Department of Mechanical and Aerospace Engineering

Implication of Renewable Energy Systems for Electricity Generation and Water Production on an island. A Case Study: Ano Koufonisi, Greece

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Signed: Georgios C. Papoutsis Date: 22/08/2018

Abstract

This thesis focuses on renewable energy systems for electricity generation and water production on the Greek island Ano Koufonisi. Initially there is conducted a literature review on the energy situation in Greece and the development of renewables. Then, the study is narrowed to the energy situation on Greek islands, focusing in the area of Aegean Sea. There is included a description of connected and non-connected islands electrical power systems and are recorded the most significant problems of these configurations. The study proceeds to the identification of the most commonly used renewable energy resources on the area and are presented some already commissioned successful projects.

Moreover, there follows a description of the water problem in the islands of the area and are presented the most popular technologies used for desalination, including the Reverse-Osmosis that is being currently used in Ano Koufonisi.

Using the findings of the literature review and data available either by statistics or similar studies, there are constructed the electrical load and the desalination unit energy demand profiles for the island. These profiles are used as inputs in Homer Pro software, that is used for the simulations on this dissertation. There are examined four possible renewable adoption rates: 25, 50, 75 and 100%. The different combinations that are feasible for each rate, are compared to define which one presents the lowest net present cost, the lowest levelized cost of electricity, the lowest water cost, the highest grid sales, the lowest grid imports, the lowest excess electricity and finally the lowest capital cost. Lastly, there is conducted a sensitivity analysis for an eventual increase in load demand on island, using the three Independent Power Transmission Operator of Greece scenarios for 2027, for the chosen 100% adoption rate combination. There are examined the alternatives of battery sales to grid being allowed or not and the options of increasing the export capacity or not. The aim of this analysis, is to give results for the proposed system, regarding an eventual future question after the island connection to the mainland and on a possible change of the electricity and water consumption behaviour, which is: “Is still the covering of local demand the top priority or is it the profit?”.

Acknowledgements

First of all, I would like to thank my supervisor Dr. Nick Kelly, for his useful guidance throughout the course of this thesis. His comments, questions and feedback, especially in the initial stages of this project helped me to shape my ideas and methodically work towards its development from the literature review to the final outcome.

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Special thanks go also to my friends both in Glasgow and Greece for their encouragement and support throughout this year.

Lastly, my deepest gratitude goes to my family for their never-ending support. Without their help it would have been impossible to go through all the difficulties, not only this year but generally in my entire life.

Contents

Nomenclature

AC - Alternating Current

APS - Autonomous Petrol Stations

B.C. - Before Christ

BW - Brackish Water

CAES - Compressed Air Energy Storage

CC - Capital Cost

CC_{EN} - Capital Cost of Energy system

CC_{RO} - Capital Cost of Reverse-Osmosis unit

CEO - Chief Executive Officer

CHP - Combined Heat and Power

CI - Connected Islands

COE - Cost of Electricity

CRES - Centre for Renewable Energy Sources

DC - Direct Current

EC - European Commission

ECB - European Central Bank

GI - Grid Imports

GS - Grid Sales

HEDNO - Hellenic Distribution Network Operator

HELAPCO - Hellenic Association of Photovoltaic Companies

IGME - Institute of Geological and Mineral Exploration

IMF - International Monetary Fund

IPTO - Independent Power Transmission Operator

km - kilometres

kV - kilovolts

kW - kilowatt

kWh - kilowatt-hour

MW - Megawatt

MWe - Megawatt of electricity

MWh - Megawatt hour

NCI - Non-Connected Islands

NPC - Net Present Cost

NREL - National Renewable Energy Laboratory

OM - Operation and Maintenance

PPC - Public Power Corporation

PV - Photovoltaics

R - Annuity factor

RAE - Regulatory Authority of Energy

ReF - Renewable Fraction

RES - Renewable Energy Systems

RO - Reverse-Osmosis

STC - Standard Testing Conditions

TEE - Technical Chamber of Greece

VRB - Vanadium Redox Battery

WC - Water Cost

WP - Water Production

WWF - World Wildlife Fund

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1. Introduction

1.1. Problem Definition

Greece is a Mediterranean country located in south-eastern Europe with a population of 10.7 million approximately. Renewables have started being adopted in the country over the last 20 years (AP, 2017), as there has been an effort to harmonise with the European instructions for the goals of 2020 and 2030 (CNN Greece, 2018).

One of the unique characteristics of the country is its large number of islands. Out of the 6000 islands of the country only 227 are inhibited (Kaldellis, et al., 2012). Most of the islands are not connected to the grid of the mainland and have their own power systems that are powered by autonomous petrol stations (APS). The operation of these stations comes with large amounts of emissions and expenses for the consumers, that pay almost double than these of the mainland (CRES, 2014).

Another significant problem on Greek islands is water. Water for many years has been transported from mainland using tankers. Rainwater is also collected from roofs, when the rare rainfalls occur (Alexakis, 2003). On both cases, water is of low quality and not suitable for drinking. This leads to bottled water overconsumption, which often creates plastic bottle waste issues.

Over the last few years and given the fact that mainland’s connection with the islands is under gradual construction (Liaggou, 2018), many studies have been conducted regarding the adoption or renewable energy systems (RES) on islands (Iliopoulou, et al., 2018). Studies also include systems that provide water using desalination technologies, such as the Reverse Osmosis technique (Kartalidis, et al., 2011).

On this thesis, there are investigated RES implications that address to electricity and water issues on small islands, using as case study the island of Ano Koufonisi. Ano

Koufonisi (or simply referred as Koufonisi) is a small island of 412 residents, located on central Aegean Sea. Koufonisi is connected with the larger nearby island of Naxos with a subsea cable, which provides power to the island. On island there is installed also, an operational RO desalination unit of 600 m^3/day capacity, which will be expanded by the end of 2018 to reach 700 m^3/day (Southern Aegean Municipality Administration, 2014).

To estimate the electricity demand profile of the island, there are used data from islands with the same characteristics of the same area, with the same climate, same building characteristics and similar professional occupation of their residents. This is being done to ensure that electricity consumers have the same behaviour and that load follows the same pattern on daily, monthly and seasonal basis (NEMA, 2014).

The estimation of water consumption and consequently the energy required for the RO desalination unit, is being done through the processing of statistics regarding human population and its seasonal fluctuation due to tourism, animal population and crops cultivated on the island. The study also takes into account the increment of water consumption of the summer period and an additional safety factor that allows to safely estimate consumption, avoiding possible underestimations.

After the definition of electric loads, there are studied combinations that include photovoltaics (PV), wind turbines and batteries in order to achieve 25, 50, 75 and 100% renewables adoption. The tool used for this purpose is Homer Pro. Results are examined according to specific indexes and the main criterion is to achieve better performance than the initial system. Then, all these combinations that achieve such performance for each adoption rate are compared to define which performs the best. Batteries are used to achieve greater on-site energy use. On the initial scenarios energy sales from battery to the grid are prohibited because priority is the local use of generated energy.

On all occasions, there is taken into account, the confinement of energy export that applies to renewable generation plants in Greece. This confinement dictates that from a renewable energy generation plant that is privately owned and meant to serve loads locally, only 20% of the rated installed capacity can be exported to the grid (Hellenic Government Gazette, 2010).

Finally, a sensitivity analysis is being conducted. This analysis examines the alterations of the indexes for the best 100% combination, assuming that the island will be connected to the mainland grid and the water consumption will increase after 10 years. Due to lack of data, there are examined the events of either maintaining the same export confinement, despite the increase in connection capacity, or doubling it assuming that now the confinement is applied per connection and not in total on the plant. On this case there are investigated also the events of prohibiting and allowing grid sales from batteries.

1.2. Aim and Objectives

1.2.1. Aim

To investigate renewable implications for electricity generation and water production on a small island located in the Aegean Sea in Greece, for different adoption rates.

1.2.2. Objectives

1. To estimate the electric load profile of the islands based on data from recent studies.
2. To estimate the water consumption and the energy required for the operation of the RO desalination unit.

3. To identify renewable energy sources available on the island and choose the most efficient ones to study further.

4. Based on the calculated electricity demand profiles and the investigation on renewables, to investigate the installation of renewable energy systems and storage systems in order to minimise the power drawn from grid for 25, 50, 75 and 100% adoption rates. Systems will be examined according to defined indexes.

5. To conduct a Sensitivity Analysis to examine system performance on eventual changes in the future, based on educated estimations from available bibliography.

1.3. Methodology-Structure

The methodology followed was organised to follow the chapter numbering. Thus, all the chapter were organised accordingly in order to follow the investigation process.

In Chapter 2, it is initially presented the current situation regarding the energy mix used in Greece and some basic features regarding incentives related to renewables and the implications over the last few years. Then, the description focuses on the Greek islands and the energy situation on them. Emphasis is given on the electric power system description and especially their problems, as well as to successful renewables projects that are already operating on some islands.

In Chapter 3, there are presented the possible energy resources that could or are being used on Greek islands for renewable energy generation. In the end of this chapter there is a comparison of different storage systems and there is defined which would better fit on an island.

In Chapter 4, is analysed the water problem on Greek islands and are presented the most popular desalination methods. On the final section of this chapter is analysed the reverse-osmosis process, its fundamental principles of operation and the main components of such a unit.

In Chapter 5, is presented the case study used. Specifically, it is described the process followed to define load and water consumption. Then, are displayed the calculations used for energy demand of the RO unit and for the cost of water, as derived from the relative bibliography. Finally, there are recorded the key model characteristics and parameters as well as the different scenarios that are examined.

In Chapter 6, are presented the results from simulations and they are being discussed. The same chapter also includes a sensitivity analysis for the combination of 100% adoption rate scenario.

In Chapter 7 there are included the final conclusions along with key project limitations and some proposals for future work based on this dissertation.

2. The Energy Situation in Greece and Greek Islands

2.1. The Energy Situation in Greece

2.1.1. Conventional Energy Sources in Greece and the Development of Renewable Energy Systems

Since the early 70's the primary source of electricity for Greece was coal and specifically lignite that is in abundancy in some specific areas of the North (Energiewende Team, 2016). As a secondary source, there were and still are used large hydroelectric power plants that incorporate large dams with artificial lakes that provide flood control and adequacy of water for some specific areas of the country. All these power plants and the power transmission and distribution network are owned by the Public Power Company of Greece S.A. (PPC), that suppliers around 56% of the electricity customers nationwide. The rest of the customers are supplied by private companies that run their own power plants (mainly fuelled by gas). These companies use the transmission and distribution networks, owned by the statutory company PPC (Hellenic Scientific Wind Energy Association, 2017). Currently, PPC is on privatisation phase, as the power plants it owns along with the networks are to be sold to private companies on bidding contests, with the state retaining a regulatory role. (CNN Greece, 2018)

The massive adoption of renewables begun in the country at 2006, with the installation of PV either in form of solar farms or in form of domestic roof installations or in rural area applications. This rapid adoption was continued up until 2012, when the Independent Power Transmission Operator (IPTO) introduced taxes to halt the rapid growth, due to inadequacy of capital to pay the high feed in tariffs. According to statistical data from EurObserv’ER, in 2006 the total installed PV capacity in Greece was 7MWpeak (EurObserv'ER, 2007) and at 2012 it had reached 1543MWpeak (EurObserv'ER, Photovoltaic Energy Barometer 2010-2018, 2018). Despite the deep recession that the country has entered since 2008 and the decrease of up to 30% of the sellback price, the increase kept its upward trend with significantly smaller ratio though, reaching the 2623 MWpeak at 2017 (HELAPCO, 2017) as seen at Figure 1.

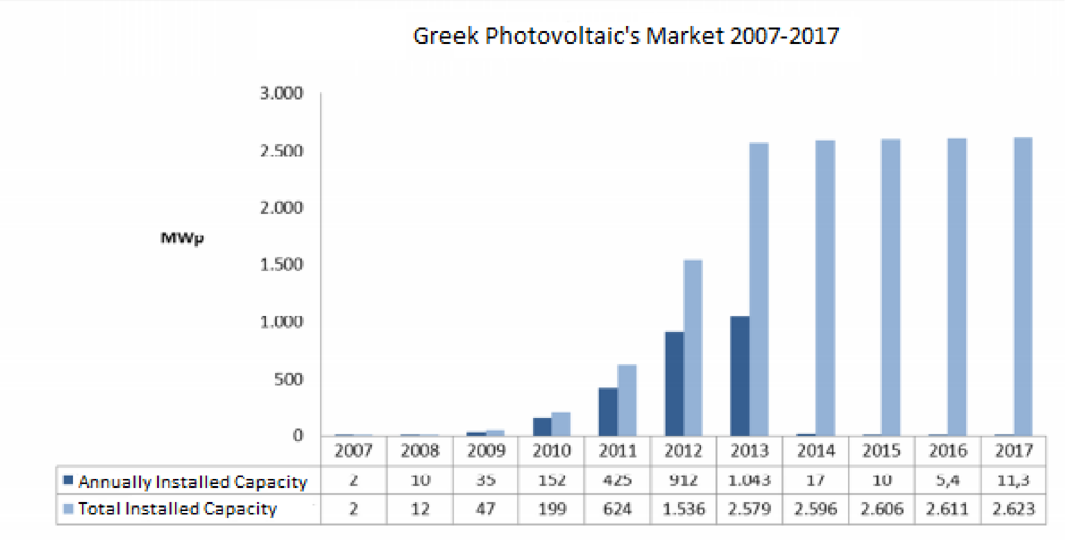


Figure 1: Photovoltaics share in Greek Energy Market 2007-2017 (HELAPCO, 2017).

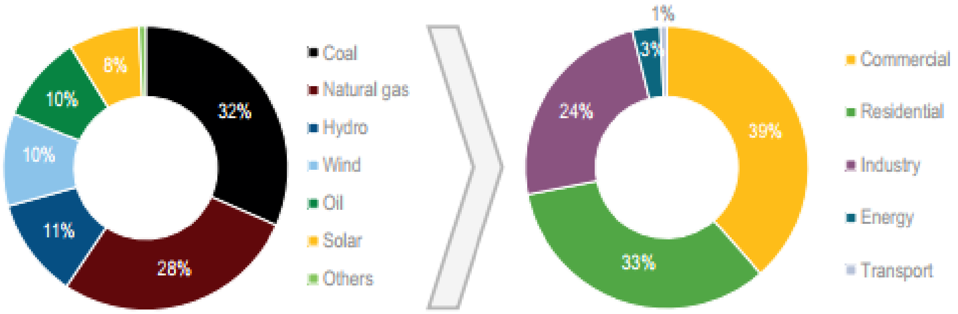
Another relatively new, but widely popular energy resource in Greece is wind. The first wind turbines were installed in the country in 1998, with an accumulative rated capacity of 39MW (EWEA Staff, 2010). At the end of 2017, according to the European Wind

Energy Association data, this capacity reached 2651 MW (EWEA Staff, 2017), recording an increase of capacity that is around 69 times hhigher than the one installed originally, 20 years before. Moreover, the Ministry of Energy and Climate Change, aims to foster even more the adoption of renewable energy and especially wind, through the introduction of the feed-in-premium scheme. The feed-in-premium scheme, basically gives automatically the license to privately-owned companies to freely built wind farms up to 6 MW and other renewable energy installations under 1 MW (PV excluded) without going for a public bidding contest among companies, as happened the years before (Hellenic Constitution, 2016). As mentioned before, the PV are excluded from this support mechanism due to an effort to stop their growth, due to overcapacity, by making them economically non-viable for future investors.

This widespread development, supported by incentives of the State, is justified by the commitments of the country to the European Union's 20-20-20 targets. For Greece, this target, in terms of generation from renewable energy was readjusted to 18%. Still, according to Eurostat's survey findings, in 2016 the renewable energy fraction of the total amount of energy produced, reached 14.1%. The most ambitious predictions for 2017-2018 projection, do not exceed 15.2% (Energypress Team, 2018). Many analysts believe that the 18% goal till 2020 is totally unachievable, due to the austerity that the country is succumbed to and the limited money flow from possible investors (Christodoulakis, N., 2017). It is also noted that major legal reformations that are still pending might be responsible for this delay (Hellenic Wind Energy Scientific Association, 2018).

2.1.2. An Aspect of Energy Consumption in Greece over the years-Lignite Decommissioning Delay

As mentioned in the previous section, Greece underwent a transition to renewables that begun nearly 10 years ago and is still progress. According to the findings of the latest International Energy Agency for Greece, which can be seen in Figure 2, coal (lignite) is responsible for the 32% of the electricity produced annually, followed by 28% of gas and 10% of oil generation.



Note: Supply data are 2016 estimates, consumption data are for 2015.

Figure 2: Electricity Generation by source and Energy Consumption by sector (International Energy Association, 2017)

Despite the governmental efforts to harmonise with the EU directive, decommission of lignite follows a slow pace. According to financial and political analysts (Artelaris, 2017) three are the primary causes behind this procrastination. The first one is the agendas within the public PPC that are being served by some local politicians and labour unions that do not want at any case to lose their power along with other privileges that their current position provides. Being in charge of the units that are responsible for serving of the base load has put some individuals to a special state in terms of rights, increased income, improved insurance and influence over politics through strikes both in coal mines and generation units. The fear of strikes resulting to blackouts has prevented many politicians to openly oppose to these unions and consequently try to decommission lignite. The problem was worsened even, because all this happens with the open support of a large part of the local societies, where these power plants are the main employer (Teloglou, 2016).

The second and probably the most important reason, is the financial crisis that the country is undergoing since 2008. This crisis has put the country in a huge recession that escalated to the point that at 2010 the Greek Government asked for support from the International Monetary Fund (IMF), the European Commission (EC) and the European Central Bank (ECB) often referred as “Troika”. According to IEA (International Energy Association, 2017), this factor widely influenced the energy consumption, as seen on Figure 3, as well as the entire electricity market limiting not only to Greece but on a worldwide scale.

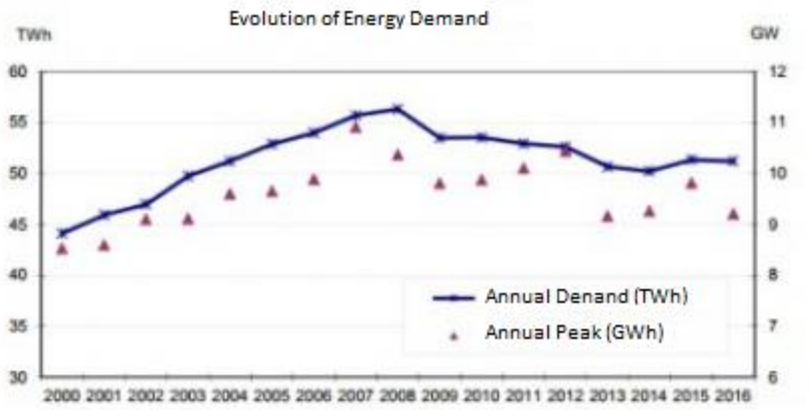


Figure 3: Evolution of Energy Demand in Greece 2000-2016 (EuroStat, 2016)

From 2000 to 2008 there was a steadily increasing rate in energy demand at a 22% rate approximately, recording the historical peak of 370,257 TWh. After 2008, this rate started having a reduction that was paused at 2015, when demand numbers reached these of 2005. After this point, there was a slightly increasing course that by many is related to the seemingly recovering course that the country’s economy started to appear (Andriosopoulos, et al., 2017).

The third reason is in close relation to the second one and it is the lack of money from investors that would contribute to the increase of the renewable palnts capacity and the simultaneously gradient decommissioning of coal (Dagoumas & Kitsios, 2014). The lack of investments private or statutory was also a product of the inability of the State that owned the energy monopoly, to provide attractive feed-in-tariffs that would also attract capitals from abroad. Although, on this area there has been some progress with incentives like the aforementioned feed-in-premium, or the fast-tracking of some major projects that eliminated bureaucracy and financial barges. The lack of stability in the energy policy of the country was also an issue that prevented many from proceeding to large investments, according to (Kalaitzoglou, 2016).

2.2. The Energy Situation in Greek Islands

2.2.1. Description of the Electrical Power Systems of Greek Islands

Greece is the country with the most extensive coastline in the Mediterranean, with a coastline that reaches almost 15,000 km of coastline. Its coastline is distributed to both its mainland and its islands that reach 6000 in number, as seen in Figure 4. These islands are either secluded or form island complexes and are located in the Ionian and the Aegean Sea, with the vast majority being located in the latest. Out of 6000, only 227 of these islands are inhibited with 78 of them having population greater than 100 inhabitants. The climate of the wider area in Greece, is characterised by two distinct periods of summer and winter with autumn and spring lasting not many time and being substantially transition periods (Kaldellis, et al., 2012). The main activities of Greek islanders include fishing, livestock farming, agriculture and tourism. On some of the bigger islands, operate few small industries that mainly are olive mills and are used seasonally to produce olive oil.

Figure 4: Map of Greece showing the mainland municipalities and major island complexes.

In terms of their connections to the grid of mainland, Greek islands are divided in two categories, the Connected (CI) and the Non-Connected Islands (NCI). Islands of the Ionian Sea are connected to the mainland-grid due to their close distance from mainland and in-between them. For the islands of the Aegean Sea the situation is different. According to the Greek Regulatory Authority of Energy (Greek Regulatory Energy Authority, 2018), there are 32 autonomous electrical power systems on Non-Connected islands. These break down to:

- 2 “large” autonomous systems with peak demand exceeding 100 MW that belong to Crete and Rhodes.

- 11 “medium” sized autonomous systems with peak demands ranging from 10MW to 100MW.

- 19 “small” autonomous systems with peak demands up to 10MW.

2.2.2. Energy Problems in Greek Islands

The primary source of problems in the Greek islands was the initial planning and development of the transmission network of the country, when it was first developed. At this time, subsea cable technology was in an early stage and economically impossible to apply at such large number of cases. Thus, the islands were supplied with generators either heavy petrol or diesel fired. Large island systems have their own generators, which are organised in Autonomous Power Stations (APS) to serve their increased load (Figure 5), whereas smaller islands are either electrified by small capacity subsea connections from the bigger islands or by smaller generators that are transferred occasionally from one island to the other (Kaldellis, et al., 2012), to cover needs wherever it is necessay. This measure is adequate to cover the low demand of winter but has a lot of problems during summer months.

Figure 5: Autonomous Generation Unit (ASP) of Mykonos Island

Official data of the Hellenic Statistic Authority for 2017 (Hellenic Statistic Authority, 2017) speak about 30 million tourists, which is 3 times the population of the country.

The main attraction are the Greek islands, which host a large amount of these tourists. This seasonal overpopulation has a significant impact on the electric load of islands at such point, that on some cases it becomes 10 times higher than this of winter (Michalakakou, et al., 2002). Another reason for the huge increase of peak loads and energy consumption generally at summer in Mediterranean countries is the use of cooling, mostly air-conditioning that requires large amounts of energy (Moumouris & Potolias, 2013).

Due to this seasonal demand increase, the small generators and limited capacity subsea connections result to frequent blackouts. Two other aspects that make the present solution unsustainable are the financial and operational impacts of fossil fuels use. Summer power bills for island inhabitants are rather high and some cases even double as these of the mainland grid customers. These costs are related to the high price of oil used, transport costs of oil with tankers and the operation and maintenance costs of generation units (Tzanes, et al., 2017). The second aspect of the problem also, includes pollution and environmental impacts that the operation of these units has on the islands. Many of the residents are opposed to their operation, due to their heavy impact on landscape and put a lot of pressure on the government to give a solution to this problem as soon as possibe (Iliopoulou, et al., 2018).

2.2.3. Connection of Islands to the Electric Grid of Mainland

As mentioned earlier, Greek Islands are separated in two categories CIs and NCIs. The vast majority of the Aegean Islands are NCIs while the Ionian Sea islands are CIs. The connection of NCIs to the grid of mainland, is something that engineers of IPTO have envisaged since 1970. Though, due to technical confinements and huge initial capital costs, the project has fallen to oblivion for many years.

Aegean Sea has three major island complexes: Sporades, Cyclades and Dodecanese Islands as seen in Figure 6.

Figure 6: Map of Greece depicting its major island complexes

At 1990, the first connection project started, and its design was completed by 1995. Project was taken over by a joint scheme of Pirelli-Alcatel contractors and it included the connection of Evia-Andros-Syros-Tinos-Mykonos. The project was redesigned and after alterations, it finally was set to use in March 2018. According to the information on the website of the IPTO (Independetnt Power Transmission Operator, 2017) the connection of Cyclades complex will follow three phases:

A. The connection of Syros Island with Lavrion (mainland) as well as with the islands of Paros, Mykonos and Tinos (Figure 7). (COMPLETED)

B. The connection of Paros island with Naxos island and the connection of Naxos island with Mykonos island.

C. The second interconnection between Lavrion (mainland) and Syros island.

D. (Proposed but still under investigation) will include connections of: Paros-Santorini-Folegandros-Milos-Sifnos-Syros, Naxos-Donousa, Naxos-Schinousa -Amorgos-Koufonisi, Schinousa - Irakleia, Paros – Ios - Sikinos-Folegandros, Sifnos – Serifos - Kythnos, Lavrion (mainland)-Kea, Santorini-Anafi-Astypalaia.

