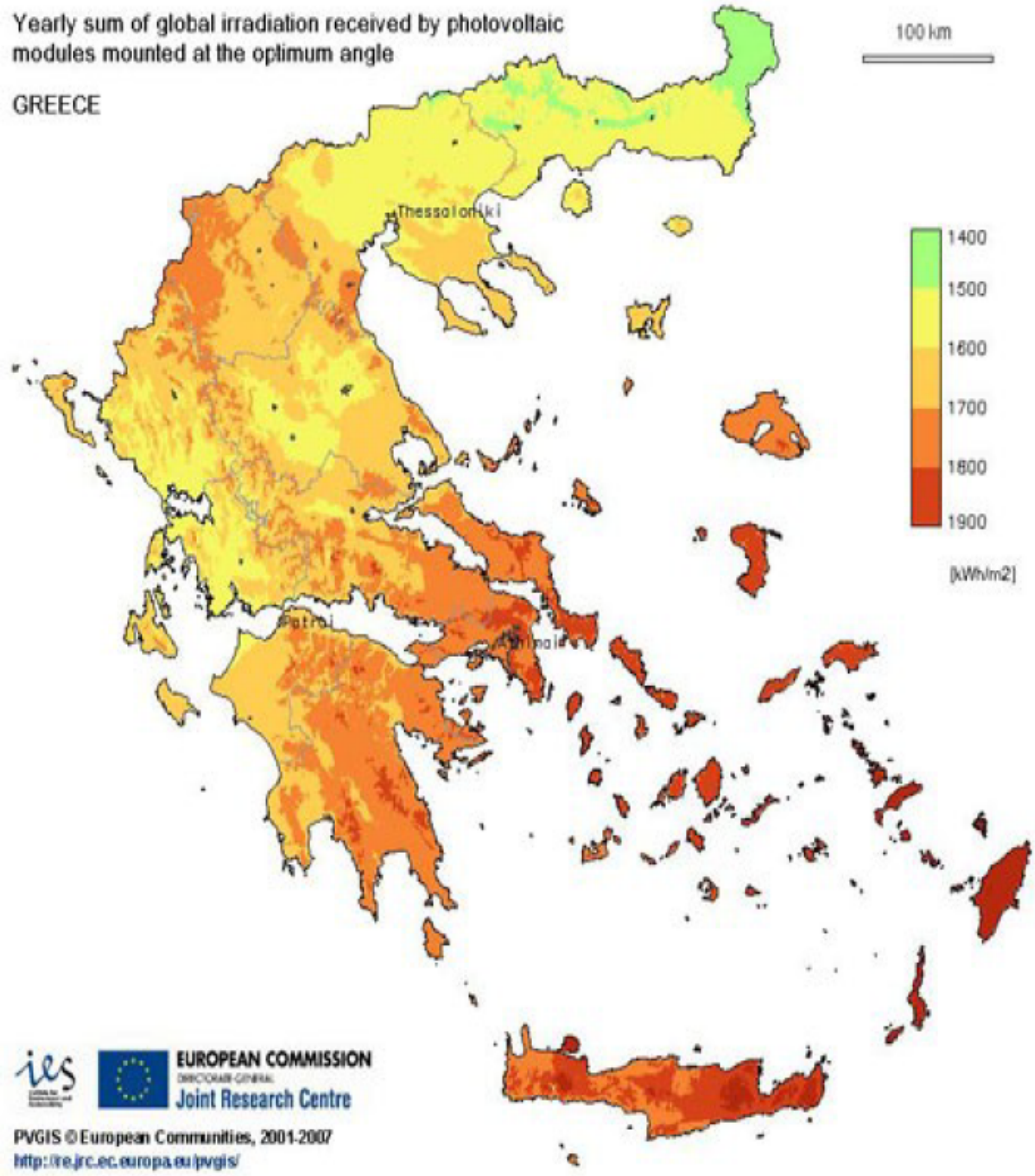
The prefectures of Crete (Rethimno, Chania, Lasithi and Hrakleio) are in the higher positions of the list, although Voiotia is on the top. (for this prefecture, 3 existing installations were checked.)

Athens, the capital of prefecture of Attiki, has an average of 38,57 kWh which is slight higher than Thessaloniki's, 37,80kWh. (those numbers come from the comparison of 4 existing installations at each case.)