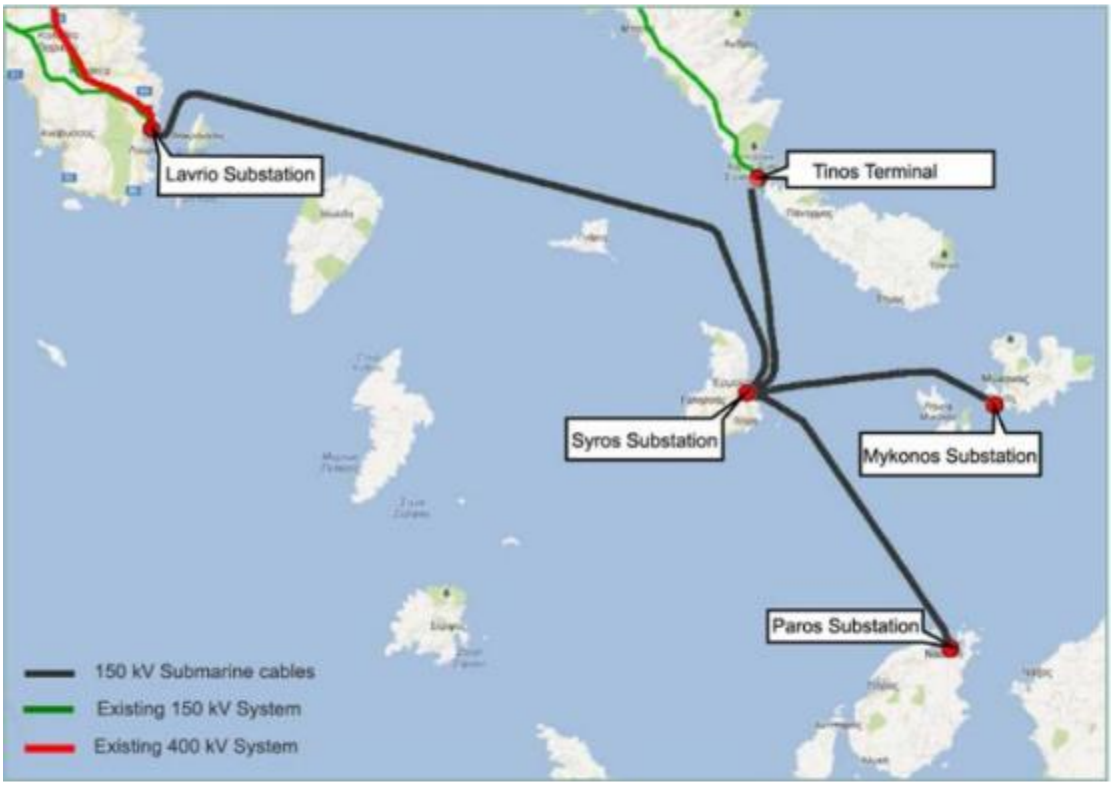


Figure 7: Phase A of Cyclades Islands connection to the grid of Greek mainland

The plan is that the Cyclades islands will be on a mesh grid with strong connection between the islands and will be electrified with more economically affordable electricity, from the mainland grid. Phases B and C are already under construction and are planned to be fully operational by 2019 and 2020 respectively (Figure 8). Phase D is under investigation and may be broken down to two or three other phases.

Figure 8: Construction works from Phases A, B, C, D of Cyclades islands connection to mainland's grid

According to IPTO, the project is designed for a 30-40 years horizon and it is estimated that it will save approximately 80 million € annually and over 2.7 billion € over the course of 20 years. The budget till 2020 is 273,573,044.17 €, and it is considered an investment worth making, because it will not only secure the power supply on islands, but it will also unlock the potential of exploitation of their vast renewable energy sources capacity and improve major environmental issues arising from burning petrol. The project is of such priority that the Ministerial Decision No. FA/E 3.2/57/3, dated 3.1.2011, specifically names it as a project of "general importance for the economy of the country". (Independetnt Power Transmission Operator, 2017)

The connection of islands though is not limited to Cyclades. Plans include the connection of Dodecanese complex, the islands of eastern Aegean and Crete. For Dodecanese the plans include two possible scenarios. Either the connection of Kos-Lavrion (mainland) and then Kos with Kalymnos and Rhodes, or the connection via

Crete. For the islands of eastern Aegean there are also two alternative plans. Either the connection of Aliveri-Skyros-Mytilene, Mytilene-Chios-Samos, Mytilene-Limnos-Ayios Eystratios or Aliveri-Mytilene and Aliveri-Skyros separately.

For Crete, planning includes a double connection to the mainland, one with a 150kV AC cable and one with a 400 kV DC cable, as seen on Figure 9.

The first reason is because Crete is the biggest in size and population Greek island, having over 600,000 residents. Crete along with Rhodes (the biggest of Dodecanese), have their own power networks that are mostly based on fossil fuels and are of 813.02MW and 233MW accordingly. The two islands are in a close distance and some plans examine their connection as well. Also, according to the islands Hellenic Electricity Distribution Network Operator (HEDNO) (Hellenic Distribution Electricity Network Operator, 2018), these islands are the biggest oil consumers and besides their loads they also cover partially the load of smaller neighbouring islands. The amount of load of neighbouring islands, they can cover is also limited by the capacity of the connections between them. Thus, through a large capacity connection of Crete to the mainland, there could be examined the connection of Dodecanese to the mainland through Crete. This, along with the other connections of the islands will increase network stability, security and reliability as they will be operating on a mesh grid topology (Aolaritei, et al., 2017).

The second reason is the long-term and ambitious plans that, according to some analysts (Rabinovich & Kambas, 2018), (AP, 2017), the Greek Government has to be a key player in the East-Med Energy Hub. The East-Med Energy Hub comprises of the electrical networks and gas networks connection of Greece, Cyprus and Israel. Greece will be the link of Israeli gas to the European market and it will completely override Turkey, as the relationships between these two countries are hostile. For years, this connection had been impossible due to Greece not having a strong electrical connection of its most south border, which is Crete, with the mainland's grid but now that problem seems to be history.

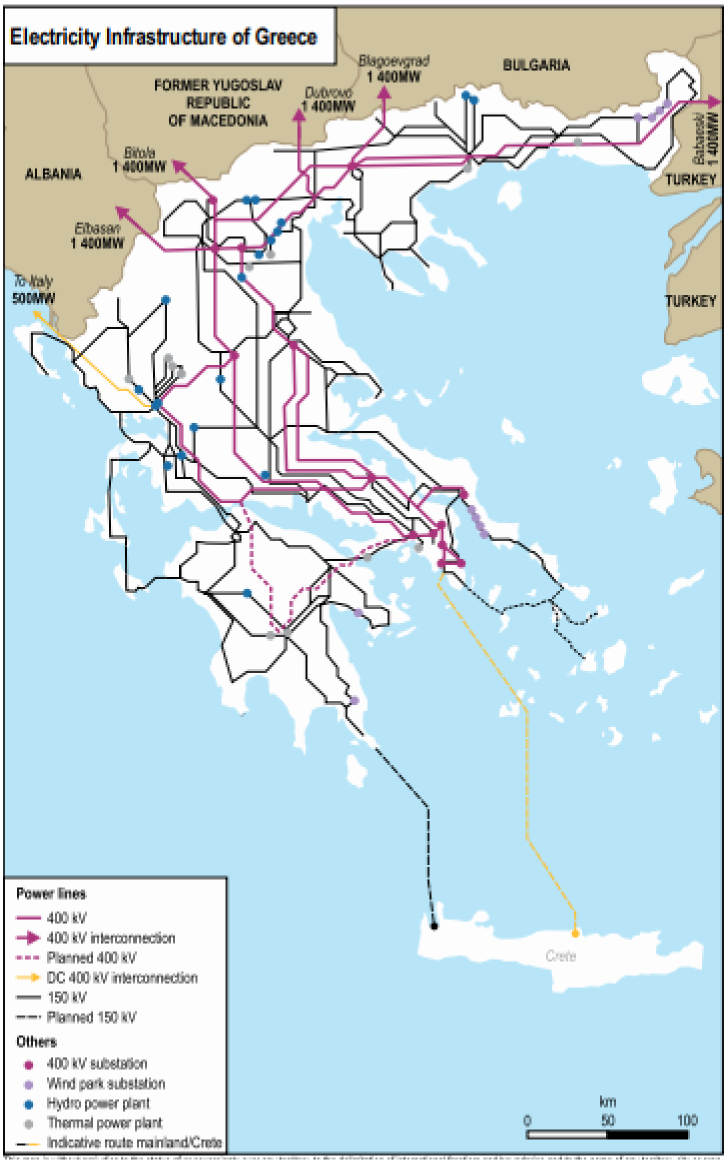


Figure 9: Map of operational and planned transition power network of Greece

In June 2017, Prime Ministers of the three countries Alexis Tsipras, Nicos Anastasiades and Benjamin Netanyahu met in Thessaloniki Greece and agreed to the connection of the three countries with 1,500 km of subsea cables capable of receiving and transmitting 2,000 MW and 2,200 km of subsea gas pipelines. The electrical connection is expected to be fully operational by 2022 and the estimated cost is 3.5 billion €. For the gas pipeline, no further information was revealed (Tsipras, et al., 2017).

2.2.4. Renewable Energy Projects on Greek Islands and Incentives

Greek islands, especially on the Aegean Sea, were for many years a consumer of electricity that was mainly produced locally by APS. Being cut off from the mainland’s grid, limited their energy potential and held them steadily in the background of the energy-related planning of the country. With the new plans for their interconnection and connection to the mainland they could, in the near future, play a key role in energy generation and aid the country to achieve its environmental goals for 2030. Achieving at the same time, the decommissioning of APS that are responsible for a huge part of emissions and by using locally produced renewable energy, the surplus of which could be fed to the mainland would significantly assist the final goal. Towards this target there is a number of projects that have been investigated and realised the past few years that show very promising results.

The most prominent and recent example of Greek island renewables success story is the island of Tilos. Tilos at 2017 won the European Union Sustainable Energy Award in two categories as the “best sustainable energy island” and as the “citizens’ choice” (European Commission, 2017). The small island of 500 residents, funded by the 2020 Innovation and Networks Executive Agency energy portfolio, installed renewable energy systems (RES) (Figure 10) and achieved its primary goal of covering the 70% of its energy demands from renewable energy sources locally and has set the goal of becoming the first island in the Mediterranean running entirely on renewables by 2020. The main contributors were 13 companies and universities from 7 countries of Europe.

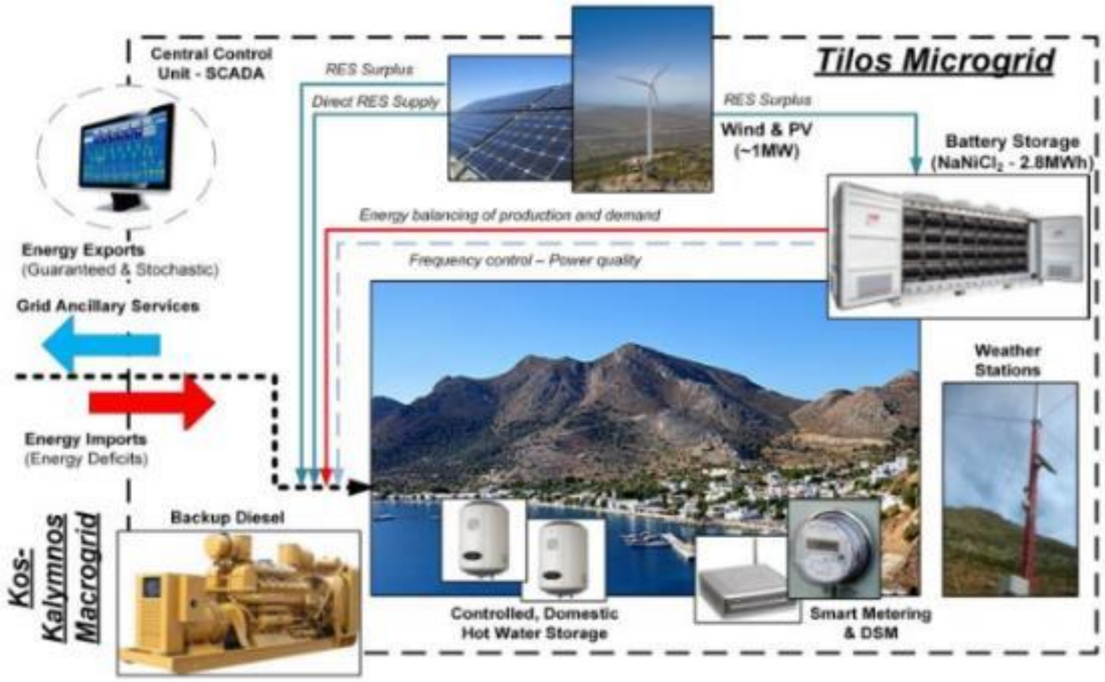


Figure 10: The renewable energy system installed on Tilos Island

Apart from its success, the project has set the example of wide public acceptance of renewables on islands and the cultivation of a positive outlook. For many years, islanders were firmly against renewables due to the impact that such implications would have at landscape, according to a report that Centre for Renewable Energy Resources in Greece released (Centre for Renewable Energy Resources, 2017). After Tilos project and its success, from a more recent survey that was conducted by WWF Greece (WWF Greece, 2018), it was found that the vast majority of public perception has started to change, with 75% of the inhabitants of Aegean islands with similar characteristics to Tilos wanting similar renewable energy projects to be done to their islands as well. The same survey also found that inhabitants of the island of Rhodes, which is the largest island of the complex that Tilos belongs to, are also positive towards renewables with only 8% of them preferring petrol to RES. Moreover, the study shown that 49.3% of the asked would be positive to install roof solar PV with energy storage systems in their residencies.

RES projects were recently embraced also, by both the State and the PPC that openly expressed their support after the wide and positive impact Tilos project has shown. According to the website of the subsidiary company of PPC, that is exclusively occupied with renewables, PPC Renewables S.A., and its CEO Mr. Ilias Monacholias the 85 million € loan that PPC received from the European Investment Bank in 12 June 2018, will exclusively be used on projects related to renewables and smart network upgrades (PPC Renewables S.A., 2017). Greek Minister of Environment and Energy, Giorgos Stathakis at the 15th Peripheral Conference of Aegean Islands, according to the press conference he gave (Giogiakas, 2018), referring to the incentives of the Government he stated that the development of RES and smart grid solutions to the islands is divided into three phases. The first phase began at October 2017, with projects regarding islands of Tilos, Ikaria and Ayios Eystratios, the second including islands of Kastelorizo, Symi and Astypalaia and finally the European incentive for "Energy Islands".

According to (Hellenic Wind Energy Scientific Association, 2018), the funding received should focus more on the reinforcement of wind farms in islands that already have some installed capacity, it should also be focused on solar farms and storage, development oh high enthalpy geothermal power plants on the three islands that cite detected geothermal fields and the modernisation of equipment of installations in areas of high renewable potential that used relatively old and low efficiency energy harvesting equipment. Suggestions do not exclude small-scale hydro, but only for bigger sized islands. The main aim of such actions is the advance to the new era that the islands actively take part in the energy generation using sustainable sources, using their potential so they start converting from consumers to prosumers of energy.

3. Renewable Energy Sources in Greek Islands

At this section, there are described the possible alternative renewable sources that could be used in Greek islands and substitute the APS. The examination of these resources was based on research of the available literature, already commissioned and operational projects and the suggestions of Centre for Renewable Energy Sources (CRES), PPC Renewables S.A. and IPTO that are the main authorities that are relevant to renewable energy projects development in Greece

3.1.1. Solar Energy

The climate of Mediterranean Sea is characterised by long warm summers (25-40 ^{o}C) and brief mild winters (5-15 ^{o}C) with scarce snowfalls and relatively low rainfall (250-2500 mm), depending on the area (Salah & Boxer, 2017). Another characteristic of Greece specifically, is its extended periods of sunshine extending from 2300-2700 hours annually (Matzarakis & Katsoulis, 2005). As seen in Figure 11, this translates to solar global irradiation of 1250-1850 kWh/m^2 annually. Specifically referring to islands, for the Ionian Islands the irradiance ranges between 1450-1550 kWh/m^2 and for the Aegean 1400-1850 kWh/m^2. This makes solar energy a very promising resource for these areas.

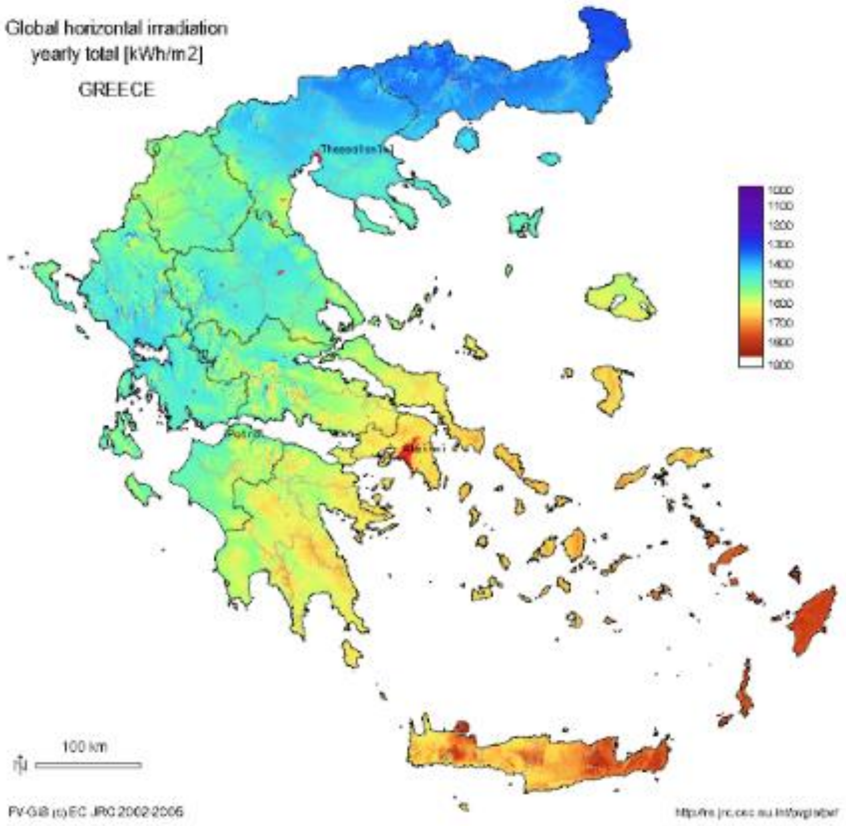


Figure 11: Map of Global Horizontal Irradiance in Greece (Global Energy Network Institute, 2017)

Indeed, as seen from the data provided by the 2016 report of the Hellenic Association of Photovoltaic Companies (HELAPCO), the total installed PV capacity in Greece by 2016 was 2623MWpeak ranging in 5 categories of capacities. The same survey showed that 71.9% of these were installed on ground and the 20.9% on roofs. Another interesting finding was that 93.9% were installed on mainland, leaving the 6.1% being installed in islands (HELAPCO, 2017).

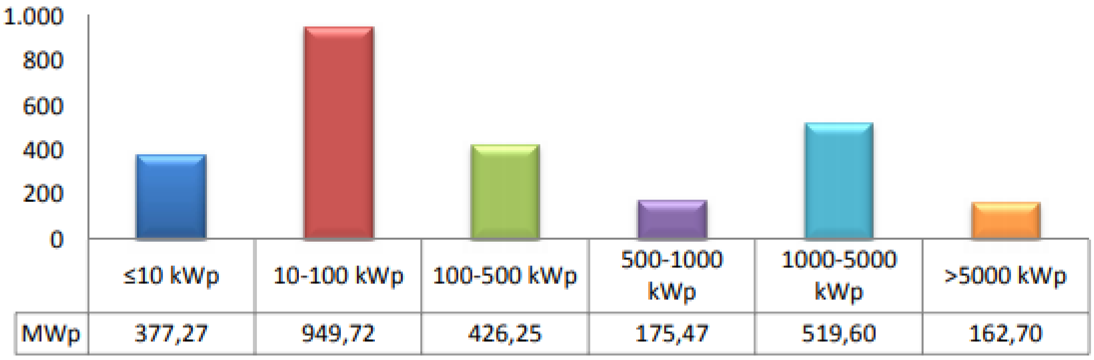


Figure 12: PV installed capacity in Greece until 2016, per category (HELAPCO, 2017)

According to the PV Installation guide that Technical Chamber of Greece (TEE) (Scientific Association of Engineers in Greece) (Damianidis, et al., 2011), the five most significant factors that affect the efficiency of PV panels, besides irradiance and ground reflectance are:

- Ambient Temperature
- Panel Slope
- Panel Azimuth Angle
- Shadowing
- Cell Efficiency

The same guide suggests that ambient temperatures below 25^{o}C, which is the Standard Testing Conditions (STC) temperature, achieve better results in terms of peak produced power than STC temperatures. Whereas, for temperatures above 25^{o}C the efficiency drops due to reduction in voltage produced that follows logarithmic law, as depicted in Figure 13. Thus, when designing temperature is a factor that cannot be neglected

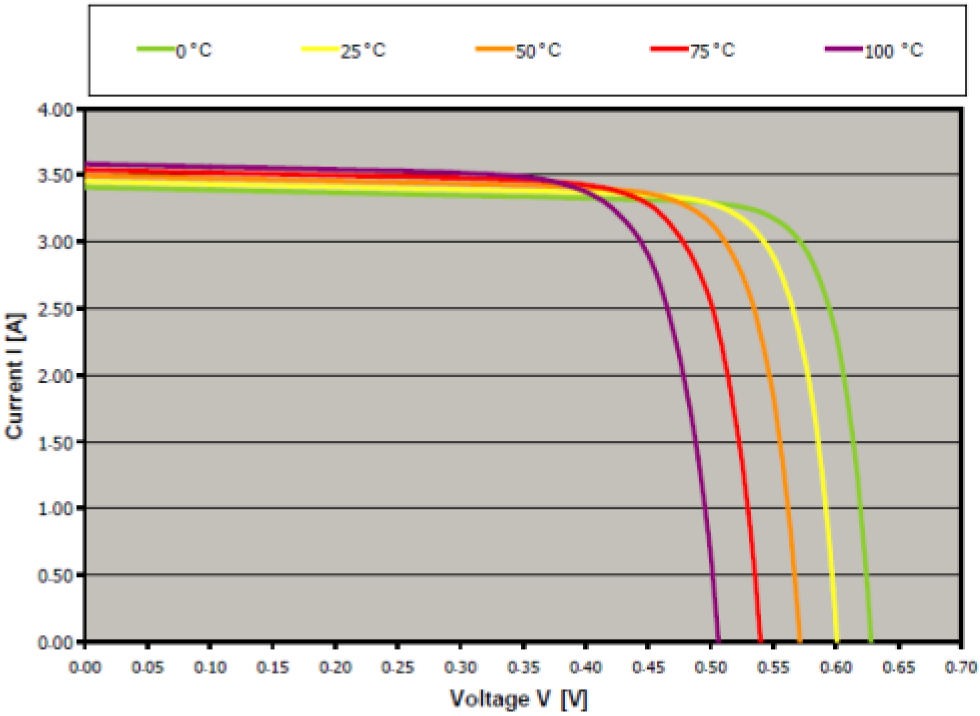


Figure 13: Effect of temperature in PV panels efficiency

As for the slope and azimuth angles, the same guide (Damianidis, et al., 2011) suggests that for the Northern hemisphere the optimum orientation is the southern (i.e. Azimuth angle = 0^o). As for the slope, the authors suggest that for Greece the optimum angle equals the location latitude. Although, there are deviations depending on the area of the PV installation and the month of the year. They suggest that those two factors can have an impact of up to $\pm 10^o$ on the efficiency of panel per month. To have the highest efficiency throughout the year, operator of the plant, should change the angle of panels each month. Otherwise, there can be used a MPPT (Maximum Power Point Tracker) that does this job automatically. Although, this significantly increases the capital cost of installation up to 1.5-2 times depending on material and structure required. Finally, they suggest for non-movable mounting mechanisms angle equal to latitude, as the losses around this value are not significant, as seen in Figure 14. Another reason is that in Greece the summer can be regarded as lasting 8 months and winter 4, due to the fact that autumn and spring are very brief and only transitional between summer and winter periods.

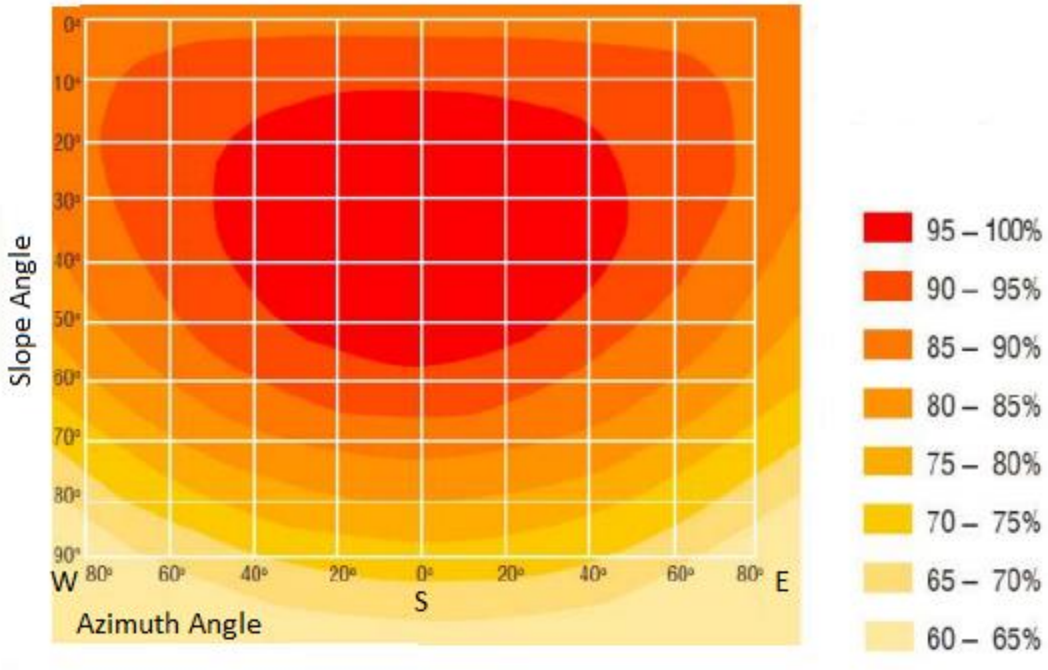


Figure 14: Effect of slope and azimuth angle in photovoltaic panel efficiency (Damianidis, et al., 2011)

Shadowing is a parameter that the designer should also consider as partial shadowing could lead to hot spots on the panel and damage it or lead to reduced efficiency (Swapnil, et al., 2013).

The last factor, which is efficiency is dependent on the material that the panels are made of. Silicon diodes are the most popular for construction of PV panels according to (HELAPCO, 2013). For silicon the three most widely used technologies are thin film, single-crystalline (or monocrystalline) and polycrystalline wafers. Thin film efficiencies range between 4.5-11%, monocrystalline 11-19% and polycrystalline 11-16% (Levi, 2018). Some manufacturers, though like LG, Mitsubishi Electric and SunPower claim to have constructed panels of 22.5% efficiency (Aggarwal, 2018).

Regarding prices for PV panels including equipment and installation according to (HELAPCO, 2017), they range at 3.5-5.5 €/W. This cost may have some fluctuations depending on the case and the specific characteristics of the installation. On some solar farms this cost might be significantly higher due to the required landscape reformations that might be required prior to the panels' installation. The prices that electricity purchased from PV from the electrical company are 0.15 €/kWh from roof mounted PV (Electric Energy Market Operator, 2018), 0.095 €/kWh for PV farms of capacities above 100 kWpeak and 0.1 €/kWh approximately for capacities equal or smaller than 100 kWpeak (Electrical Energy Market Operator, 2018).

3.1.2. Wind Energy

Wind energy is another promising energy resource for Greek Islands that is widely investigated as the already installed wind farms already have shown a possibly great unexploited potential. As seen in Figure 15, western Greece has relatively milder winds as velocities range between 4.5-6.5 m/s. On the other hand wind in eastern Greece range between 6.5-9 m/s. In western Greece the winds are mostly south eastern, while in eastern Greece they are north western as seen on the wind rosettes of Figure 16 (Windfinder, 2018). Aegean Sea, located in eastern Greece is also known for its strong, dry, etesian "Meltemia" winds that blow from mid-May till mid-September. Their direction is north eastern or north western, depending on the local topology. They start blowing from the morning or early midday and they wear out at night. These seasonal phenomena, according to (Vlahakis, 2010) could be exploited to generate free energy.

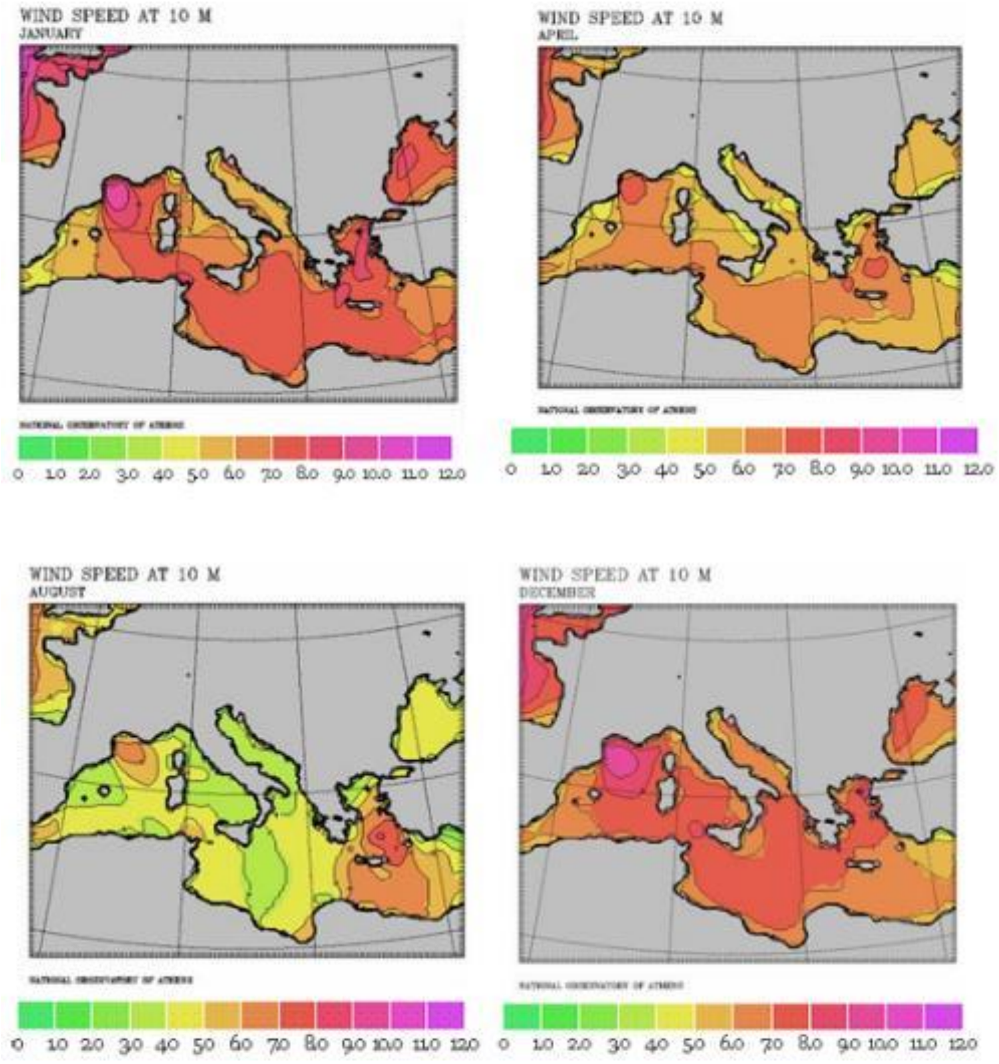


Figure 15: Wind speed in the Mediterranean for January, April, August and December (National Observatory of Athens, 2018).

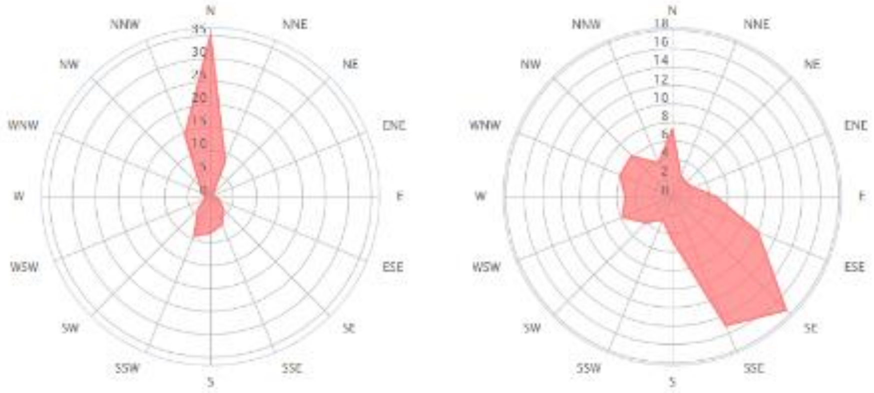


Figure 16: Wind rosettes for eastern Greece (right) and western Greece (left) (Windfinder, 2018)..

The great wind energy potential of Greece, was not left unoticed by investors. According to the most recent statistical data that Hellenic Wind Energy Association (HWEA) released, by September 2017 in Greece the installed wind capacity was 2,491 MW (Hellenic Wind Energy Association, 2017). The same authority, stated that by the end of 2017 the installed capacity would reach 2,651 MW. Wind farms connected to the mainland-grid were of total capacity of 2,329.9 MW, while the remaining 321.7 MW belonged to non-connected systems within the country. As seen by the map in Figure 17, currently there are another 655 wind farms that are planned across Greece, which construction is temporarily halted due to bureaucratic reasons (CRES, 2018).

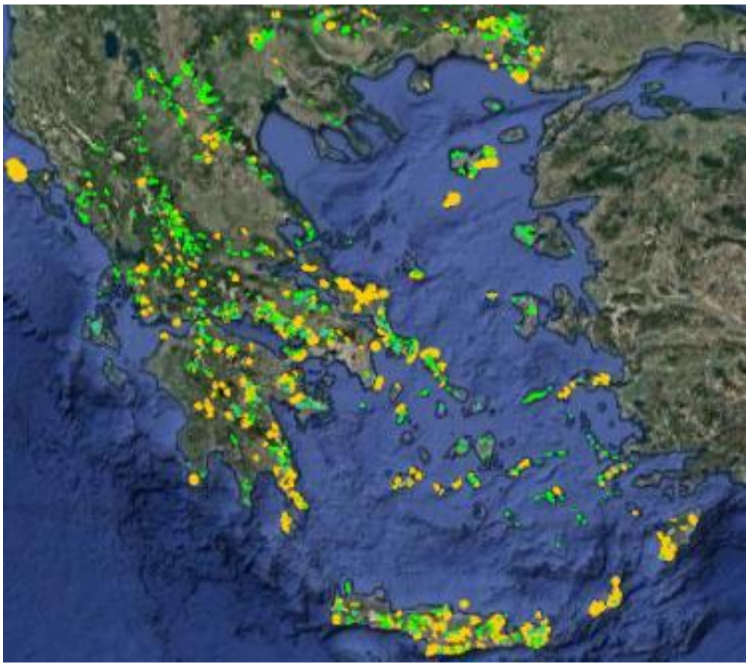


Figure 17: Operational (green, blue) and planned (yellow) wind farms in Greece (CRES, 2018).

Another noticeable feature of the map in Figure 17, is the early stage development of wind farms in the Aegean Sea. For many years, the RES projects were considered a taboo as the local societies did not by any chance negotiate the installation of any form of structures that would alter the form of landscape. This comes naturally, taking into consideration that the basic source of income for these islands is tourism. Thus, their primary concern was that such interventions would destroy the landscape and they would lose a large part of their income. Many also feared the damage that would be caused to local fauna and sea life. Livestock farming and fishing are the second most popular sector on those islands (Hellenic Statistic Authority, 2017), (Greek Regulatory Energy Authority, 2018). These negative opinions were mostly a product of misinformation or some specific agendas run by some individuals, deficiency of an organised national strategical approach towards renewables and low education level of huge part of island population.

Though, as the years passed and after the efforts of the State to inform properly the local communities in most of these islands, this situation was reversed. The main contributors to this shift according to (Hellenic Wind Energy Scientific Association, 2018) were the:

- huge operating cost of ASPs that burdened the island inhabitants bills
- heavy air pollution caused from burning fossil fuels
- local unemployment on some islands
- will to contribute to country’s environmental goals
- investigation of installation of RES in small non-inhibited islets or offshore
- profit possibility by the installation of wind turbines, exploiting the feed-in-tariff.

Regarding prices of electricity for wind, according to the (Electric Energy Market Operator, 2018), there are four tariffs in use currently on the Greek market:

- Onshore farms > 50kW connected to the grid of mainland: 0.08785 €/kW.

- Onshore farms > 50 kW not connected to the grid of mainland: 0.09945 €/kW.
- Onshore farms ≤ 50kW: 0.25 €/kW.
- Offshore farms: 0.18083 €/kW.

Regarding the cost for the construction of wind farms in Greece they mostly variate in the range of 1.2-1.8 €/W. This value includes landscape formation prior to installation of wind turbines, electrical equipment, transfer costs, payments, materials and miscellaneous other costs (Ioannidou & Argyros, 2011).

3.1.3. Small-scale Hydroelectric Power Plants

For the time being, according to data provided by HEDNO latest report for November 2017, currently there are 0.3 MW of hydroelectric power plants installed in NCIs and specifically in Crete (Hellenic Distribution Electricity Network Operator, 2017). This comes pretty natural as Greek islands have a very serious water deficiency problem. The problem is more intense in the area of Aegean, where rainfall heights are among the lowest in the country, as seen by the rainfall map in Figure 18.

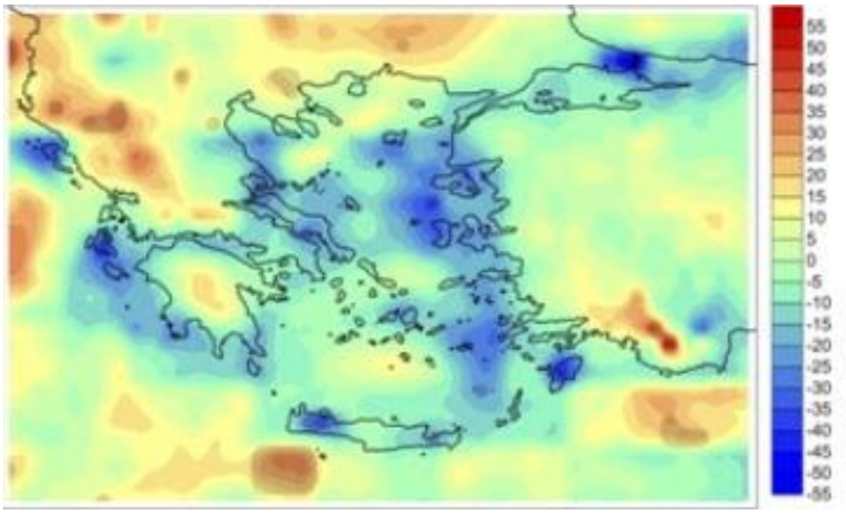


Figure 18: Map of mm of rainfall in Greece (National Observatory of Athens, 2018).

The problem is often intensified more in the summer, when apart from the permanent residents, islands host millions of visitors. Water is often transferred using special water carrier tankers (Kaldellis, et al., 2012). Consequently, discussing about hydroelectric power plants even in small scale on Greek islands is futile. Besides that, a hydroelectric power plant would need a head of specific height to operate, which does not exist on many of the small islands. Significant landscape interventions are also needed, but this is something that would arise conflict with the local societies that want to maintain its picturesquiosity (Bertsiou, et al., 2017).

3.1.4. Geothermal Energy

Greece is an earthquake-active country with paused, former volcanic activity. Its volcano was located in Santorini Island in southern Cyclades island complex. As depicted on the map in Figure 19, geothermal areas are located in regions of Quaternary or Miocene volcanism and in continental basins of high-heat flow. Depending on temperatures they are separated in 3 categories: temperatures > 200^{o}C (high), 100 ^{o}C≤ temperatures ≥ 200 ^{o}C (medium) and temperatures > 100 ^{o}C (low) (Mendrinos, et al., 2010). The basins with highest enthalpies are located in Milos, Nisyros and Santorini islands that consist a volcanic arc. Medium energy enthalpies can be found in the Lesvos-Chios-Samothraki complex. The rest of geothermal areas have low temperatures that range between 85-45 ^{o}C (Koutroupis, 1993).

The existence of geothermal energy initially investigated by the Institute of Geological and Mineral Excavation (IGME) in 1970, by the construction of geothermal maps (IGME, 1983) that included the aforementioned islands.

At 1987, there was commissioned a 2 MWe power plant using high energy enthalpy on Milos island (Papamanolis, 2015), that was shut down a year later. The closing of the facility came after the complaints of local society against excess steam venting to the atmosphere, Silica in the steam, H_2S odour and loud noise.

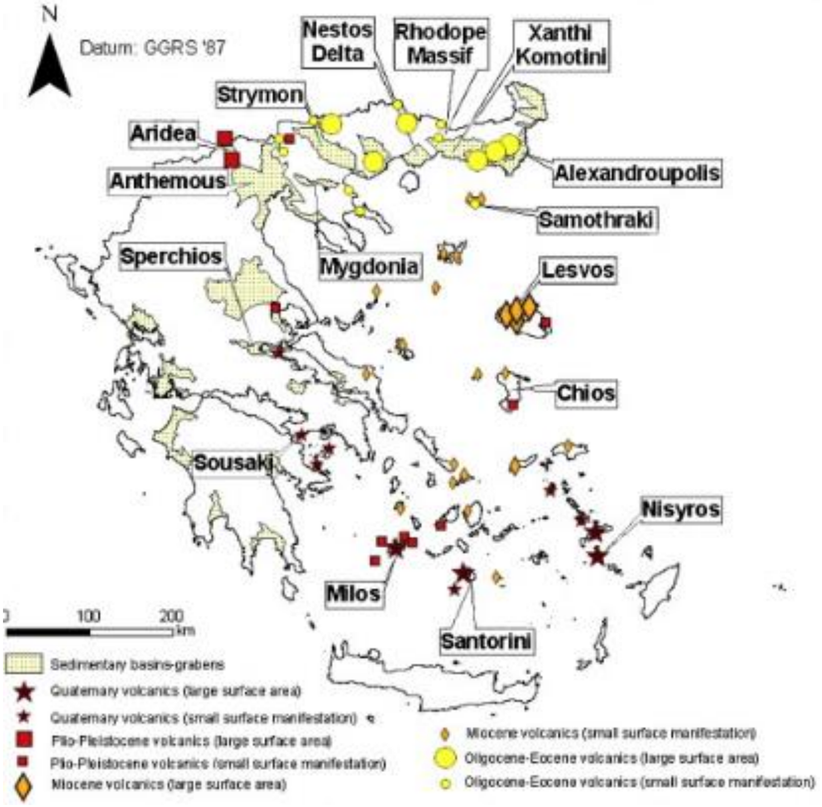


Figure 19: Geothermal map of Greece (Mendrinos, et al., 2010)

The terminal closure of the facility came a few years later after the blow out of M2 well. After the incident all the wells on island were plugged. Today, only a small number of residencies and hotels on island use geothermal energy to produce hot water (Koroneos & Fytikas, 1999). Regarding the rest of geothermal locations in Greece, energy from wells is used either in space heating or in hot water for use heating (with main application spas) or for agricultural use (Mendrinos, et al., 2010).

Geothermic energy according to (Koutroupis, 1993) is a relatively unstable resource of energy for Greece, as it may be susceptible to alterations through time, that are mostly caused by the seismic activity of the wider area of the Mediterranean arc. Due to that, investments in that source are avoided due to high risk of failed exploitation of this source (Andritsos, et al., 2013).

3.1.5. Biomass

Biomass could be an alternative for Combined Heat and Power (CHP) production on islands. Biomass could be produced by livestock farming waste, domestic waste, wood/ woodchips and oil mill by products. For small islands though, biomass supply could be a problem (Regional Agency of Central Macedonia, 2013).

The problem derives mainly, from the small number of residents and livestock. Wood and woodchips would not be a good alternative as well, as the vegetation on most of islands due to aridity is limited. The most promising solution seems to be the olive cake, produced by the numerous olive mills across Greece (Institute of Agriculture and Tourism POREC, 2008).

Olive cake is the residue of the process of olive oil extraction. The 98% of the produced olive oil worldwide is done in the Mediterranean area. Greece is the third biggest olive oil producer globally with a large amount of olive oil, high energy density by-products left unexploited (www.renergyuk.com, 2018). Olive cake according to (Oktay, 2006), can be used in biomass boilers in form of briquettes and substitute other solid fuels. A study conducted in Morocco, included the development of a Stirling engine used specifically for burning olive by-products for maximum efficiency (Rassai, et al., 2018). These experimental applications could potentially aid the adoption of olive-originated biomass in larger scale. Currently, olive briquette burners are used for greenhouse and space heating in Greece, only in small-scale applications. Retail price for olive cake briquette if around 3.5 €/kg, its caloric value ranges between 5.2 and 5.6 kWh/kg depending on humidity (9-10%) (Probio Energy International, 2018).

Although, the planning for an olive cake biomass-fired boiler unit needs a number of things that have to be considered beforehand. First of all, such units are highly dependent on crops for refuelling. This means that fuel availability might have a seasonal variation, which in periods of low production could cause shortage. Moreover, in the case of smaller islands the local production might be inadequate, thus fuel might need to be shipped from the mainland or from other islands. In that case, the expenses of fuel will be burdened by shipping tolls and its reliability will be dubious, due to weather conditions that might prevent ships from travelling or harbouring at winter. Besides that, space might also be a significant issue on islands, where space is limited. Olive cake processing units and biomass boilers need to be far from resided areas, due to the smell stemming from pilling, processing and then burning the biomass (Brlek, et al., 2016).

Figure 20: Olive cake biomass pilling are on-site, with an olive mill (www.renergyuk.com, 2018).

3.1.6. Tidal and Waves Energy

Regarding sea kinetic energy harvesting device, little to none studies regarding Greece exist, for the time being. Generally, offshore structures are very difficult to apply in Greek Seas. The main problem is the intense maritime activity of Greece and the congested sea traffic in the sea routes that can be seen in Figure 21 (www.marinetraffic.com, 2018). Aegean is the Sea connecting Black Sea with the Mediterranean and the Middle East. Millions of tankers, bulk carriers, cargo and passenger ships cross the country’s seas every day (Hoffman, 2017).

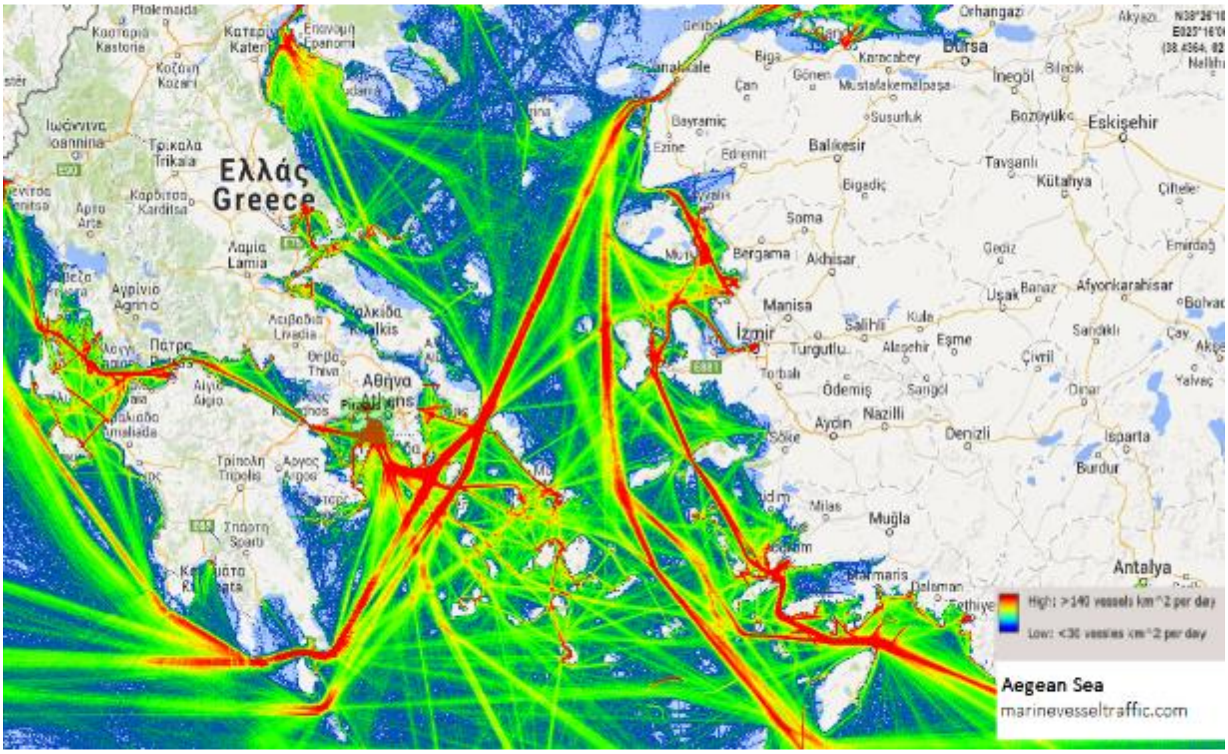


Figure 21: Map showing the sea routes in Greece including the daily capacity in vessels/km^2/day (www.marinetraffic.com, 2018).