Achaia and Evros, on the other hand, are at the last positions of the list. (also 3 existing installations check, respectively.)

For the non-interconnected islands, Samos and Lesvos are on top, but unfortunately their energy production was calculated only during the simulation process, since no existing installation was found to be checked.

In general, the above results look to go together with the map showing the solar potential of Greece, found in the PVGIS website, approved by the European Commission.



Picture 13: Solar potential of Greece.

5 Conclusions

In this study, a statistical analysis of the electricity production from residential photovoltaics, at an hourly level, for the fifty one prefectures of Greece, was performed. A predefined photovoltaic installation, with installed capacity ≤ 10kWp was checked through a simulation program, across the country for the energy production and the electricity (kWh/year) that is injected to the national grid. The next step was to compare the theoretical results to data obtained by existing installations, as more found as possible in a website where owners of such systems, have the ability to watch from distance the energy production and also may allow visitors of the site to see the performance of their installations. Finally, a table showing the fifty one prefectures in a descending order according to their average (between theoretical and practical results) production was presented.

More specifically, some basic terms regarding to the solar radiation were explained through the literature review, the photovoltaic effect showing how photovoltaic panels produce electricity from the radiation also presented, whereas the reader got the opportunity to learn about the different categories of the solar cells and the available applications of the photovoltaic systems. Finally, the basic legislation framework on which the residential photovoltaic systems are applied in Greece was provided and an effort was made check how much electricity could those systems provide to the national grid of the country, at an hourly level.

The general conclusions of this study are:

The Green House Effect is a natural phenomenon. It is of paramount importance and desirable, but what is considered as a severe threat for our planet is the excessive existence of this phenomenon, basically due to gases from human procedures.

The increase of the emissions of the Green-House-Gases (GHG), results to the increase of infrared radiation trapped in the atmosphere of Earth.

Global search for new, alternative energy sources began, with higher target to avoid even at all the finite fossil fuels, like coal and oil, or even better the nuclear power plants, with all the commonly known negative effects that had to humanity.

During the 70's it was when the first ideas about energy saving and sustainable use of energy, also appear for the first time.

The poverty of energy is the new type of poverty that people face during the 21^{st} century. This modern poverty explains the lack of some people to fulfill their energy needs.

Energy plays a crucial role in a country's development and the lack of access to modern energy services can be a serious obstacle.

Greece gained the 4^{th} place in Europe and the 7^{th} globally, regarding to the new installed capacity in 2012. More specifically, 912MW, were added in 2012 and the largest percentage of 19,4% was coming from residential photovoltaic installations on top of roofs of the Greek houses, across all over the country.

The more specific conclusions of this study are:

For the 40 out of 51, Greek prefectures, at least one existing installation was found to be checked and compared to the theoretical results.

For Thessaloniki the real energy production (kWh), of a residential photovoltaic system is more than 20% higher than it was supposed to be from the simulation process.

The average energy production per Greek prefecture is between 42, 99-22, 90 kWh. This average is derived from the 21^{st} of June and December of installations checked with a simulation program and in real-time.

The prefectures of Crete (Rethimno, Chania, Lasithi and Hrakleio) are in the higher positions of the list showing the average energy production, per prefecture in Greece.

Athens, the capital of prefecture of Attiki, has an average energy production slightly higher than Thessaloniki's.

Achaia and Evros, on the other hand, are at the last positions of the list which shows the average energy production, at a prefecture level.

For the non-interconnected islands, Samos and Lesvos have the highest solar potentials.

Recommendations for future research are:

Check if and on how much could the national grid rely on to the electricity provided by residential photovoltaic systems in Greece, to cover the energy needs of the country especially during peak hours.

Check if and on how much could the national grid rely on to the electricity provided by commercial (≥ 10kWp) photovoltaic systems in Greece.

Experimental study: Installation of a Sensorbox, directly onto the modules of a residential photovoltaic system, to measure the solar radiation, the wind speed and the ambient temperature. Then, combined with a WebBox and through Sunny Portal, it will be able to provide continuous target-actual comparison of the system's performance. This would make it possible to detect shading, dirt and a gradually declining array performance, thus maximizing the yield's security.

This installation would give the possibility to compare detailed data on production, correlation between weather conditions and production and comparison with hourly results of the PVSyst model.

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Appendix