Other confinements of the application of tidal and wave energy device are also related with the economic activity of the areas. Many of the islanders are occupied in the professional fishing industry. The installation of such device might alter the seascape and turn populations of fish to migrate, due to disturbance, resulting many locals to lose their only source of income (Nederland Maritiem Land, 2016). Thus, this implication is almost impossible, and nobody have conducted research related to this topic.

3.1.7. Summary

On Table 1, there are depicted the energy resources available on Greek islands according to the examined literature. The main criteria are: Availability, Similar

Implications in the Area and Local Community Acceptance. Availability was set as a criterion, because some energy resources, despite being promising their abundancy may not allow their development even in small scale. Similar implications was the second criterion, because such implications are able of giving valuable information regarding systems performance in the same area and function as a guide towards the direction to focus on when investigating possible solutions. Studies concerning nearby areas were assessed to define characteristics as climate, energy needs, human behaviour and individual characteristics.

The last criterion was used because, as it was concluded by the literature review, for many years the fostering of RES in Greek islands stumbled upon local community opposition. Through better information campaigns and success of similar projects though, in many cases this negativity was reversed, and inhabitants now ask for greater scale RES implications on their islands, after having witnessed the benefits from similar projects.

Table 1: Comparison of the available energy resources in Greek Islands

Form of Energy	Availability	Similar Implications in the Area	Local Community Acceptance	Total
Solar	√	√	√	√
Wind	√	√	√	√
Small-Scale Hydro	conditional	conditional	X	X
Geothermal	conditional	√	X	X
Biomass	conditional	X	unknown	X
Tidal & Wave	unknown	X	X	X

From the results of Table 1, the resources that will be further investigated in this thesis will be the solar and wind energy, as these two resources seem to fulfil all the set criteria.

3.2. Storage Options

In this section, there was done a comparison between energy storage solutions that are common in hybrid RES-storage energy systems. Apart from these listed below, that are going to be investigated further, a research was conducted on three other possible solutions that were rejected due to confinements that prevent their application in the case of Greek islands. Namely, these were: Flywheels, Pumped Hydro, and Compressed Air Energy Storage (CAES). Flywheels were rejected because they are mostly a form of kinetic energy storage that is primarily used for frequency stability in electric generators, so it would not be a solution capable of storing energy for a long time (Warmburg, 2006). Pumped Hydro, as explained in Section 2.2.3, is not a feasible solution for the arid Greek islands and the CAES systems are mostly applied in industry and not in community scale (Energy Storage Association, 2018).

Regarding the energy storage solutions that were further examined, as seen on Table 2 these are mostly battery systems and electric/electromagnetic systems (Mohanty, et al., 2016). The latter are on experimental stage and for the time being their significantly bigger cost is preventing their mass implications.

Table 2: Comparison of Energy Storage Technologies

	Technical Data	**Possible Environmental Impacts/ Dangers**	**Costs**
Hydrogen Fuel Cells[1]	Efficiency: 45-80%[2]	No pollution, Highly flammable[3]	Initial Capital: 86047486[3] €/MWh
	Weight: 30kg/MWh		Maintenance Cost: 1 €/MWh
	Lifetime: 10 years		
Lead Acid Batteries (VRLA)[4]	Efficiency: 50-90%	Extremely toxic, corrosive fluids, long term pollutants[5]	Initial Capital: 62427 €/MWh
	Weight: 11340 kg/MWh		Maintenance Cost: 203680 €/MWh
	Lifetime: 5 years		
Vanadium Redox flow batteries (VRB)[6] [8]	Efficiency: 75%	Non-toxic, requires huge space for fluid tanks[7], non-flammable[7]	Initial Capital: 500000-850000 €/MWh
	Weight: 5220 kg/MWh		Maintenance Cost: 15000 €/MWh
	Lifetime: 15 years		
Lithium-Ion Batteries (Li-Ion)[4] [5]	Efficiency: 85-90%	Non-recyclable, highly flammable when in contact with oxygen[7]	Initial Capital: 600000-950000€/MWh
	Weight: 2767 kg/MWh		Maintenance Cost: 47982 €/MWh
	Lifetime: 17 years		
Supercapacitors[1]	Efficiency: 95%	No chemical reactions, no pollution	Initial Capital: 29709680 €/MWh
	Weight: 10000 kg/MWh		Maintenance Cost: 5 €/MWh
	Lifetime: 40 years		
Superconducting Magnetic Energy Storage[1]	Efficiency: 97%	No chemical reactions, no pollution	Initial Capital: 10611 €/MWh
	Weight: 10 kg/MWh		Maintenance Cost: 1 €/MWh
	Lifetime: 40 years		

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[1] (Rinkesh, 2017)

[2] (Eriksson & Gray, 2017)

[3] (U.S. Office of Energy Efficiency & Renewable Energy, 2018)

[4] (Alevar & Zacho, n.d.)

[5] (Aquino, et al., 2017)

[6] (Watkins, 2014)

[7] (ENERGY RESPONSE SOLUTIONS, 2017)

[8] (Skyllas-Kazacos & McCann, 2015)

4. The Water Problem in Greek Islands

4.1. Problem Description

Cyclades and Dodecanese islands that belong to the Aegean Sea, apart from the energy problems mentioned in the previous sections also face serious water deficiency problem. Geomorphology of the area, low precipitation levels (Paliatsos, et al., 2004), seasonal human population fluctuations and constantly growing local economic activity are only a few of the reasons that create this deficiency. This shortage also contributed largely to the shaping of the occupational activity of the inhabitants on the islands. Agriculture is held back and almost all the cultivation products are shipped from the mainland or other bigger islands. Livestock farming is also limited due to shortage of water and vegetation that allows limited grazing on islands (Kaldellis & Konduli, 2007).

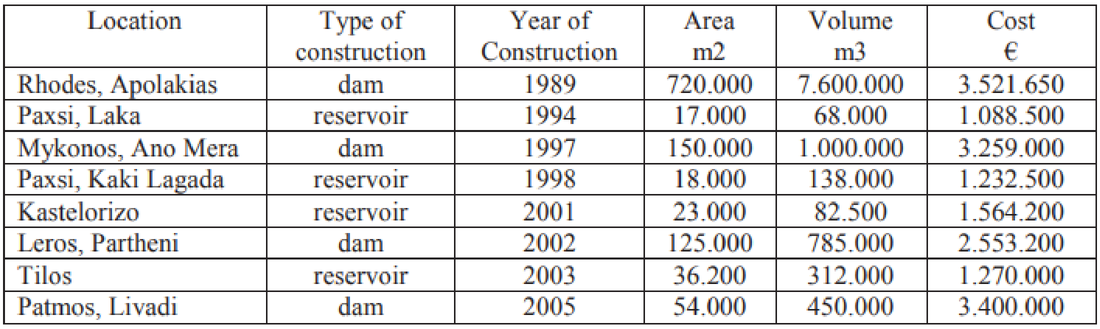
Apart from the mentioned above, the last 20 years the situation is deteriorated further due to the rapid development of the islands. The number of permanent inhabitants has increased 14-16%, more tourist accommodations are being built, the number of visitors increases by approximately 50,000 every year and the area experiences a growth in development that is totally different from the rest of the country (Hellenic Association of Tourism (EOT), 2013). The issue of water shortage has become a matter of grave importance for most of the islands, as it is directly related to the quality of life on those islands.

The most common solutions to address to the water problem on islands, are:

- ground reservoirs and dams (often associated with water treatment plants)

- boreholes and wells
- home reservoirs that collect rainwater from roofs-bottled water
- transportation of water using tanker ships
- desalination units.

Ground reservoirs are a natural method of storing water on large cavities underground. This water is generally considered of good quality and on some islands like Ikaria are exploited for domestic and agricultural use (Bertsiou, et al., 2017). Dams on islands are mostly related to the control of processes in wastewater treatment plants. These plants collect drainage water, then filter/purify it and later can be used for agricultural or farming purposes, but rarely for drinking (Karagiannis & Soldatos, 2007). The existing reservoirs on Greek islands can be seen in Figure 22.



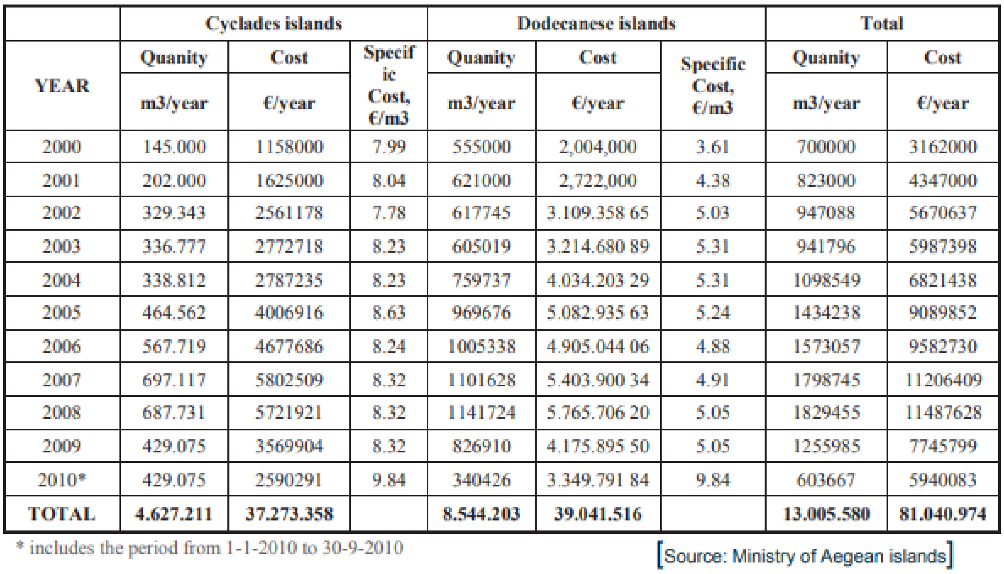
Location	Type of construction	Year of Construction	Area m2	Volume m3	Cost €
Rhodes, Apolakias	dam	1989	720.000	7.600.000	3.521.650
Paxsi, Laka	reservoir	1994	17.000	68.000	1.088.500
Mykonos, Ano Mera	dam	1997	150.000	1.000.000	3.259.000
Paxsi, Kaki Lagada	reservoir	1998	18.000	138.000	1.232.500
Kastelorizo	reservoir	2001	23.000	82.500	1.564.200
Leros, Partheni	dam	2002	125.000	785.000	2.553.200
Tilos	reservoir	2003	36.200	312.000	1.270.000
Patmos, Livadi	dam	2005	54.000	450.000	3.400.000

Source: Ministry of Agricultural Development and Food, 2006

Figure 22: Dams and water reservoirs on Greek islands (Ministry of Agricultural Development and Food, 2006).

Home reservoirs are a very common practise in the arid areas of southern Greece and especially in the Aegean Sea. Water from roofs is collected through drains to large tanks located on the basement of homes or buried underground and is stored for use later. Rainwater after filtration, might on some cases, but not always, be suitable for drinking. If not, it is used for other purposes (Gkikas & Tchobanoglous, 2009). As a complementary measure, many drill low depth wells that take advantage of the shallow but small in quantity water reserves. These reserves often offer low quality semi-saline water (brackish water (BW)) that is neither suitable for consumption nor for irrigation of plants and crops. Another very common problem is the “contamination” of such wells with sea water. This happens when over-pumping of water occurs, mostly on dry seasons, when saline water finds its way from sea and trough the soil to these emptied cavities. Contaminated wells might take years to be restored and until then they are practically useless (Karachaliou, 2010).

Transportation using tanker ships is another common practise in the islands of the Aegean Sea. Tankers either carry water from the mainland or from bigger islands to the smaller ones. The water is stored in large reservoirs and the refilling process happens every 10-12 days on winter and every 3-5 days on summer. The first and most great disadvantage of this process is the cost. Cost often varies to 7-10 €/m^3, which is very high considering that on the mainland it is around 0.35-0.41 €/m^3. The final cost of water on islands, is readjusted to 0.44-0.50 €/m^3 on most cases, with the city council collecting the residue from taxes (Tzen, 2015). Costs for water transport in Greek islands can be seen on Figure 23, that shows the amounts of transported water and its cost for Cyclades and Dodecanese islands for the decade 2000-2010.



YEAR	Cyclades islands			Dodecanese islands			Total	
	Quanity	Cost	Specific Cost, €/m3	Quanity	Cost	Specific Cost, €/m3	Quanity	Cost
	m3/year	€/year		m3/year	€/year		m3/year	€/year
2000	145.000	1158000	7.99	555000	2,004,000	3.61	700000	3162000
2001	202.000	1625000	8.04	621000	2,722,000	4.38	823000	4347000
2002	329.343	2561178	7.78	617745	3.109.358 65	5.03	947088	5670637
2003	336.777	2772718	8.23	605019	3.214.680 89	5.31	941796	5987398
2004	338.812	2787235	8.23	759737	4.034.203 29	5.31	1098549	6821438
2005	464.562	4006916	8.63	969676	5.082.935 63	5.24	1434238	9089852
2006	567.719	4677686	8.24	1005338	4.905.044 06	4.88	1573057	9582730
2007	697.117	5802509	8.32	1101628	5.403.900 34	4.91	1798745	11206409
2008	687.731	5721921	8.32	1141724	5.765.706 20	5.05	1829455	11487628
2009	429.075	3569904	8.32	826910	4.175.895 50	5.05	1255985	7745799
2010*	429.075	2590291	9.84	340426	3.349.791 84	9.84	603667	5940083
TOTAL	**4.627.211**	**37.273.358**		**8.544.203**	**39.041.516**		**13.005.580**	**81.040.974**

* includes the period from 1-1-2010 to 30-9-2010

[Source: Ministry of Aegean islands]

Figure 23: Quantities and costs of water transportation in Cyclades and Dodecanese islands in the decade 2000-2010.

The second most important disadvantage of this practice is the quality of water. Water often arrives on the islands contaminated with odours or sediments. This pollution occurs at transfusion procedure, or due to the bad quality of transportation tankers containers (Mentis, 2011). On this case, like the others the primary demand for fresh and safe to consume water is covered with bottled water. Statistics show that bottled water consumption in the Aegean islands is up to seven times higher than in the rest of the country for areas with the same demographic characteristics (Margaris, 2008). Moreover, transportation through sea is considered an operation of high risk that might be paused or be difficultly conducted during the winter period due to bad weather. Very often, the National Meteorological Office of Greece on winter, gives a forbidding order for the ships and they are not allowed by the Coast Guard to leave harbours. This makes the reliability of the water supply chain ambiguous and dependant on stochastic parameters such as the weather or winds (Manolakos, et al., 2001).

All of the measures mentioned above consist solutions that can not effectively counter the water shortage problems on islands. Thus, the islands inhabitants, addressed to the State to give a solution to the water problem. In 1981 the first two reverse-osmosis (RO) desalination units were put to use in Mykonos and Ithaca islands. This was only the start, as until 2014 numerous other desalination plants were established in the whole islandic territory of the country, as seen in Figure 25. These units provide the vast majority of the consumed water on the islands today, providing them with good quality fresh water. Most of these units utilise the reverse-osmosis technique, which will be explained in the next section. Although, desalination is a process known to humans since the ancient times with many different configurations. The most of them, included the boiling of seawater and collection of steam to provide sailors with small amounts of seawater to be able to survive. With the advance of technology, fire was replaced with solar energy.

The first and very small scale solar desalination units installed on islands, included heating and evaporation of the water and its collection as depicted in Figure 23. This type of units could only provide small quantities of fresh water for domestic use at a very slow rate. For states of emergency, the method is considered adequate but for mass production and long-term supply not. Besides that, such methods need a very careful planning and are highly dependent on stochastic factors like weather, sunshine and water temperature. Thus, it was necessary to be replaced with industrial, large scale and fully controllable methods (Nydreos-Sakouelos, 2010).

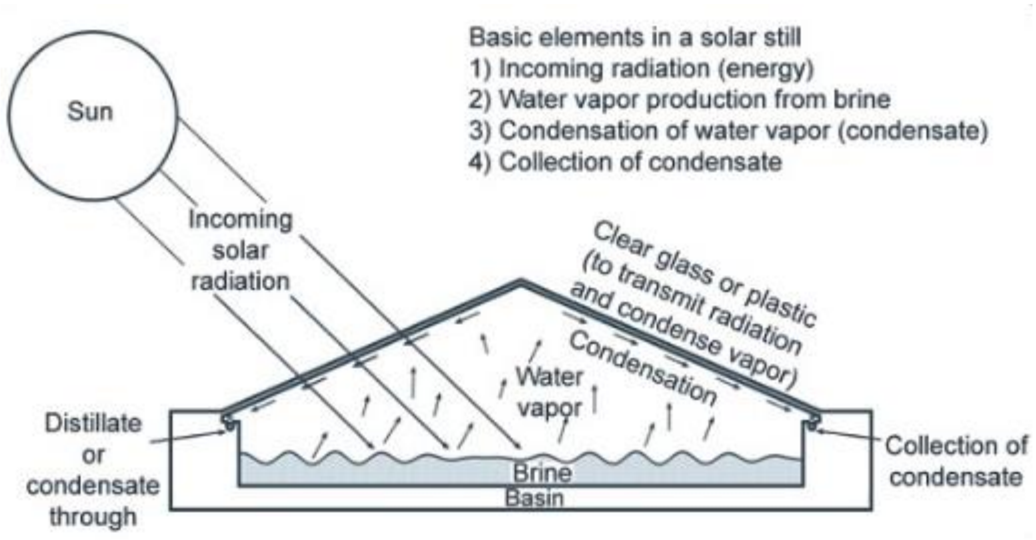
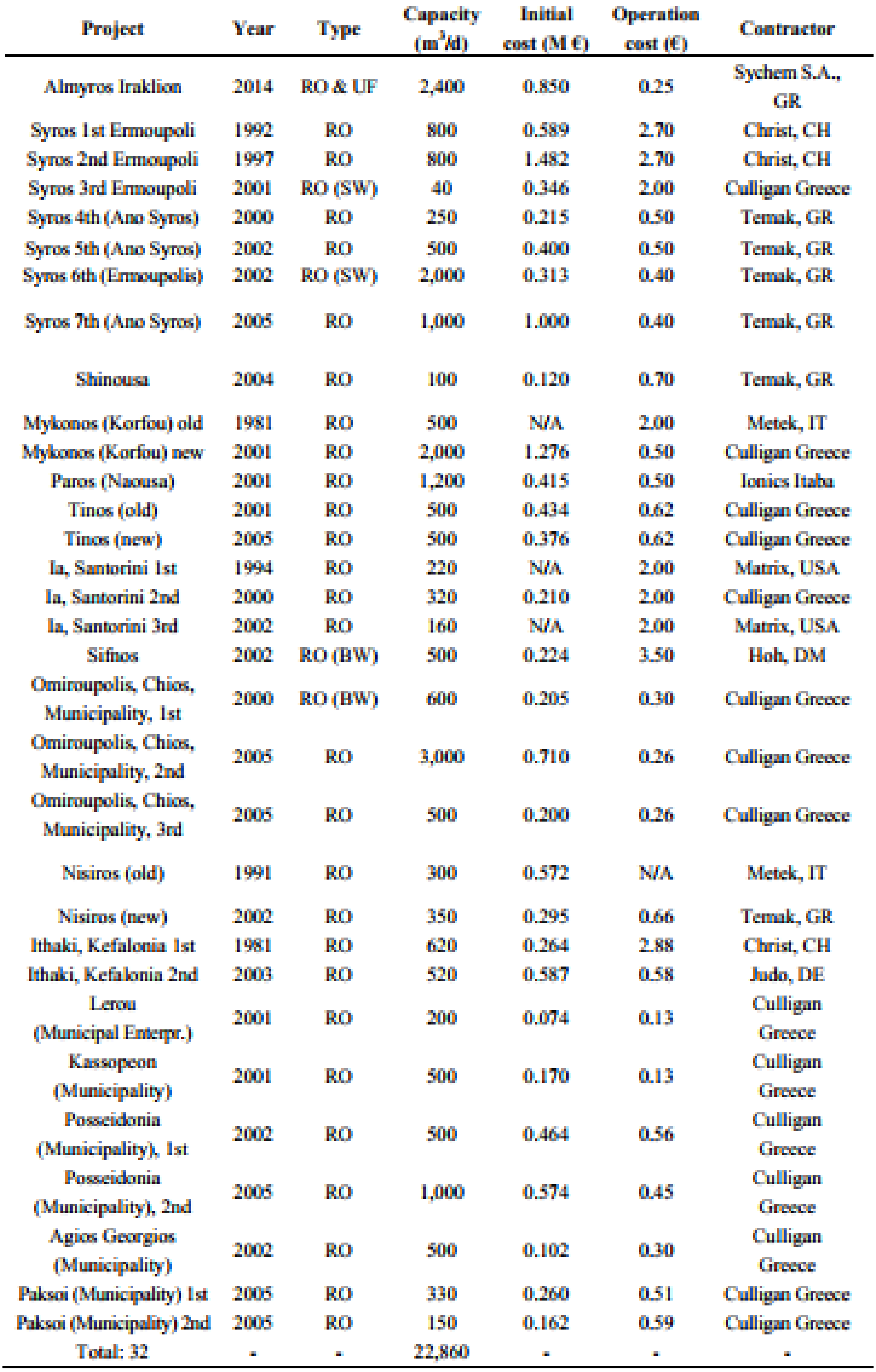


Figure 24: Solar seawater desalination unit configuration



Project	Year	Type	Capacity (m^3/d)	Initial cost (M €)	Operation cost (€)	Contractor
Almyros Iraklion	2014	RO & UF	2,400	0.850	0.25	Sychem S.A., GR
Syros 1st Ermoupoli	1992	RO	800	0.589	2.70	Christ, CH
Syros 2nd Ermoupoli	1997	RO	800	1.482	2.70	Christ, CH
Syros 3rd Ermoupoli	2001	RO (SW)	40	0.346	2.00	Culligan Greece
Syros 4th (Ano Syros)	2000	RO	250	0.215	0.50	Temak, GR
Syros 5th (Ano Syros)	2002	RO	500	0.400	0.50	Temak, GR
Syros 6th (Ermoupolis)	2002	RO (SW)	2,000	0.313	0.40	Temak, GR
Syros 7th (Ano Syros)	2005	RO	1,000	1.000	0.40	Temak, GR
Shinousa	2004	RO	100	0.120	0.70	Temak, GR
Mykonos (Korfou) old	1981	RO	500	N/A	2.00	Metek, IT
Mykonos (Korfou) new	2001	RO	2,000	1.276	0.50	Culligan Greece
Paros (Naousa)	2001	RO	1,200	0.415	0.50	Ionics Italia
Tinos (old)	2001	RO	500	0.434	0.62	Culligan Greece
Tinos (new)	2005	RO	500	0.376	0.62	Culligan Greece
Ia, Santorini 1st	1994	RO	220	N/A	2.00	Matrix, USA
Ia, Santorini 2nd	2000	RO	320	0.210	2.00	Culligan Greece
Ia, Santorini 3rd	2002	RO	160	N/A	2.00	Matrix, USA
Sifnos	2002	RO (BW)	500	0.224	3.50	Hoh, DM
Omiroupolis, Chios, Municipality, 1st	2000	RO (BW)	600	0.205	0.30	Culligan Greece
Omiroupolis, Chios, Municipality, 2nd	2005	RO	3,000	0.710	0.26	Culligan Greece
Omiroupolis, Chios, Municipality, 3rd	2005	RO	500	0.200	0.26	Culligan Greece
Nisiros (old)	1991	RO	300	0.572	N/A	Metek, IT
Nisiros (new)	2002	RO	350	0.295	0.66	Temak, GR
Ithaki, Kefalonia 1st	1981	RO	620	0.264	2.88	Christ, CH
Ithaki, Kefalonia 2nd	2003	RO	520	0.587	0.58	Judo, DE
Lerou (Municipal Enterpr.)	2001	RO	200	0.074	0.13	Culligan Greece
Kassopeon (Municipality)	2001	RO	500	0.170	0.13	Culligan Greece
Posseidonia (Municipality), 1st	2002	RO	500	0.464	0.56	Culligan Greece
Posseidonia (Municipality), 2nd	2005	RO	1,000	0.574	0.45	Culligan Greece
Agios Georgios (Municipality)	2002	RO	500	0.102	0.30	Culligan Greece
Paksoi (Municipality) 1st	2005	RO	330	0.260	0.51	Culligan Greece
Paksoi (Municipality) 2nd	2005	RO	150	0.162	0.59	Culligan Greece
Total: 32	-	-	22,860	-	-	-

Figure 25: RO Desalination units operating on Greek Islands (Zotalis, et al., 2014).

4.2. Desalination Methods and RO Desalination

4.2.1. Comparison of Desalination Methods

According to (Voutchkov, 2013), the four most popular and widely adopted methods for desalination are:

- Reverse Osmosis (RO)
- Vapour Compression (VC)
- Multi-Stage Filtration (MSF)
- Multi-Effect Desalination (MED).

The vast majority of desalination worldwide is occurring in the countries of Middle East and especially on the Persian Gulf and in Australia, as it is depicted on Figure 26.

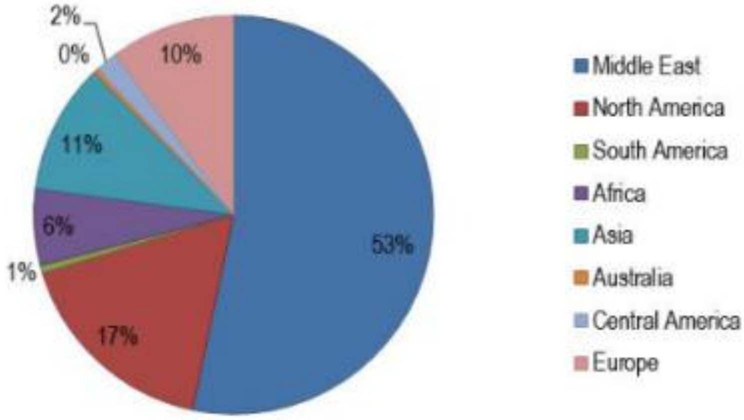
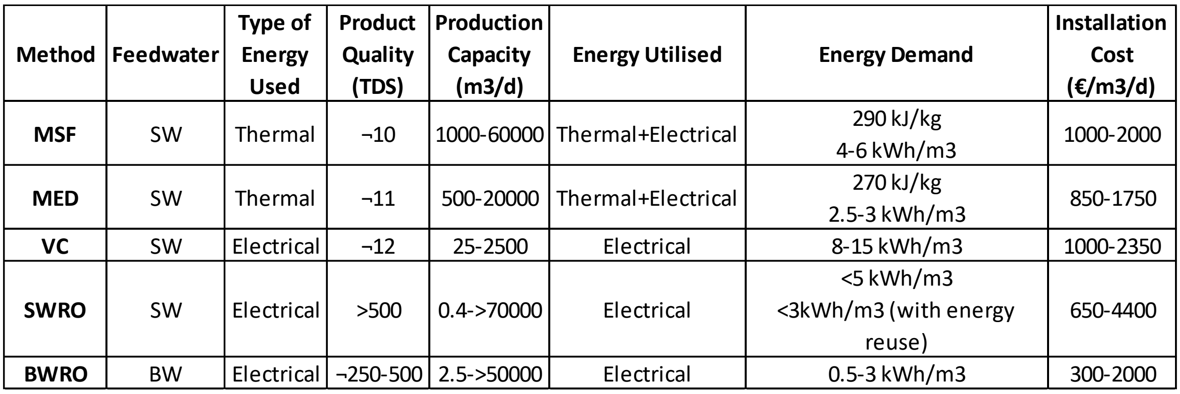


Figure 26: Percentage of the worldwide operating desalination units, for each country (Zotalis, et al., 2014).

The dominant technology in desalination for the time being is considered the RO desalination, due to its numerous advantages over the others due to: its easily customisable size, capacity and expandability, the use of electricity only and not thermal energy, its applicability on both seawater and brackish water and the fact that RO units come as turnkey solutions in small sizes that can easily be fitted into containers. (Fahmy, et al., 2012).

The other very important advantage of RO over the other methods is its low energy consumption and low initial cost of the installation. As show in the Figure 24, from the (Mentis, 2011) thesis, that was derived from the CRES scientific report on desalination methods (Tzen, 2010) the RO units the only energy used is electric and not thermal. This is a great advantage because it offers portability and the opportunity to apply more easily a renewable supply system as it has been done in numerous occasions especially on islands. In terms of the total dissolved minerals (TDS) RO shows significantly higher concentrations than the other methods. These concentrations though are below acceptable levels, which makes the produced water suitable to consume (Oram, 2014).



Method	**Feedwater**	**Type of Energy Used**	**Product Quality (TDS)**	**Production Capacity (m3/d)**	**Energy Utilised**	**Energy Demand**	**Installation Cost (€/m3/d)**
MSF	SW	Thermal	¬10	1000-60000	Thermal+Electrical	290 kJ/kg 4-6 kWh/m3	1000-2000
MED	SW	Thermal	¬11	500-20000	Thermal+Electrical	270 kJ/kg 2.5-3 kWh/m3	850-1750
VC	SW	Electrical	¬12	25-2500	Electrical	8-15 kWh/m3	1000-2350
SWRO	SW	Electrical	>500	0.4->70000	Electrical	<5 kWh/m3 <3kWh/m3 (with energy reuse)	650-4400
BWRO	BW	Electrical	¬250-500	2.5->50000	Electrical	0.5-3 kWh/m3	300-2000

Figure 27: Comparison of the most popular desalination methods

Significant is the difference as well for the maximum produced capacity of RO units over the rest as these units can reach the maximum capacity of 70,000 m^3/day, while the highest for the others is MSF with 60,000 m^3/day. This extra capacity comes with almost half of the electric demand and at a considerably lower price.

All of the advantages of RO, which can be discerned on Figure 27, have led to its techno-economical prevail over the other methods. This method is relatively newer and it has been adopted in applications that range from small units in hotels (Fahmy, et al., 2012), to building scale (Alsgeghri, et al., 2015), to island-scale even for bigger islands (Moutafis, 2008) and to entire areas (Cisneros Ramirez & Racalde, 2015).

4.2.2. Reverse Osmosis Desalination

Currently in Greece there are 35 RO desalination units of 22,860 m^3/day capacity with operation costs 0.13-2.7 €/m^3. New units are under construction and the expansion or refurbishment of older units is continuous. RO desalination though, is considered an energy consuming method, with energy requirement that often makes its sustainability doubtful (WATEREUSE Association, 2011) in applications that energy generation is limited. Before proceeding further, there will be explained the fundamental principle of operation of this method.

4.2.2.1. Principle of Operation

The basic component of RO process is a semi permeable membrane. This membrane acts as a filter that removes salts from the water, leaving clean water on its output. For the explanation of the system and the role of membrane, there will be given a description so that it is easier to perceive, on how these types of systems work.

Imagine a large vessel with two discernible parts A and B, that are separated by a membrane. Part A is filled with a quantity of clean, distilled water. Part B is filled with the same quantity of water as Part A with a few grams of salt (NaCl) dissolved in it. The two parts have the same volume and their levels are the same. After a few time, the level of Part B starts to increase, as molecules of water contained in Part A cross the membrane leading to the increase of volume of Part B. This process continues up until two solutions come to molecular balance, when their content is almost equalised. This procedure of one fluid trying to dissolve the other is called osmosis and occurs naturally in fluids.

If now, on the same vessel, a pressure is applied in Part B using a piston in order to keep the volume of its contained liquid constant, the system reaches balance as well. The pressure applied on the piston, which is required to maintain the pressure equilibrium of the two fluids is called osmotic pressure. If the pressure on Part B is increased further, then the level of fluid in Part A, will start to increase. This happens because molecules of clean water are forced to travel through the membrane leaving salt in Part B. In the end of the process, Part B is left with salt residue and a small quantity of water, while Part A has a volume of water much bigger than its initial. This process is called reverse osmosis and is the fundamental or the RO desalination units (Mentis, 2011). The process can be used to purify water with different salt concentrations, in installations of various capacities that are entirely customisable (Voutchkov, 2013). The key in the entire process is the membrane that separates the two fluids.

4.2.2.2. Basic System Components and Process Description

The most common type of desalination device is the one that is depicted in Figure 28.

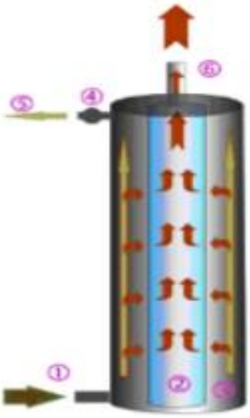


Figure 28: RO Desalination device (Alexakis, 2003)

Saline water enters through inlet (1), in the empty space (3). There are two possible outlets (5) and (6). Water at (3) is pressurised and the 25% of its volume is forced to travel through membrane (2) and leave through outlet (6). Water on outlet (6) is cleaned, purified and ready to consume. The rest of the water in (3) leaves the vessel through outlet (5), after the pressure in valve (4) exceeds a limit. Pressurised water cleans all the residues on the surface of membrane (2), which mostly are consisted of salts *(Alexakis, 2003)*. This system uses the principle described on Chapter 4.2.2.2 and is part of a bigger system that will be described further below.

A typical configuration of a RO unit water treatment plant can be seen on Figure 29. Each of these systems consists of four major sub-systems:

1. Seawater Feed Pump with its piping.
2. Seawater Pre-Treatment.
3. Basic Treatment Facility (Reverse Osmosis Unit)
4. After-Treatment and clean water Tank.

The procedures that take place at each sub-system are described briefly below:

1. <u>Seawater Feeding:</u>

The seawater feeding is conducted through the Seawater Pump that inputs the water in the system. The three alternatives for seawater feeding include: well construction, drilling or the connection of a pipe that pumps seawater directly to the system from the sea. The chosen method varies depending on the case and the individualities of each project. The most common method though is the offshore drilling, as this method does not have the technical challenges that well construction opposes and is considered more effective than the direct seawater pumping.

2. Seawater Pre-Treatment

For better performance in membrane systems the pre-treatment stage is very important. At this stage particles and small floating solids that are contained in seawater are extracted to prevent them from building up on the surface of the membrane at later stages of the process. More specifically, the process includes:

- Pre-filtering with a grid that prevents algae, fish and rubbish from entering the system.
- Chloride addition and acidity regulation with the addition of chemicals.
- Polypropylene filtration with special filters that can retain particulates up to 1 μm, that could cause damage to the membranes.
- Removal of free chloride as on this form it could damage the membranes.
- Ultraviolet (UV) sterilisation.

3. Main Treatment (RO)

At this stage the water undergoes the treatment that is described in the beginning of this chapter. The aforementioned pressure ranges between 40-80 atm.

4. After-Treatment

In that stage, the water undergoes its final treatment before reaching consumers. This process often has multiple stages that include:

- Removal of toxic gases like H_2S.
- Final chlorination.
- Final pH regulation.
- Addition of CO_2.

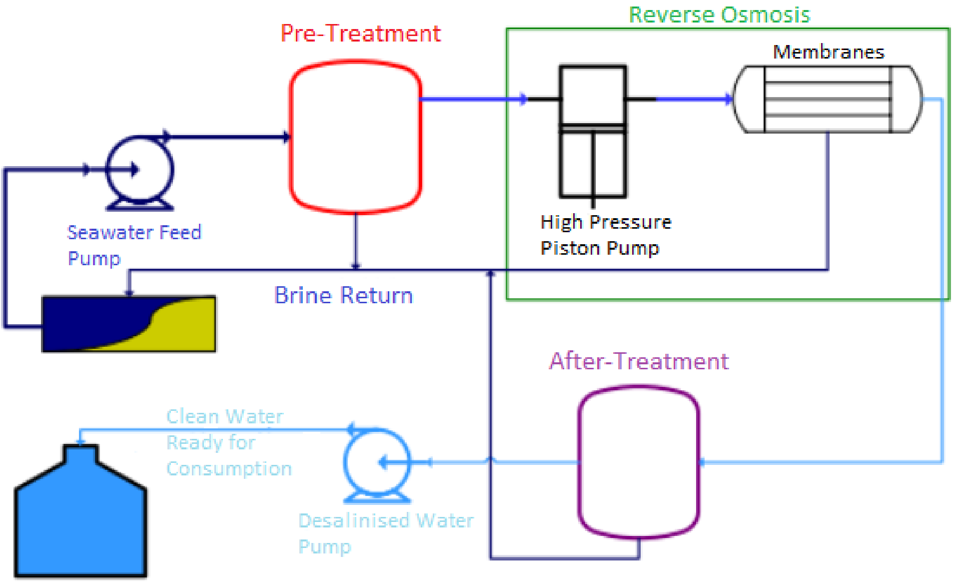


Figure 29: RO unit configuration (ITA Corporation, 2006)

It is obvious that in that method, the major energy consumption is on the pumps that pressurise and circulate the water. The required pressure depends on water salinity. For brackish water, the pressures range between 15-25 bar and for seawater 54-80 bar, as osmotic pressure is related to salt concentration of the input solution (Mentis, 2011).

5. Case Study

5.1. Modelling

5.1.1. Microgrids

According to IEEE, “Microgrids are localized grids that can disconnect from the traditional grid to operate autonomously. Because they are able to operate while the main grid is down, microgrids can strengthen grid resilience and help mitigate grid disturbances as well as function as a grid resource for faster system response and recovery” (Hyland, n.d.). Microgrids operate complementary to the main grid, switching from grid-connected to island mode, and often utilise renewable sources and storage technologies (Ton & Smith, 2012).

Figure 30: A typical microgrid configuration with its possible components

National Electrical Manufacturers Association (NEMA) in their report separate the benefits of microgrids in two distinct categories, the individuals' benefits and the societal (NEMA, 2014). Their various configurations that may include the powering of a home, a block of flats, a small village, an island, a college or a military base oppose numerous benefits to both the owners and the society in a wider aspect.

Some of the individual benefits mentioned on the report, include:

- Flexibility in development in terms of the gradual increase of size, that these grids have.
- Price security, as the operation of microgrid is not prone to seasonal or daily price fluctuations due to peaks in demand.
- Uninterrupted power supply that is not vulnerable to conditions that may happen in another area but affect the consumers of another area.

- Money saving and revenue generation, as using the current tariffs and maximising the renewable capacity can offer great profits over time.
- Reliability, resilience, security of supply, independency and total control of the generation system.
- Microgrids are a diversified, not a concentrated financial risk (International District Energy Association , 2017).

As for the societal benefits these are:

- The increase of network efficiency and its gradual decarbonisation by the replacement of old, polluting units with green ones.
- The creation of a new market with numerous work vacancies for scientists, technicians and retailers.
- Public health and safety improvement. Securing the power supply is very important for premises like clinics, hospitals, schools and for the society entirely as more and more the use of fossil fuels is reduced.
- The development of local economies of areas that were decreased due to poverty. These areas could possibly take part in the energy commerce, by utilising their energy surplus and selling it back to the grid.
- The support of places of refugee camps in regional crises (International District Energy Association , 2017).
- Allow the development of thermal networks as CHP installations can be used to store energy surplus (International District Energy Association , 2017).

5.1.2. Microgrid Simulation Software Comparison

For the research on this thesis there were assessed three pieces of software related to microgrid simulations. These were HOMER Pro, RET Screen and MERIT. The first two are commercial and developed by the National Renewable Energy Laboratories of the U. S. and Canada accordingly, while the third was developed by the University of Strathclyde and is free to download. In Table 3, there are shown the basic features of the assessed softwares, so that it will be easier to compare.

Table 3: Comparison of microgrid specialised software.

	HOMER Pro	**MERIT**	**RET Screen**
Cost	10 £/month (student version)	Free	500 £/year (Expert version)
Customisability	High	Medium	High
User-Friendliness	High	High	Medium
Sufficient Weather Database	Yes	No	Yes
	• offers system optimiser features • sensitivity analysis for various parameters • very easy to use • sufficient help/guidance material online • widely used in similar studies	• free software good for basic simulations • unable to perform detailed financial analysis • sensitivity analysis for various parameters requires a lot of work from the user	• similar characteristics with HOMER Pro • more difficult to use • large number of parameters that need to be defined by the user • does not offer shorter period licenses or student license

After comparison of the softwares on Table 3, HOMER Pro was chosen for this case study. It is more sufficient in terms of components, it has sufficient weather database from at least 10 years derived from NASA, the material available online regarding projects using this software is plenty and finally it was the choice of the author due to previous experience.

5.1.3. HOMER Pro

HOMER Pro or more simply referred as Homer (which stands for "*Hybrid Optimisation Model for Electric Renewables*"), is a microgrid-specialised software that was developed by the National Renewable Energy Laboratory (NREL) of the United States of America and was set to commercial use (U.S. NREL, 2018). The software has three main functions which are: Simulation, Optimisation and Sensitivity Analysis.

Regarding Simulation, Homer can simulate grid connected and off-grid systems and uses the NASA weather database to measure the performance of renewable device that user adds to the system. The software offers the opportunity of techno-economic calculations, as apart from performance, it can measure the cost and benefits of the simulated systems (Farret & Simoes, 2006). Among other parameters, it can calculate the Net Present Cost (NPC), initial Capital Cost (CC), Cost of Energy (COE) produced, Cash Flow, Renewable Fraction of energy consumed by the load, Grid Import and Export rates and many more. It also has a huge library of components not only limited to electricity, but also thermal energy device.

Homer has another very important feature, which is the Optimisation. This tool allows the user to define the best-performing system according to the inputs given. Homer runs thousands of simulations for different capacity of components combinations and after comparisons gives the best solutions, among the feasible ones. It not only sizes generation but also storage device for the optimal financially combinations (Franklyn, 2018). Using this sizing tool, the user is able afterwards to compare similar systems and choose the best for the occasion.

The third major feature of Homer is the sensitivity analysis tool. When modelling systems, there is a number of parameters that no one can be 100% sure of their values. Thus, the performance of the simulated system might deviate from the real systems. To counter that variance, there is a process that is referred as “Sensitivity Analysis”, which is actually the measurement of performance of an estimation for different inputs (Saltelli, 2002). Homer can perform such analysis basically for every parameter that is required as an input by the user. This is very useful, as the user is given the opportunity to examine their designed system performance results for different initial conditions (U.S. NREL, 2018).

As seen from Figure 31, which was derived from Sinha & Chandel’s journal, Homer uses load demand (which can be user defined as a time series of up to 1-minute time-steps for the entire year) and other inputs like controls, constraints, financial and emission data. These inputs are used in equations that calculate the systems that achieve the desired results. Then, after comparison the software proposes the optimal solution using the lowest NPC as criterion. User though, can as well see all the calculated systems because NPC is not necessarily the main criterion in all the cases.

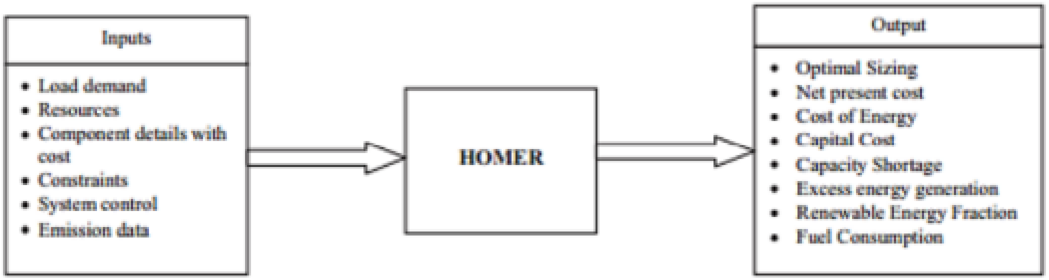


Figure 31: HOMER Pro inputs and possible outputs (Sinha & Chandel, 2014).

5.2. Case Study Model Description

This section is consisted of five discrete parts that describe the model of this case study. The software used for modelling was HOMER Pro, as it could model both the electric demand and the energy demand of the RO desalination unit, using grid connection, renewables, system controls and limitations.

The case study of this thesis was chosen to be Koufonisia islands, which belong to Cyclades island complex in the Aegean Sea in Greece. As seen in Figure 32, Koufonisia complex is located between Naxos and Amorgos and consists of three smaller islands: Ano (Upper) Koufonisi, Kato (Lower) Koufonisi and Keros.

Figure 32: Koufonisia islands in Greece (red circle).

Currently, out of the three islands only Ano Koufonisi is inhibited. Kato Koufonisi has some seasonal residencies only and was deserted from permanent residents at the 60's. Keros island is not inhibited because the National Archaeological Agency of Greece has prohibited any activity on the island, as on that there were found ancient antiquities and statues dating to 4000-4300 B.C. One of the reasons of Kato Koufonisi abandonment from its residents, is the fact that on the island there does not exist any type of electrical grid. This limits human activity to Ano Koufonisi only (Koufonisia Municipality, 2016).

Ano Koufonisi has around 412 permanent residents according to a report released by Southern Aegean Islands Municipality Administration and the premises can host up to 1530 people. Apart from that, Koufonisia are considered one of the most popular free camping destinations in Greece. There are no official data but from descriptions of locals, the number of free campers on the islands might exceed 500-800 per day. (Southern Aegean Municipality Administration, 2014). According to the same report, the main activity of every single family on the island is fishing. The younger generation has turned the last decade to tourism, as it could provide a more stable income.

Regarding electricity, the island has a double connection with Naxos and Amorgos islands with two subsea cables. Naxos is supplied with electricity by Paros island that has a diesel APS unit. Amorgos has a similar unit (CRES, 2014). Recently, IPTO has announced that all these islands will be connected to the grid of mainland in the final phase of the ongoing island interconnection plan, that is expected to be completed by 2023 (Liaggou, 2018). Already, some of the biggest islands of Aegean are powered by newly established connections to the mainland and have completely decommissioned their APS (Iliopoulou, et al., 2018).

Despite its environmental friendly and ecological consciousness Koufonisia for the time being have no RES installed on island. The main contributor to that is the opposition that residents had in the past, due to fears that such projects would have a terrible effect on the landscape. This negative stance has changed the last few years and now they have addressed publicly their interest on systems similar to those of Tilos island (WWF Greece, 2018). Islanders might have seen the increase of grid connection capacity and the opening of energy market in Greece, as a chance to form an energy community capable of covering its own needs and selling electricity to the grid. Additionally, they might have witnessed the benefits of such investments on local scale and on the local economy from similar projects. These facts are believed by the aforementioned research by WWF Greece, that contributed to the shift of public opinion towards renewables.

5.2.1. Electric Load Profile Synthesis

For the modelling of electric load profile of Ano Koufonisi, there were used data from projects of Greek universities regarding Donousa island. Electrical grids of the two systems are completely different as Donousa has its own autonomous grid powered by a diesel APS, while Koufonisi is connected to other islands and does not have its own power station. The demand data were provided by HEDNO and are considered valid despite the fact that they are from 2014, due to small fluctuations of population on islands over the last two decades (Municipality of South Aegean, 2016). Donousa island was chosen due to similarities with Ano Koufonisi, as the two islands are located in a 23 km distance and have same architectural characteristics, residents have the same occupation, the same daily routine and both islands have same temperatures and climate. Moreover, these were the only publicly available data from the nearby area from previous studies.

The difference of two islands, has to do with the number of permanent residents and tourists. Donousa has 167 permanent residents and can host around 600 tourists (Southern Aegean Municipality, 2014). These numbers are 2.5 higher than those of Ano Koufonisi that has 412 and 1530 accordingly. Thus, an incrementation of the load profiles from HEDNO, found on (Stamatopoulos, 2014; Katsifis, 2015) work was needed. The form of load profile concerning its daily and seasonal form, was assumed similar due to common features of the two areas. Following this methodology based on similarity and incrementation using straight analogy, also followed in (Moutafis, 2008; Mentis, 2011; Euaggelopoulou, 2013), the monthly average profiles were extracted. They were modelled with Homer, using its variability feature by applying 20% day-to-day and 10% timestep variabilities. These numbers are used in (Vassileiadis, 2014; Stamatopoulos, 2014) in their projects, as they are considered sufficient regarding the amount of randomness that they insert to the system. The final profile used by Homer Pro, is depicted on Figure 33.

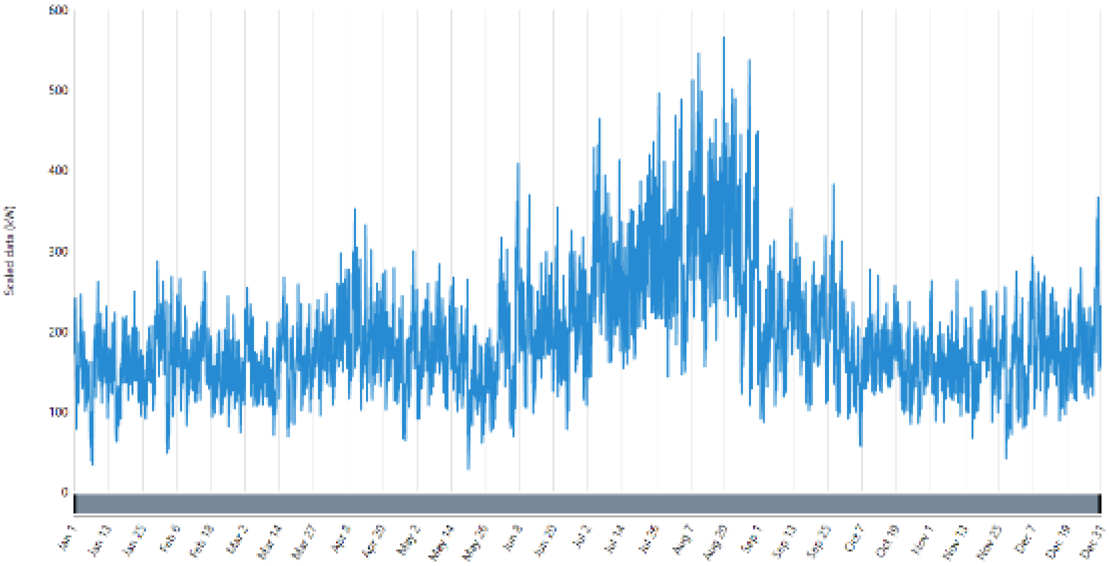


Figure 33: Annual electric load of Ano Koufonisi

Regarding the profile of Figure 33, there can be observed that peak load is during July and August and reaches values of up to 565 kW. There are also two other seasonal increases one in April and on in December, though significantly smaller. These are due to the two major Greek holidays of Easter and Christmas that slightly increase demand on island due to the visitors that arrive for these days for short vacation. The average energy consumption of Koufonisi is 4614.33 kWh/d.

In Figure 34, there can be seen the monthly profiles from Homer in greater detail.

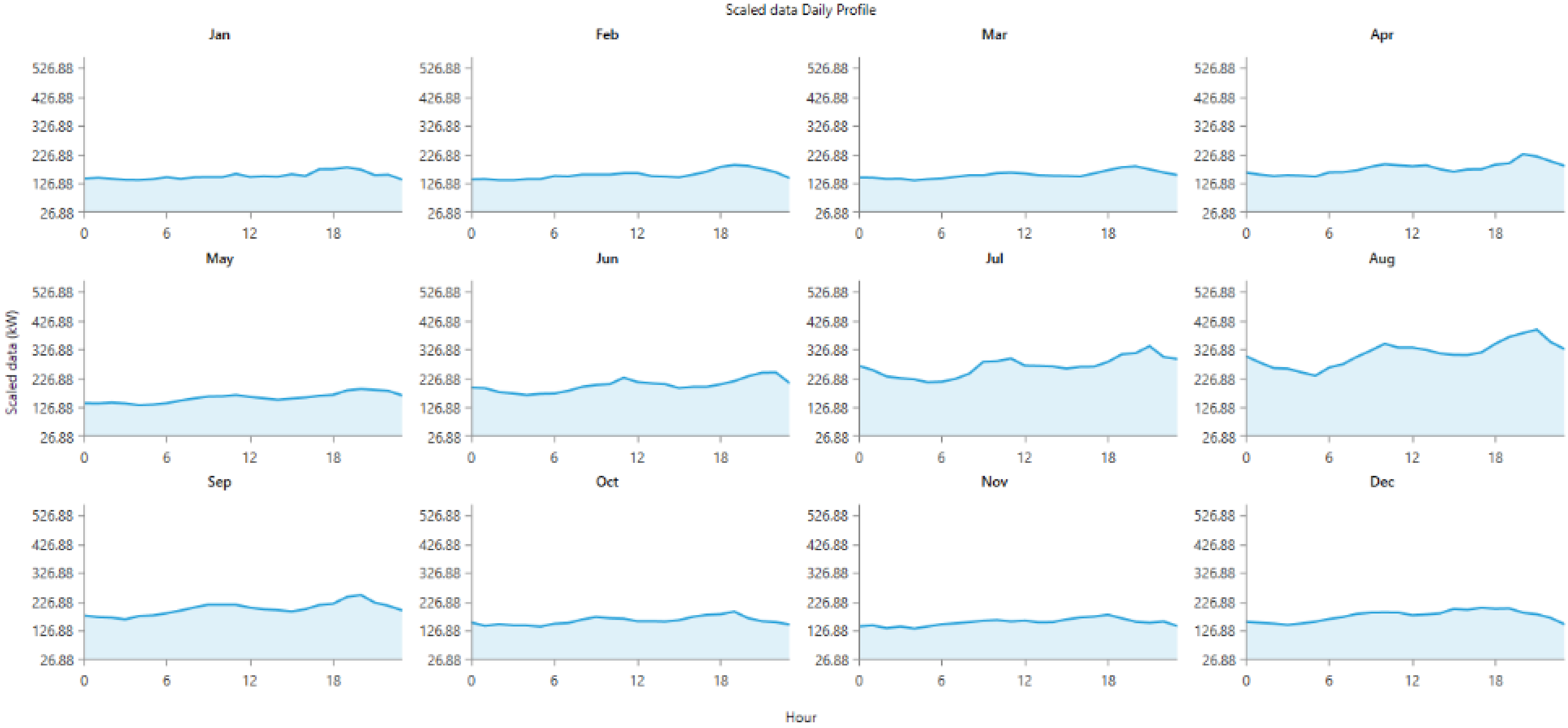


Figure 34:Monthly Average Electricity Demand profiles for Ano Koufonisi

As seen from Figure 34, the daily peak in the average daily demand profile happens around 21:00. During summer months there is a smaller peak that occurs around 12:00, and generally energy consumption remains high after that. This happens probably, due to air-conditioning loads and the opening of the most touristic enterprises like beach bars, cafeterias, etc. as noticed in (Bertsiou, et al., 2017).

5.2.2. Water Demand Calculation

For the calculation of water that the island consumes on average, on daily basis every month, there were taken into account the number of humans, livestock and crops cultivated on island. Information were derived by the Southern Aegean Municipality Business Plan for the island, that contained a very detailed statistic regarding all forms of human activity on the island for the last two decades (Municipality of South Aegean, 2016). From this point on, in this chapter, when mentioning statistics without a reference, the author refers to this statistic.

The water consumption difference between summer and the rest of the year, was taken into consideration as well. The calculation of the water demand was done to estimate the energy demand of the desalination unit that already operates on the island since 2014, as no data were available concerning that unit. Moreover, according to the local media, the increase of the capacity of this unit is under construction and is expected to be operational by July 2018 (Naxos Press, 2018). Thus, the energy demand of this unit could only be based on estimations.

5.2.2.1. Water Consumption of Humans

For water consumption related to humans, two were the key data that were needed. The first was the hot and cold period daily average water consumption in Greece. These numbers were taken 0.17 and 0.16 m^3/d accordingly, based on an UNESCO report cited on (Moutafis, 2008) report. The second important element was the number of people on the island. Hot period was considered the period between June and August and the rest of the months were considered as cold period.

According to the statistics the permanent residents are 412 and the tourists that can be hosted in touristic accommodations 1530. So, for the entire year there is a constant consumption related to permanent residents and another one related to tourists. The same report provides this information about tourists living on vacation premises on the island. More specifically, the report mentions that during July and August the accommodation is at 100% full, on June 55% full and on April and September there are on average around 123 visitors each day on the island. During May this number is half and for the rest of the year number of tourists was taken as 0, as less than 10 people are likely to visit the island monthly. As mentioned before, during July and August there is a large number of free campers that settle on the beaches of the island. These camps are not organised and do not have electricity, but often there is a water tap nearby. Thus, the consumption of these camps needed to be considered as well. From the report, witnesses speak about 450 and 550 campers on July and August accordingly, on daily basis.

By combining these data, the final daily average water consumption by humans on the island was calculated and can be seen in Table 4.

Table 4: Water Consumption of Humans in Ano Koufonisi Island.

Month	Inhabitants Consumption (m^3/d)	Tourists Consumption (m^3/d)	Total Consumption (m^3/d)
January	65.92	0.00	65.92
February	65.92	0.00	65.92
March	65.92	0.00	65.92
April	65.92	19.58	85.504
May	65.92	9.79	75.712

Month	Inhabitants Consumption (m^3/d)	Tourists Consumption (m^3/d)	Total Consumption (m^3/d)
June	70.04	143.06	213.095
July	70.04	336.60	406.64
August	70.04	353.60	423.64
September	65.92	9.79	75.712
October	65.92	0.00	65.92
November	65.92	0.00	65.92
December	65.92	0.00	65.92

5.2.2.2. Livestock Water Consumption

Concerning the livestock being farmed on the island, there can be generally mentioned that they serve the island families' needs in milk and meat. There are only 2-3 big farms, that are run by people as a complementary activity to provide a small income. In periods of aridity, farming water needs are covered by bad quality brackish or well-pumped water. On this study farming water needs are assumed to be covered by the desalination unit, as it was found that its capacity would allow that.

The numbers of animals on the island were derived from the report and the water consumption for animals from (The Enineering ToolBox, 2010) and (Ministry of Agriculture, 2015). A proportional increase of 10% was also taken into account, between hot and cold period, as animals and humans are living organisms and follow the same behaviour regarding their primal needs. Results from the research are shown on Table 5. The number of animals is regarded as being stable as there are not any significant fluctuations to be expected, due to them being bred for domestic need purposes.

Table 5: Animals farmed in Ano Koufonisi island and their average water consumption for cold and hot period

Animals	Number	Cold-Period Water Consumption (m^3/d)	Hot-Period Water Consumption (m^3/d)
Sheep	700	5.25	5.78
Horses/Steer	6	0.27	0.30
Cows	5	0.205	0.23
Chicken	1200	0.276	0.30

5.2.2.3. Crops Water Demand

Data regarding agricultural activity were derived from the Municipality report as well. The data also contained information regarding wheat plantations on island that is cultivated as food for farmed animals. It is a common practise on arid areas, not to irrigate these plantations, thus they were not taken into consideration when calculating crops water demand. For the irrigation needs and the cultivation period of the various plants found on the island, a Greek website was consulted, specialised in providing advice to new farmers (www.kalliergo.gr, 2018). This site was chosen specifically among others because it has data related to Greece and the increase in water needs that depend on types of soil and climate zone depending on the different areas of Greece. The data combined and used to calculate crops water demand are presented in Table 6.

Table 6: Agricultural data for Ano Koufonisi island

Crop Type	Area (m^2)	Water height needed (m/d)	Period of Irrigation	Volume Required (m^3/d)
Vegetables	2000	0.0045	January-June	9
Onions	2000	0.0045	March-October	9
Tomatoes	2000	0.00715	April-August	14.3
Lettuce	1000	0.00715	All year	7.15
Cucumbers	2000	0.00405	March-August	8.1
Artichokes	1000	0.00405	November-June	4.05

The data mentioned above, are presented cumulatively in Table 7 for the entire year and are presented in Figure 35. As seen by Figure 35, for water and by Figure 33 for electricity demand, they follow the same pattern regarding peaks, as they are both related to human activity.

Table 7: Cumulative results for water consumption in Ano Koufonisi.

Month	Total Consumption Humans (m^3/d)	Total Consumption Animals (m^3/d)	Total Consumption Crops (m^3/d)	Sum (m^3/d)
January	65.92	6.00	20.2	92.12
February	65.92	6.00	17.1	89.02
March	65.92	6.00	37.3	109.22
April	85.504	6.00	51.6	143.11
May	75.712	6.60	51.6	133.91
June	213.095	6.60	51.6	271.30
July	406.64	6.60	38.55	451.79
August	423.64	6.60	38.55	468.79
September	75.712	6.00	42.55	124.26
October	65.92	6.00	19.3	91.22
November	65.92	6.00	11.2	83.12
December	65.92	6.00	8.1	80.02

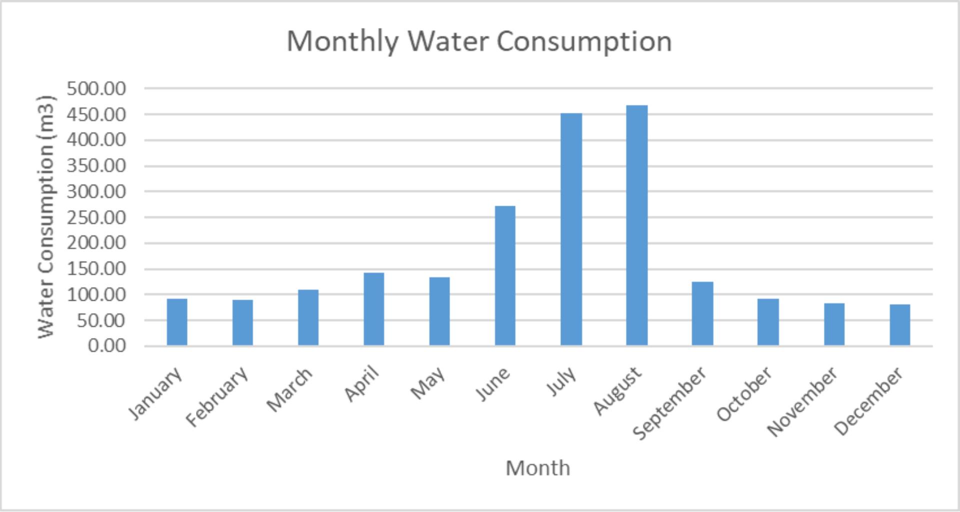


Figure 35: Monthly water consumption for Ano Koufonisi.

5.2.3. RO Electrical Energy Demand Profile

The next step was the relation of water consumption to the energy required to produce this water quantity. As mentioned earlier, the island has already installed a RO desalination unit of 600 m^3/day capacity, since 2014. By July 2018, this capacity will be increased to 700 m^3/day. The existing system has a storage of 2500 m^3 as mentioned in (Municipality of South Aegean, 2016). To relate these quantities with energy, there were used the case studies of (Kartalidis, et al., 2011; Mentis, 2011; Moutafis, 2008; Alsgeghri, et al., 2015; Cisneros Ramirez & Racalde, 2015) along with the desalination-specialised book of (Voutchkov, 2013). On those, it is stated that up-to-date RO desalination units using the regeneration technology have a specific energy consumption of 4.5 kWh/m^3 and their working cycle is up to 97-98%. This practically means that desalination unit could possibly act like an industrial load as the same amount of power (the rated more specifically) would be required for 23.5-23.6 h/day, when water demand requires it. In those units, power is required for the pumps that pressurise saline water to force it to the RO process.

As the unit runs at its full power for 23.5 h/d, the average energy consumption is 4.5 kWh/m^3 and the full capacity 700 m^3, the power rating, considering 5% losses is:

$$P = \frac{700\text{m3 x 4.5 kWh/m3}}{23.5\text{ h}} \cong 135\ kW$$

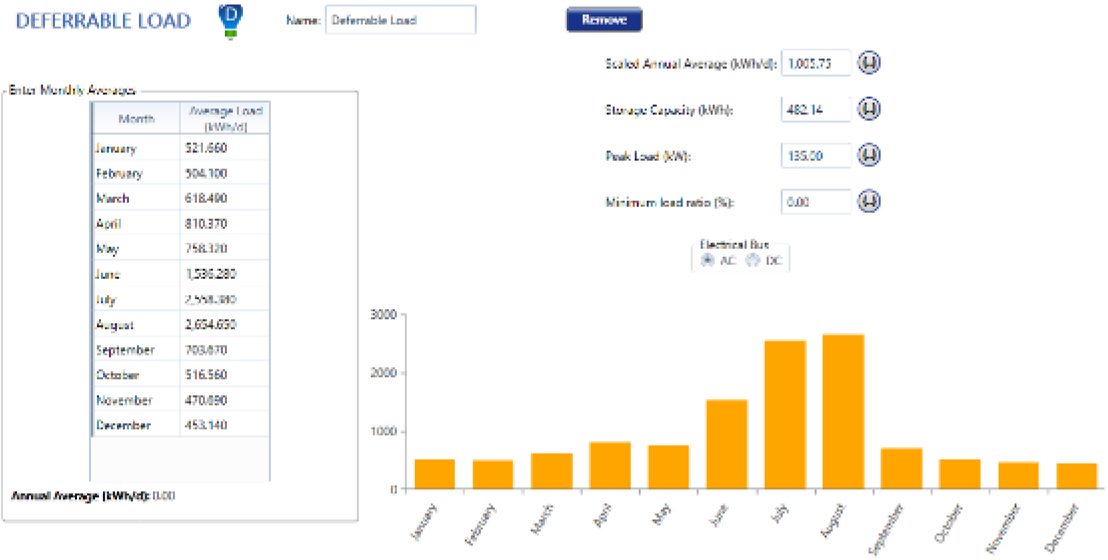
The power rating of the RO unit is then used to calculate the average monthly energy for desalination by multiplying with the volume of water required daily and the power rating and the number of hours required for the daily operation. In order to make safe estimations regarding the system operation (Euaggelopoulou, 2013) suggests that an oversizing of 25% is required in daily water consumption. This is done due to the fact that in some cases, after the installation of such units, the consumer profile changes, with people consuming more as they stop caring for water economy as it is abundant.

Table 8: Calculation for average daily energy consumption of the RO desalination unit of Ano Koufonisi

Month	Daily Consumption (m^3/d)	Daily Consumption Increased by 25% (m^3/d)	Monthly Consumption (m^3)	Operation hours (h)	Energy Consumption per day (kWh/d)
January	92.12	115.2	3569.7	4	521.66
February	89.02	111.3	3115.7	4	504.10
March	109.22	136.5	4232.3	5	618.49
April	143.11	178.9	5366.4	6	810.37
May	133.91	167.4	5189.1	6	758.32
June	271.30	339.1	10173.6	11	1536.28
July	451.79	564.7	17506.9	19	2558.38
August	468.79	586.0	18165.7	20	2654.65
September	124.26	155.3	4659.9	5	703.67
October	91.22	114.0	3534.8	4	516.56
November	83.12	103.9	3117.0	3	470.69
December	80.02	100.0	3100.8	3	453.14

The RO desalination unit load was modelled as a Deferrable Load in Homer Pro. According to Homer Pro Help section, Deferrable Load is a component that represents either a pumping or a thermal or another load with embedded storage, that can be charged from energy surplus from renewables. As charging strategy in this case there was chosen the Load Following (LF) strategy as “when a generator is needed, it produces only enough power to meet the demand. Load following tends to be optimal in systems with a lot of renewable power that sometimes exceeds the load” (HOMER Pro HELP, 2018). The last two parameter that needed to be specified for modelling the RO where the Peak Load and Storage Capacity. Peak Load was chosen to be the same as rated power of the RO unit, i.e. 135 kW, while to calculate the Storage capacity there was used the methodology described in (Farret & Simoes, 2006). This methodology suggests that in systems that use tanks and pumps, the storage capacity can be found by dividing the volume of the tank with the pumping capacity of the system and then multiplying with the power rating of the system. In this case, this is done as follows:

$$\text{Storage Capacity (kWh)} = \frac{2500 \text{ m3}}{700 \text{ m3/d}} \text{ x } 135 \text{ kW} = 482.143 \text{ kWh}$$



Name: Deferrable Load

Scaled Annual Average (kWh/d): 1,005.75

Storage Capacity (kWh): 482.14

Peak Load (kW): 135.00

Minimum load ratio (%): 0.00

Electrical Bus ● AC ○ DC

Enter Monthly Averages

Month	Average Load (kWh/d)
January	521.660
February	504.100
March	618.490
April	810.370
May	758.320
June	1,536.280
July	2,558.380
August	2,654.630
September	703.670
October	516.560
November	470.890
December	453.140

Annual Average (kWh/d): 0.00

Figure 36: The Deferrable Load used for modelling the energy demand of the RO desalination unit operating in Ano Koufonisi.

As seen in Figure 36, the peak energy demands occur during July and August. This would mean that the power imports from grid are increased further. Thus, it is urgent to use local distributed energy resources to cover this demand locally and limit imported electricity. This would also mean reduction to operation costs, increase of resilience and the provision of locally produced green electricity and water.

5.2.4. Water Cost Calculations

On this section, there will be explained the methodology that will be followed to calculate the Water Cost (WC). WC on systems that use renewable electricity for desalination is a significant parameter that indicates the system financial performance (Cisneros Ramirez & Racalde, 2015) and shows the benefit of using such units for clean water production, comparing to methods like transportation with tankers or solar distillation.

All of the formulas used were derived from (Kartalidis, et al., 2011) work, where there was studied a standalone desalination system using PV and wind turbines. These formulas were adjusted to this specific case study and are displayed below:

$$\mathrm{WC} = \frac{(\mathrm{CC_{EN}} + \mathrm{CC_{RO}}) * \mathrm{R} + \mathrm{OM} + \mathrm{EC} - \mathrm{ES}}{\mathrm{WP}} \qquad (1)$$

Where:

WC = Water Cost in €/m^3.

CC_{EN} = Capital Cost of Energy System in €.

CC_{RO} = Capital Cost of Reverse Osmosis desalination unit in €.

R = annuity factor given by

$$\mathrm{R} = \frac{\mathrm{i}}{1 - (1 + \mathrm{i})^{-\mathrm{n}}} \qquad (2)$$

i = interest rate (6%).

n = duration of the investment in years (20 years).

OM = Operation and Maintenance cost in €.

EC = Energy Cost in €, given by:

$$\mathrm{EC} = (\text{Cost of Electricity from Grid}) * \sum_{j=1}^{8760} \mathrm{E_{imported}}(j) \qquad (3)$$

ES = Energy Surplus sold to grid in €, given by:

$$\mathrm{ES} = (\text{Price of Electricity to Grid}) * \sum_{j=1}^{8760} \mathrm{E_{sold}}(j) \qquad (4)$$

WP = Water Produced in m^3, given by:

$$\mathrm{WP} = \sum_{m=1}^{12} [\text{Average Monthly Water Consumption} * \text{days of month}](m) \qquad (5)$$

Regarding the OM costs included in Formula (1), they were calculated using the values of Table 9, that were derived from (Kartalidis, et al., 2011). As WP was taken the total annual volume of produced water by the system, which was assumed to equal the total WC, hence 81,732 m^3. CC_{RO} was taken 694,152 €, as mentioned in the statements of mayor in an interview on a local news website (Kovaios, 2017; Lianos, 2018).

Table 9: OM cost breakdown for the RO Desalination Unit

OM Cost		**Calculation (€)**
Labor	25000 €/yr	25,000.0
Chemicals	0.065 x WP €/m^3	5,312.6
Membranes	0.15 x WP €/m^3	5,312.6
Consumables	0.04 x WP €/m^3	5,312.6
Insurance	0.05 x (CC_{RO})	5,312.6
Total		46,250.3

In this case study, given the fact that there is a specific desalination unit, the only variables for each of the proposed systems are: CC_{EN}, EC and ES. This means that when comparing systems in terms of WC, the one that at the same time has the lowest CC_{EN} and achieves the highest fraction of load covered by renewables will achieve the lowest WC. This will be used later in the results comparison as an index regarding financial performance of systems in terms of costs related to water.

5.2.5. Key Model Characteristics

On this section there will be analysed and presented accumulatively all the key parameters that were taken into consideration in the system modelling. Some of the parameters will be analysed further in the Sensitivity Analysis section, as they might be succumbing to changes over the project lifetime and affect the system performance.

5.2.5.1. Resources Characteristics- System Components

The two sources that were chosen to be examined in the project for different adoption rates and configurations are wind and solar energy. Both sources are in abundancy in the area of Koufonisi and may similar projects that were mentioned on previous sections utilise them. The main goal of the proposed systems is to reduce the use of subsea cables for Koufonisi and cover as much as possible the demand for the RO desalination unit that the system has. To achieve that goal, storage was necessary as besides other limitations, there are legal restrictions on the amount of power exports from renewables to networks in Greece.

The resources data used, were all derived from Homer Pro database that has data of 20 years, so they can be considered valid.

1. **Wind:**

The average wind speed for Koufonisi can be seen in Figure 37. The annual wind speed in 6.28 m/s, the Weibull k parameter 1.43 and the autocorrelation facto 0.886 as derived from a similar project in a nearby island used in (Vassileiadis, 2014).

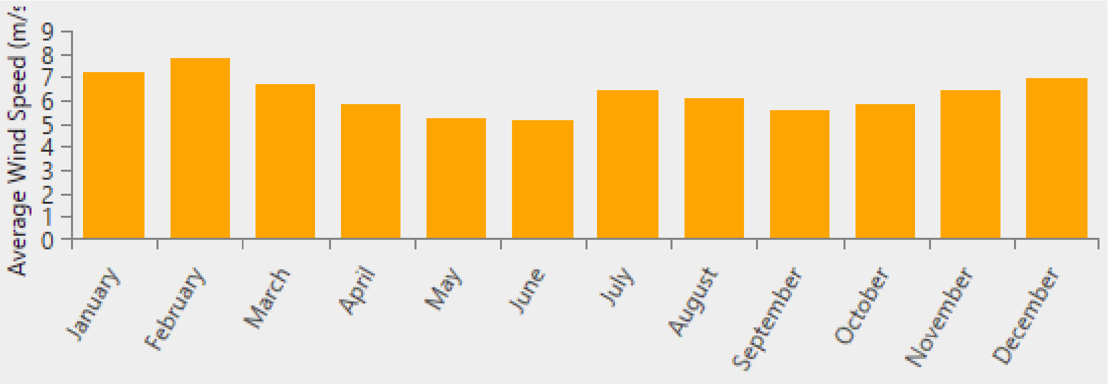


Figure 37: Average wind speeds in m/s for Ano Koufonisi.

A significant parameter that defined the type of wind energy device used was the hub height. Hub height had to be below or equal to 40, as above that height any type of device would have a heavy impact on the landscape. As mentioned earlier the impact on landscape is very important for the local community, as they do not want at any occasion any intervention to ruin landscape.

Taking into consideration the average wind speeds and the hub height limitations there was decided to examine three types of wind turbines of rated power of 100, 250 and 500kW. Specifically, these were: Norvento nED 24 [100kW], WES 30 [250kW] and Windflow 45 [500kW]. Due to similarities, the losses were taken as 10% on each case and Temperature Effects were taken into account. Initial and replacement costs were taken as equal as there were not found any guarantee forms mentioning the difference of such costs. Operation and Maintenance (OM) costs were taken as approximately 1% of the initial CC as was consulted by (Mentis, 2011; Vassileiadis, 2014; Euaggelopoulou, 2013). For the three types of turbines, the costs (CC, OM) at the time of the writing of this text were:

- 100 kW: CC=129,000€, OM=1300€ (www.conserve-energy-future.com, 2017).
- 250 kW: CC=530,000€, OM=5000€ (German & Newton, 2010).
- 500 kW: CC=785,000€, OM=7900€ (Windflow Technology Ltd., 2016).

On the Results section for simplicity purposes, wind turbines will be referred only with their power rating, i.e. 100 for 100kW, 250 for 250kW and 500 for 500kW wind turbine accordingly.

2. Solar PV:

The second resource that was chosen was solar radiation. As seen in Figure 38, for the specific location the average Global Horizontal Irradiance is 5.23 kW/m^2/day and the average clearness index 0.55, as derived from Homer database. This gives a significant potential to use solar PV for energy generation. Another important parameter is the latitude which is 36.5^o, as it will be the slope for the system. Azimuth was taken 0^o, as Greece is located on the northern hemisphere.

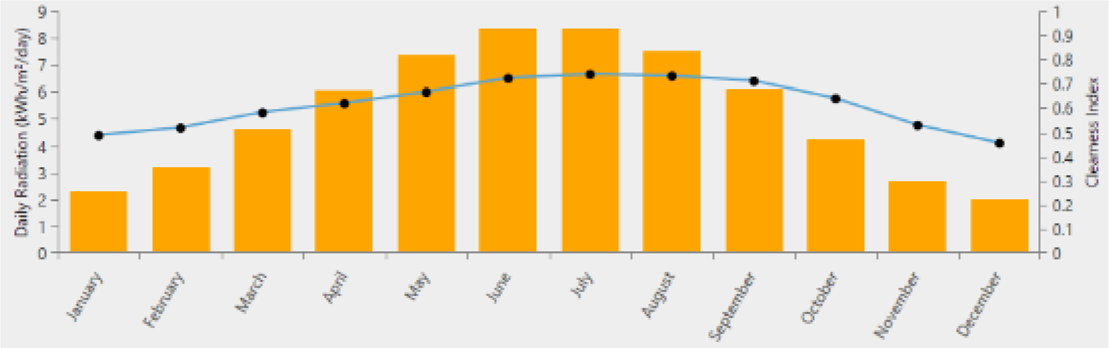


Figure 38: Global Horizontal Irradiance in $kW/m^2/day$ and Clearness Index in %, for Koufonisi.

Regarding the other parameters, ground reflectance was taken as 25%, according to (Vassileiadis, 2014), temperature effects were considered because at summer temperature might drop the efficiency significantly as it was analysed in section 3.1.1. Efficiency was taken as 16% according to (HELAPCO, 2017), nominal operating temperature as 47^{o}C and temperature effects as 0.5% of nominal power per ^{o}C. The module that was used was the generic one of Homer Pro as it could be widely customised. The derating factor was calculated taking into consideration 3 major parameters, hence module production tolerance mismatch (0.95), dust and dirt (0.95) and the east-west shading factor (0.9) (Damianidis, et al., 2011) and was calculated to be 0.8123 or 81.23%. Regarding the price of PV in Greece, the costs are: CC = 1000 €/kW, Replacement Cost = 750 €/kW and OM = 10 €/year (HELAPCO, 2017). Maximum Power Point Trackers (MPPT) were not used.

On the Results section solar PV capacity will be referred as (number)PV, for example a 40 kWp PV will be referred as 40PV.

3. <u>Storage:</u>

Regarding storage, there was chosen the Vanadium Redox Battery (VRB) technology, as for the time being it is the most promising technology for grid-scale storage. It is also highly customisable as capacity depends on electrolyte tank size and can be scaled up or down to meet the needs (Atwell, 2018). Moreover, the technology seems to compromise an affordable price and not have limitations similar to other forms of massive storage for islands.

More specifically, the battery used was Gildemeister's CELLCUBE 200 kW/400 kWh. The battery was used in many projects around the world like Cardongianos in Italy, Ontario in Canada, Tussenhausen and Pellworm in Germany, etc. for grid scale and microgrid scale storage in different sizes (Maiers, 2017; Blatsios & Feichtinger, 2016). The battery as shown in Figure 39 comes at a double container enclosure, as a turnkey solution and can be easily transported when necessary. Besides that, it had been used in other studies like the one in (Blatsios & Feichtinger, 2016) for Sifnos island, and its technology performance does not seem to deteriorate with temperature increases that could happen during summer period in Greece.

Nominal Voltage (V): 700
Nominal Capacity (kWh): 576
Maximum Capacity (Ah): 822
Capacity Ratio: 0.281
Rate Constant (1/hr): 8.74
Roundtrip efficiency (%): 65
Maximum Charge Current (A): 230
Maximum Discharge Current (A): 354

Figure 39: CELLCUBE 200/400 VRB with its main parameters (Blatsios & Feichtinger, 2016)

In the Results section, when referring to the amount of batteries, there will be used the abbreviation (number) BATT. For example, 2 200/400 CELLCUBE batteries will be simply referred as 2BATT.

4. Converter:

The Converter that was used was the Generic AC-DC converter of Homer Pro. Its costs according to (Vassileiadis, 2014) were:

- CC = 250 €/kW.
- Replacement Cost = 200 €/kW.
- OM = 10 €/year.

Its efficiency was taken: 95%.

5. System Controls:

The Control strategy used was Load Following. Although, in the grid-connected configuration that is being studied here, the dispatch strategy does not affect results. It would though play a very significant role if there were used fuel-fired generators on the system.

6. Grid:

The Grid configuration used was the Scheduled Rates, as this allows for Grid Sales limitation and Net Metering simultaneously. The total energy that can be supplied is set at 1050 kW. According to the legal framework mentioned on the next section, each time the maximum exportable power is 0.2*Peak Power of the RES installed on island. For all of the system components the lifetime was set 20 years, which is the lifetime of the project. Project lifetime was set on 20 years as this is the maximum price guarantee contract that the State signs with energy related enterprises (large or small) for energy sales and imports (IPTO, 2016).

5.2.5.2. Regulations and Legal Framework

The most significant parameter when it comes to design of RES in Greece is the legal framework. Designs for projects that do not follow the energy related laws are never approved, thus for every design to be considered valid, should be within specific margins. The law 3851/2010 (Hellenic Government Gazette, 2010), states that for small energy prosumers, including desalination units using RES: "the amount of power sold to grid must not exceed the 20% of the rated power of the energy generating unit". For this case study this limitation has a major impact to the maximum renewable energy system peak power capacity. To be able to make full use of the transmission lines the maximum renewable capacity in total must not exceed: 1050 kW / 0.2 = 5250 kW. Otherwise, a lot of energy will have to be curtailed as there will not be neither load to consume it nor the proper infrastructure to export it to the grid.

Consequently, this law also shapes the form of the adopted solutions regarding the components used, as storage becomes necessary, because of the export limitation, that prevents selling the 80% of energy surplus. Energy storage is preferred to serve local needs rather than being sold to the grid, to increase local resilience. Adoption of massive storage also allows the operation of network in island mode, when this is possible. Although this mode requires device that can regulate frequency and voltage (Ismail, et al., 2015)

Regarding tariffs, the Greek network operator applies different rates for non-connected and grid connected areas. In the examined case, Koufonisi will be regarded as connected area, as it does not own an APS. Thus, the energy purchase-price will be the same as that of the island that operates the APS and feeds Koufonisi substation. In Table

10, there can be seen the prices set by the aforementioned law, as they are formed for 2018 and apply to the present case study criteria.

Table 10: Energy Tariffs for various resources in Greece

Source	**PV**	**Wind**	**Hybrid**	**Purchase from Grid**
Price (€/kWh)	0.08	0.09945	0.147	0.1145

Due to higher price of grid imported energy, on this project, the charging of batteries from grid will be prohibited and they will only be allowed to charge from surplus. Moreover, the battery charging from grid will also be prohibited in order to avoid capacity oversizing and to keep the initial cost as low as possible.

5.2.5.3. Performance Indicators Used

The performance indicators that will be used to compare different systems on this case study are[8]:

1. Net Present Cost (NPC): NPC represents the life-cycle cost of a project for its entire lifetime. This includes all the costs minus revenues and present value. It is a very important indicator as it gives an aspect of the costs or revenues to the project investment as a whole.

2. Levelized Cost of Energy (COE): It represents the average cost per kWh of useful electrical energy produced by the system. It is calculated from the formula:

$$\mathrm{COE} = \frac{\frac{\mathrm{i} * (1+\mathrm{i})^{\mathrm{N}}}{(1-\mathrm{i})^{\mathrm{N}} - 1} * \mathrm{NPC}}{(\text{AC load served} + \text{Deferrable load served} + \text{Grid Sales})} \tag{6}$$

---

[8] All definitions were derived from (HOMER Pro HELP, 2018).

Where:

i: discount rate

N: project lifetime

3. Renewable Fraction (ReF): The amount of energy delivered to load from the system renewables, given by:

$$\mathrm{ReF} = 1 - \frac{(\text{Energy delivered from Grid and Generators})}{(\text{AC load served} + \text{Deferrable load served} + \text{Grid Sales})} \tag{7}$$

4. Excess Electricity (EE): Is the amount of energy per year (kWh/yr) that cannot be consumed, neither be sold to the grid.

Renewable resources are of stochastic nature, which means that their dispatch cannot be scheduled. Thus, large quantities of energy can be generated when load is low. This creates a surplus that on some cases cannot be used or stored. In systems with transmission capacity limitation, like the examined one, it cannot either be sold. For this reason, it is important to keep EE as low as possible. By doing so, the RE system is used as much efficiently as possible.

5. Grid Sales (GS): The amount of energy in kWh that is sold to grid annually.

6. Grid Imports (GI): The amount of imported energy from the grid in kWh.

7. Capital Cost (CC): The initial cost required for the purchase and installation of the RES used.

The last three indexes not only affect the financial performance of the investigated systems but also affect directly the water cost as displayed in Formula (1). These indexes are included in NPC, so configurations that achieve the lowest NPC will be considered as being better as they achieve better cost-profit ratio over the project lifetime. Due to that fact, WC will only be examined for the configuration with the lowest NPC for each scenario, as this configuration will be the “winner”. This is done because if the system was to be built, NPC would be the primary criterion for the investment.

5.2.6. Scenarios

0. <u>Current Situation Scenario (0% Adoption Rate)</u>

This will be the base case scenario, which is used to evaluate the current system and have a basic aspect on the main indexes before proceeding to any further implications. The result will be used as a limit for the examined systems, as they are supposed to perform better than the base case.

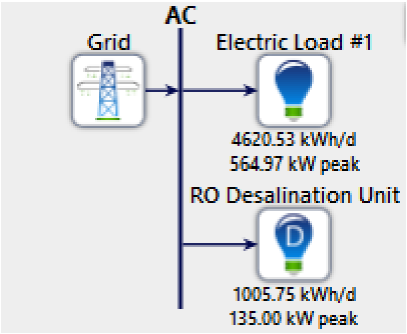


Figure 40: 0% Adoption Rate system

The following scenarios are related to four different renewables adoption rates. By adoption rate, the author refers to the percentage of the electrical load that is covered by a combination of systems. These systems include wind turbines, PV and battery. For each of the combinations there were examined:

- PV systems including batteries or not, depending on the case, Figure 41.
- Wind turbines of three different power ratings (100, 250 and 500 kW) including batteries or not, depending on the case, alike, Figure 42.

- Hybrid systems with batteries, PV and three different types of wind turbines, Figure 43.

1. **Small-Scale Adoption Scenario (25% Adoption Rate)**
2. **Net Balance Adoption Scenario (50% Adoption Rate)**
3. **Large-Scale Adoption Scenario (75% Adoption Rate)**
4. **Full-Scale Adoption Scenario (100% Adoption Rate)**

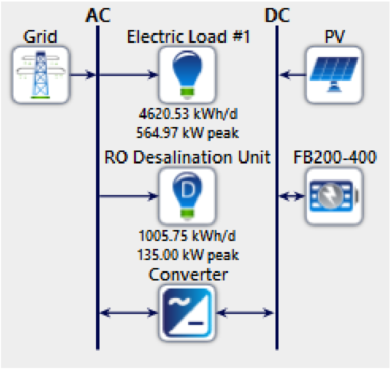


Figure 41: PV system examined for Scenarios 1-4.

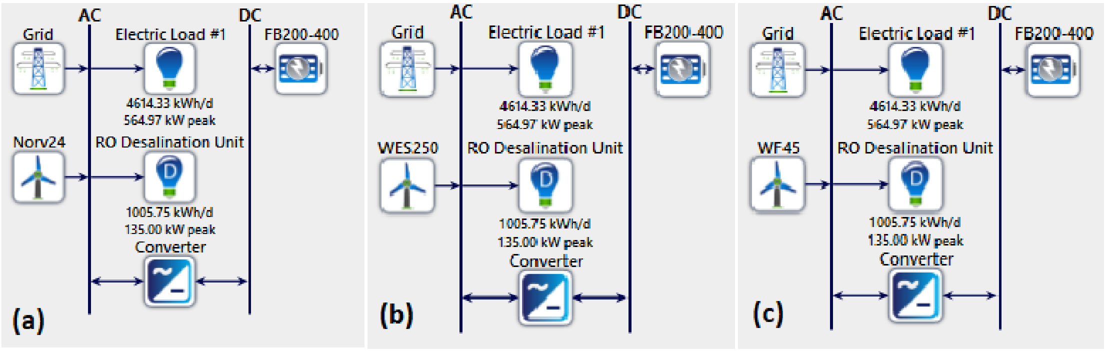


Figure 42: 100kW (a), 250kW (b) and 500kW (c) wind turbine systems examined for Scenarios 1-4.

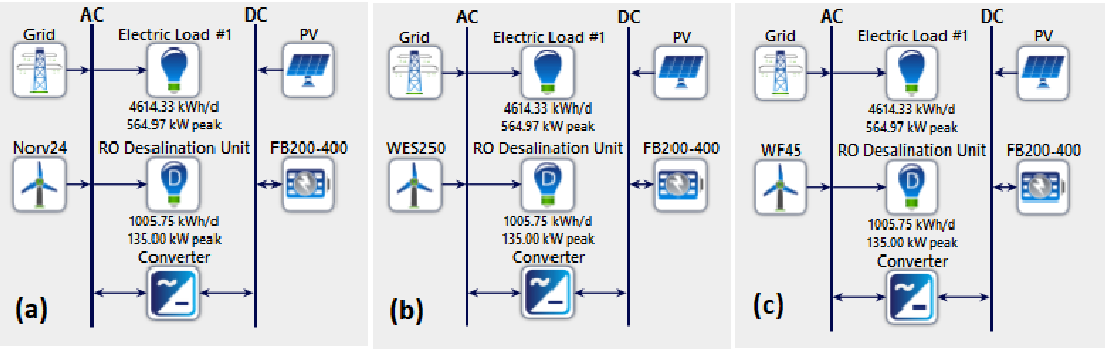


Figure 43: PV + 100kW wind turbines + battery Hybrid system (a), PV + 250kW wind turbines + battery Hybrid system (b) and PV + 500kW wind turbines + battery Hybrid system (c) examined for Scenarios 1-4.

6. Results and Discussion

Before proceeding to the results, it would be useful to explain the method that was followed to choose the appropriate combinations. First of all, Homer was regulated to the wanted ReF each time, using the Minimum Renewable Fraction Constraint from the Constraints section. After that, the Optimiser was run, and the results were filtered according to the following criteria by order of priority:

- examined system ReF< examined ReF+0.5% (e.g. for 25% adoption rate there were examined all the results between 25-25.5%).
- examined system NPC<NPC $_{\text{base case}}$.
- examined system COE<COE $_{\text{base case}}$.
- For systems that had almost the same values for the three indexes there was chosen the one with the lowest EE.

Systems that did not achieve in any combination results within the set limits were not regarded as acceptable and were not included on the Results. For wind or PV and battery systems, if a solution without batteries gave better results than those including batteries, it was chosen instead. For hybrids, the battery used was dependant on the case.

For each adoption rate, only the successful combinations were compared to find the “winner”. A system was awarded winner if it had as many of the requirements as possible from the following:

- the lowest NPC
- the lowest CC
- the lowest COE
- the lowest WC
- the lowest EE
- the lowest GI
- the highest GS

6.1. Current Situation Scenario (0% Adoption Rate) Results

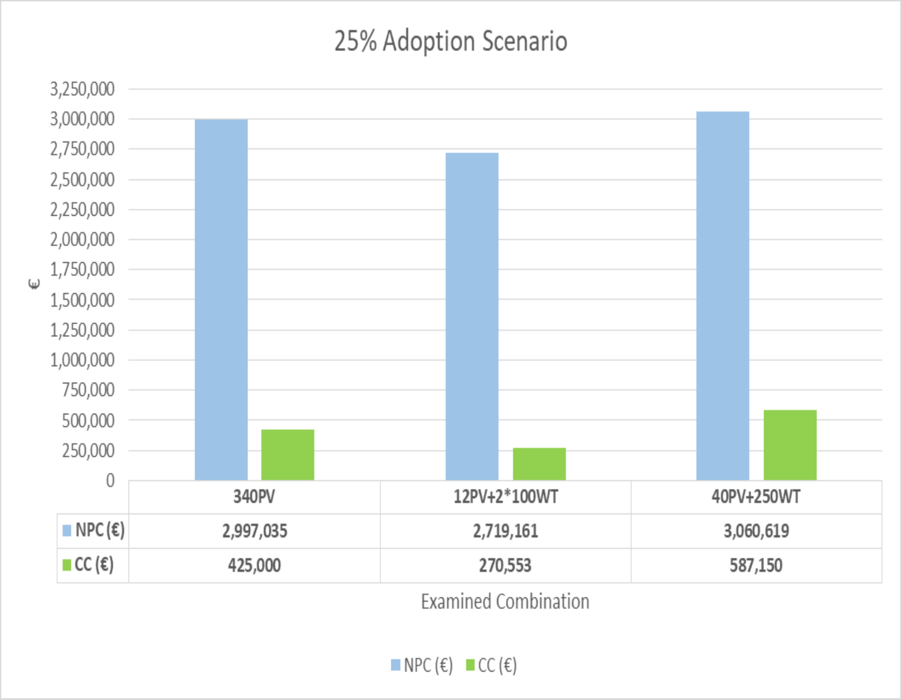
The results for the 0% renewables scenario, which is the base case on this case study, act as limits for the results of the different examined combinations. If and only if a combination for a specific ReF could achieve better results than the base case system, (for every of the examined indexes) then the combination was regarded as successful and compared with other successful systems in order to determine which was better on each adoption rate.

Results for the base case system are presented in Table 11. As it is obvious there are no exports and no EE, as there are no renewables on the island and it is supplied by a neighbouring island. The index values that are the most important are the NPC, the levelized COE and WC, which all three are the upper limits for the examined combinations in order for them to be successful.

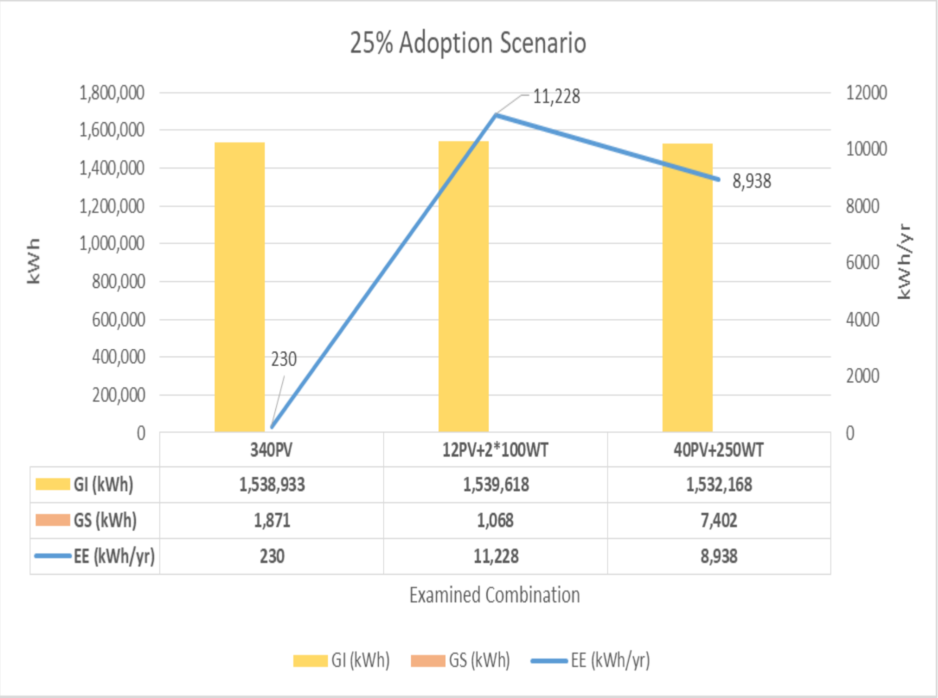
Table 11: Values of the examined indexes for the base case system.

NPC (€)	3,215,277
COE (€/kWh)	0.1145
CC (€)	0
EE (kWh/yr.)	0
GI (kWh)	2,052,105
GS (kWh)	0
WC (€/m3)	4.18

6.2. Small-Scale Adoption Scenario (25% Adoption Rate) Results



	340PV	12PV+2*100WT	40PV+250WT
NPC (€)	2,997,035	2,719,161	3,060,619
CC (€)	425,000	270,553	587,150



	340PV	12PV+2*100WT	40PV+250WT
GI (kWh)	1,538,933	1,539,618	1,532,168
GS (kWh)	1,871	1,068	7,402
EE (kWh/yr)	230	11,228	8,938

Figure 44 (Left): Comparison of NPC, CC for the successful combinations of the 25% Adoption Scenario.

Figure 45 (Right): Comparison of GI, GS and EE for the successful combinations of 25% Adoption Scenario. The left axis in kWh refers to GI, GS and the right in kWh/yr. refers to EE.

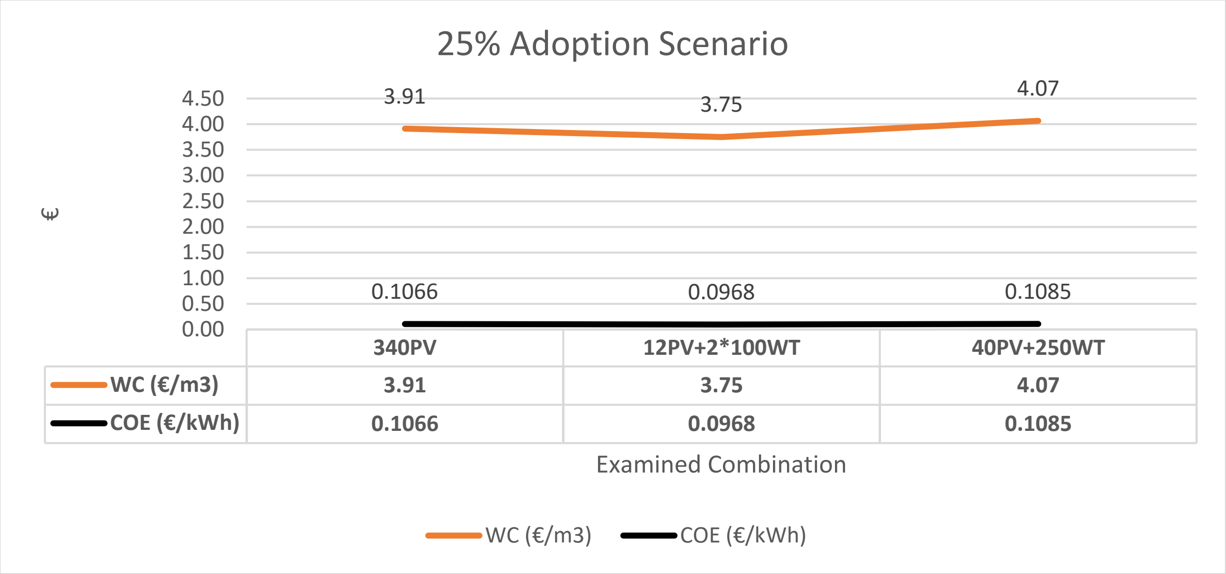
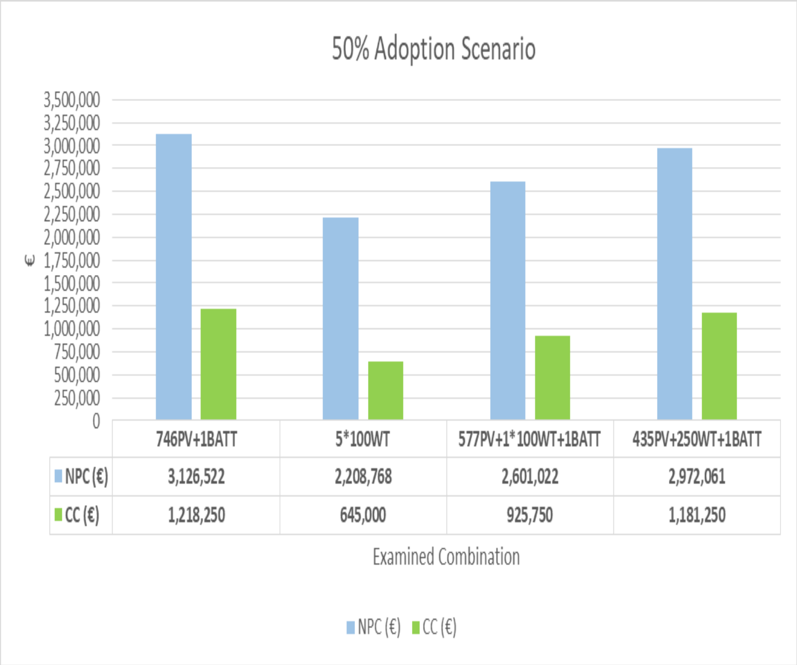


Figure 46: Comparison of COE and WC for the successful combinations of 25% Adoption Scenario.

For 25% the only feasible combinations were: 340PV, 12PV+2*100WT and 40PV+250WT. Wind turbine-only systems were rejected as with 100 kW wind turbines the COE was higher than 0.1145 €/kWh, for 250 kW the lowest NPC was higher than 3.22 million € and for 500 kW the renewable fraction exceeded by far 25%. Batteries were avoided at this rate because the surplus electricity was too low and due to that fact, the use of batteries would increase the initial CC without improving the rest of the indexes significantly. Also, given the fact that this adoption rate covers part of the load, this excess could be used increasing the adoption rate, rather than being stored.

As displayed in Figure 44, the system with the lowest NPC and CC was the 12 PV+2*100WT hybrid. The system with lowest GI and highest GS was 40PV+ 250WT, while the lowest EE was achieved by the 340PV system, according to Figure 45. The 12PV+2*100WT hybrid also achieved the lowest COE and WC as depicted in Figure 46. This system achieved the best performance in most of the indexes, thus it would be preferred if a small-scale adoption of 25% was ever attempted on site.

6.3. Net Balance Adoption Scenario (50% Adoption Rate) Results



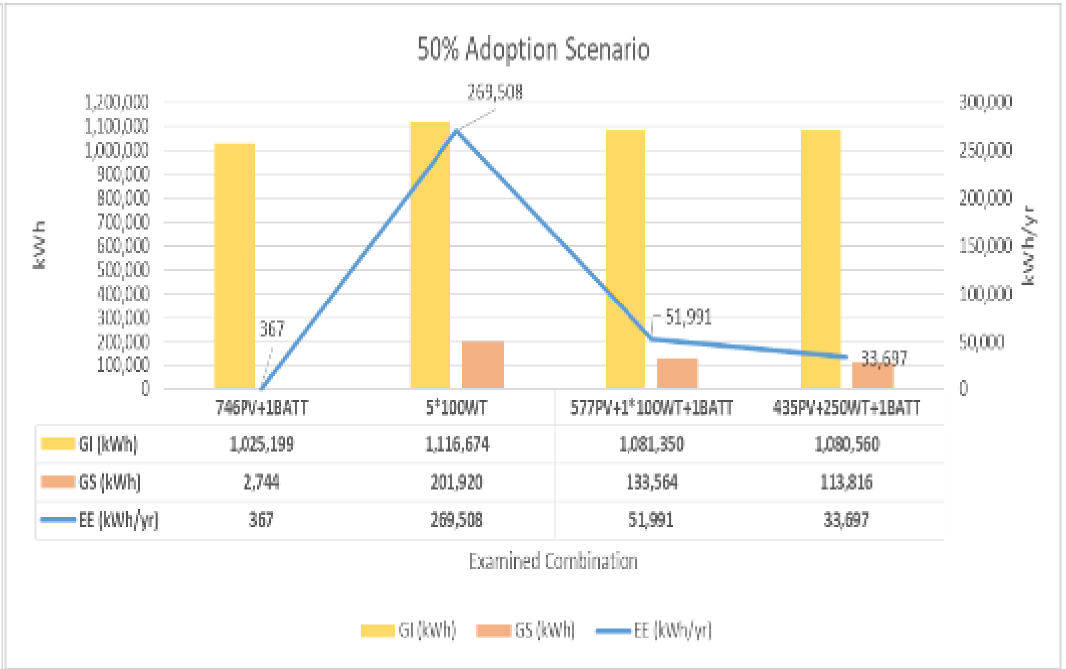
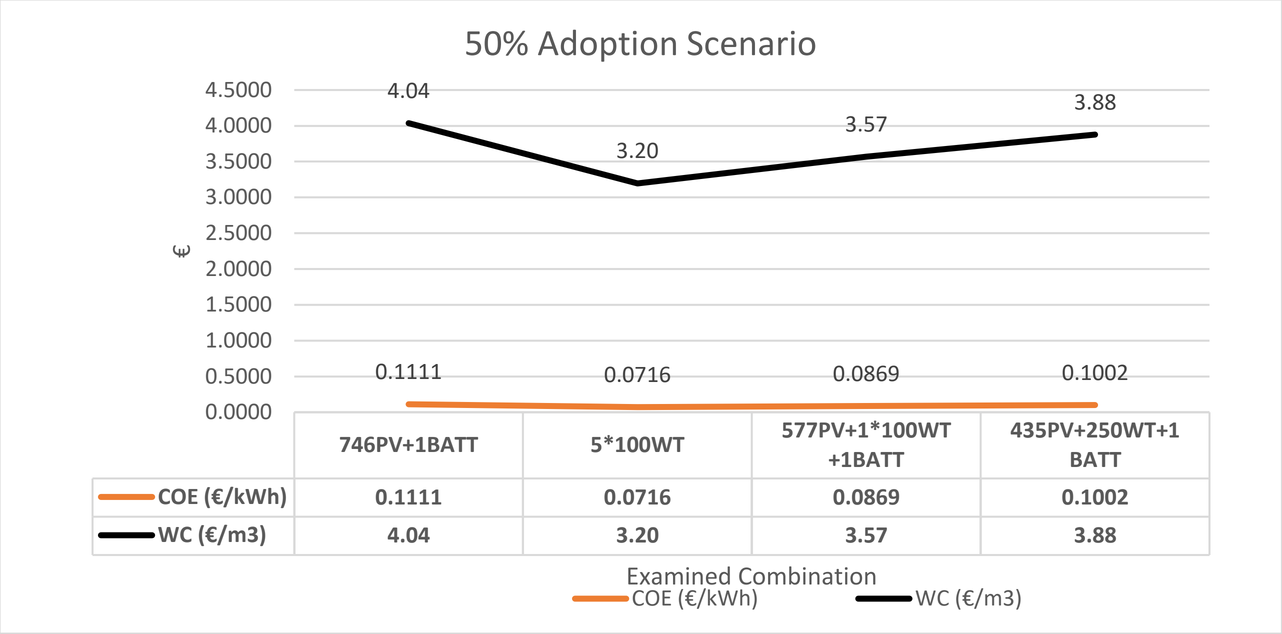


Figure 47 (Left): Comparison of NPC, CC for the successful combinations of the 50% Adoption Scenario.

Figure 48 (Right): Comparison of GI, GS and EE for the successful combinations of 50% Adoption Scenario. The left axis in kWh refers to GI, GS and the right in kWh/yr. refers to EE.



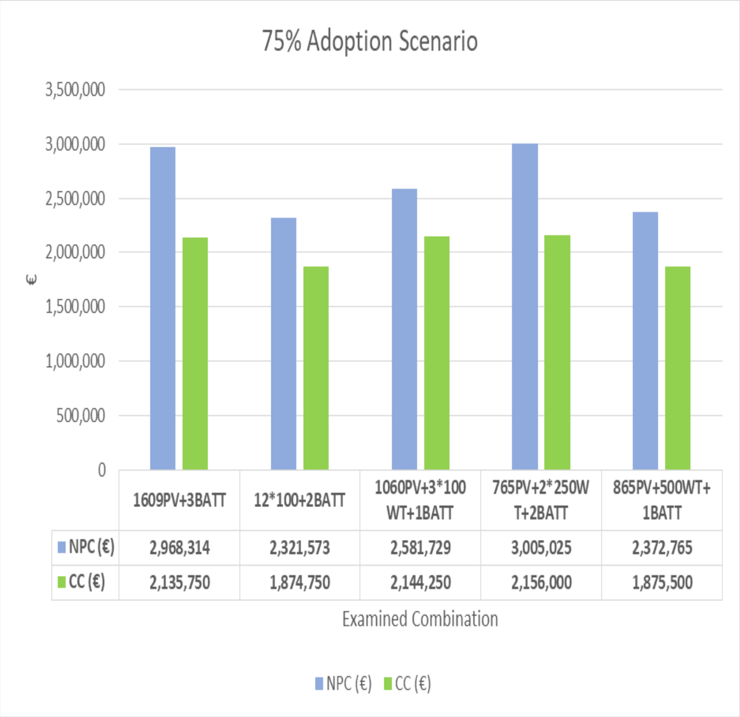
	746PV+1BATT	5*100WT	577PV+1*100WT +1BATT	435PV+250WT+1 BATT
COE (€/kWh)	0.1111	0.0716	0.0869	0.1002
WC (€/m3)	4.04	3.20	3.57	3.88

Figure 49: Comparison of COE and WC for the successful combinations of 50% Adoption Scenario.

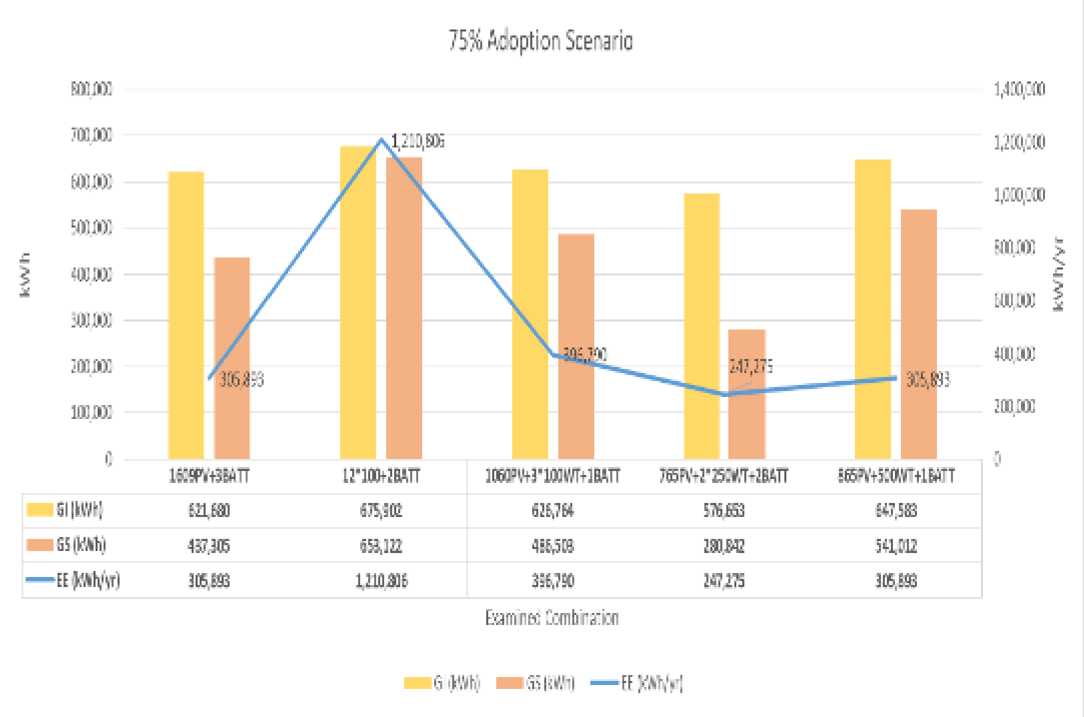
For the 50% combinations and given the fact that surplus was relatively big there were examined combinations with batteries. On some cases though, Homer Optimiser showed that combinations not including them achieved better performance on the examined indexes. For the 50% adoption rate the combinations that were successful were: 746PV+1BATT, 5*100WT, 577PV+100WT+1BATT and 435PV+250WT +1BATT. The PV+500WT+BATT hybrid failed as its NPC was higher than the initial system, while for the 250/500WT+BATT systems the COE was above the 0.1145 €/kWh limit. Because of that these systems were rejected.

As shown in Figure 47 the 5*100WT combination achieved the lowest NPC with the lowest initial CC at the same time. This system, according to Figure 48, also had the highest GS and the lowest GI. The same figure shows that the lowest EE was achieved by the 746PV+BATT. As for the WC and COE indexes the 5*100WT again achieved the lowest prices, as depicted in Figure 49 and by that it establishes as the most preferable combination for the 50% renewables adoption rate.

6.4. Large-Scale Adoption Scenario (75% Adoption Rate) Results



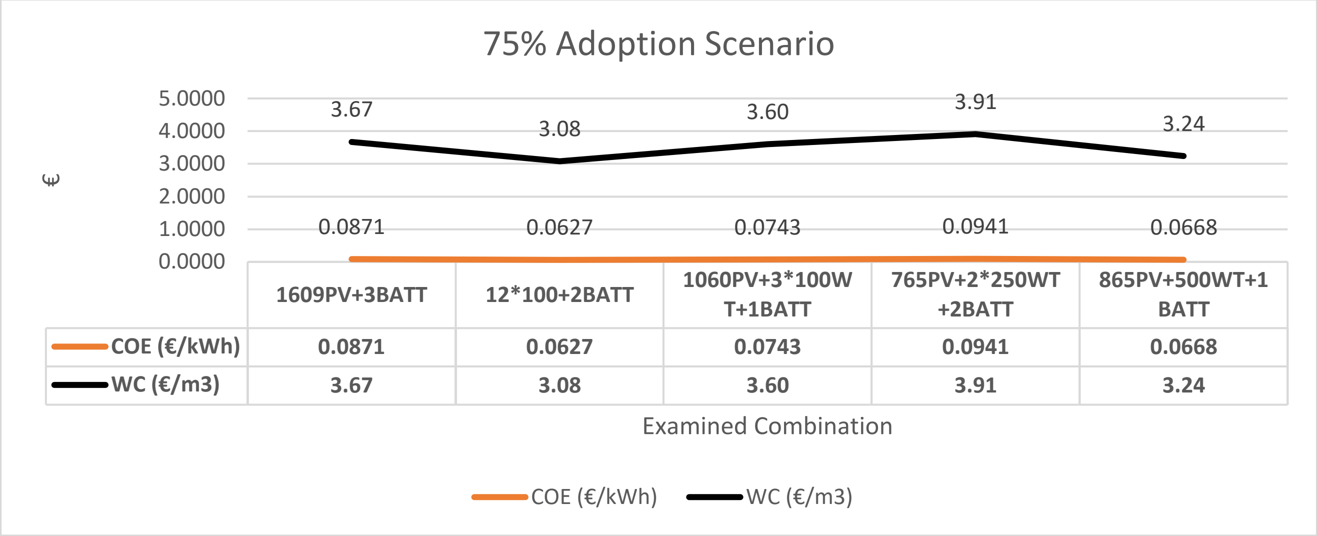
	1609PV+3BATT	12*100+2BATT	1060PV+3*100WT+1BATT	765PV+2*250WT+2BATT	865PV+500WT+1BATT
NPC (€)	2,968,314	2,321,573	2,581,729	3,005,025	2,372,765
CC (€)	2,135,750	1,874,750	2,144,250	2,156,000	1,875,500



	1609PV+3BATT	12*100+2BATT	1060PV+3*100WT+1BATT	765PV+2*250WT+2BATT	865PV+500WT+1BATT
GI (kWh)	621,680	675,902	626,764	576,653	647,583
GS (kWh)	437,305	653,122	486,508	280,842	541,012
EE (KWh/yr)	305,893	1,210,806	396,790	247,275	305,893

Figure 50 (Left): Comparison of NPC, CC for the successful combinations of the 75% Adoption Scenario.

Figure 51 (Right): Comparison of GI, GS and EE for the successful combinations of 75% Adoption Scenario. The left axis in kWh refers to GI, GS and the right in kWh/yr. refers to EE.



	1609PV+3BATT	12*100+2BATT	1060PV+3*100WT+1BATT	765PV+2*250WT+2BATT	865PV+500WT+1BATT
COE (€/kWh)	0.0871	0.0627	0.0743	0.0941	0.0668
WC (€/m3)	3.67	3.08	3.60	3.91	3.24

Figure 52: Comparison of COE and WC for the successful combinations of 75% Adoption Scenario.

For the 75% adoption rate the successful combinations were: 1609PV+3BATT, 12*100WT+2BATT, 1060PV+3*100WT+1BATT, 765PV+2*250WT+2BATT and 865PV+500WT+1BATT. The 250/500WT+BATT systems were rejected because for these wind turbine ratings in order to achieve the desired adoption rate, it was necessary to keep the wind turbine number low (achieving adoption rate numbers below 75%) and increase the batteries' number (to reach 75%). This increased the NPC above the acceptable limit and these configurations were rejected.

As shown in Figure 50, the combination that achieves the lowest NPC and lowest initial CC is the 12*100WT+2BATT. The same combination achieves the highest GS, while the lowest GI are achieved by the 1609PV+3BATT system and the lowest EE by the 765+2*250WT+2BATT system, as shown in Figure 51. In Figure 52, it can be seen that the 12*100WT+2BATT system achieves the lowest COE and WC and by that, after having achieved the best performance in the majority of the examined indexes, this system appears to be the most preferable for this adoption rate.

6.5. Full-Scale Adoption Scenario (100% Adoption Rate) Results

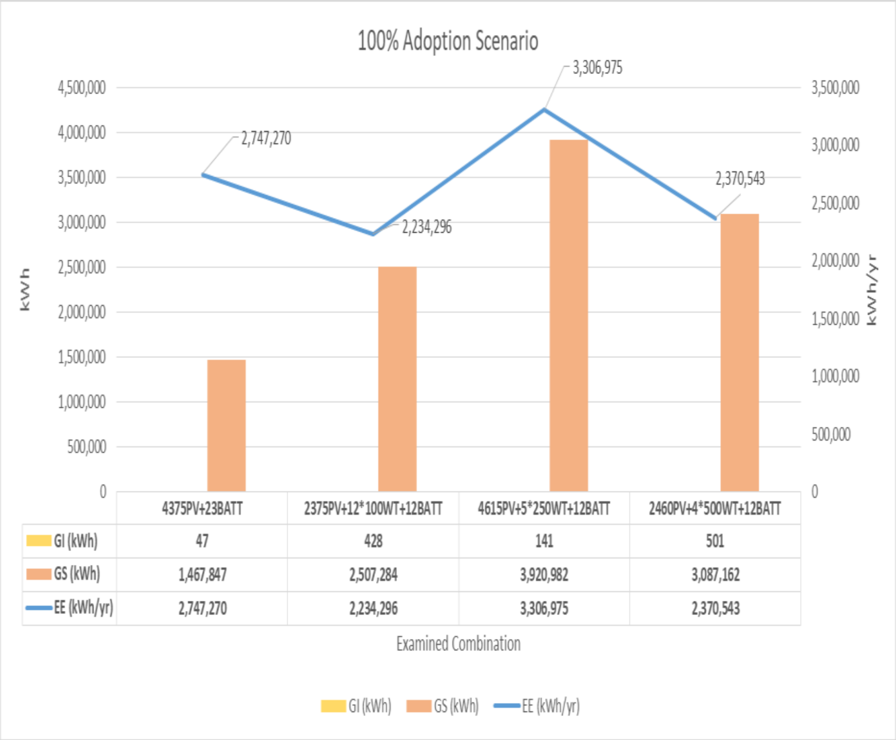
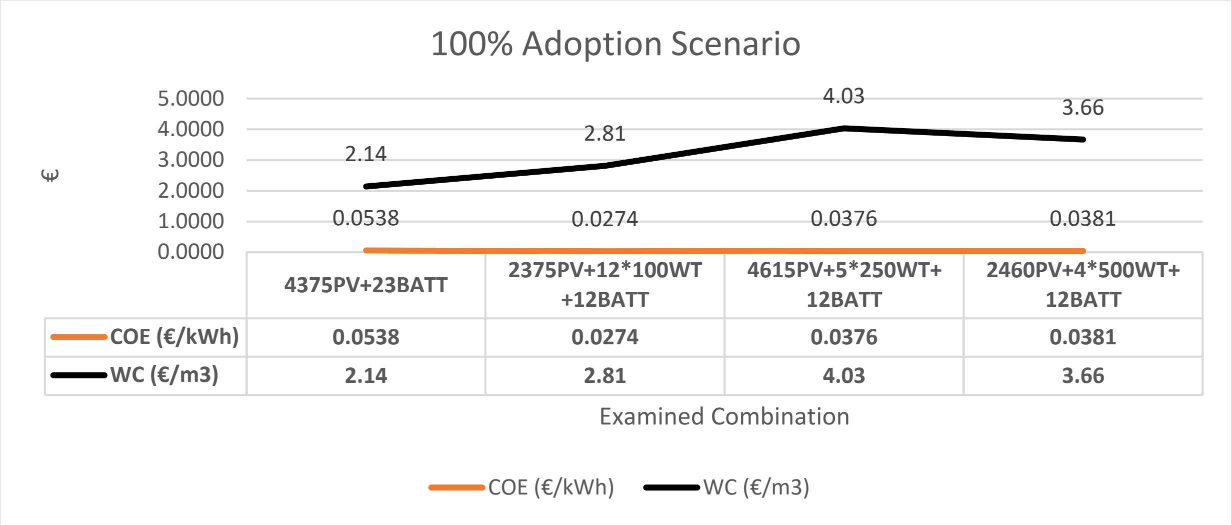


Figure 53: Comparison of NPC, CC for the successful combinations of the 100% Adoption Scenario.

Figure 54: Comparison of GI, GS and EE for the successful combinations of 100% Adoption Scenario. The left axis in kWh refers to GI, GS and the right in kWh/yr. refers to EE.



	4375PV+23BATT	2375PV+12*100WT +12BATT	4615PV+5*250WT+ 12BATT	2460PV+4*500WT+ 12BATT
COE (€/kWh)	0.0538	0.0274	0.0376	0.0381
WC (€/m3)	2.14	2.81	4.03	3.66

Figure 55: Comparison of COE and WC for the successful combinations of 100% Adoption Scenario.

For the 100% adoption scenario the successful combinations were 4375PV+23BATT, 2375PV+12*100WT+12BATT, 4615PV+5*250WT+12BATT and 2460PV+ 4*500WT +12BATT. All of the systems that were based on wind turbines and batteries solely, were rejected as they could not achieve this ReF and at the same time remain under the set NPC and COE boundaries.

Regarding the indexes performance, the 2375PV+12*100WT+12BATT hybrid achieved the lowest NPC while the 4375PV+23BATT achieved the lowest initial CC, as shown in Figure 53. The highest GS were achieved by 4615PV+5*250WT+12BATT and the lowest EE by 2375PV+12*100WT+12BATT. The lowest imports were achieved by 4375PV+23BATT as depicted in Figure 54. Even though the adoption rate is 100%, the GI are not zero which means that neither of these systems can operate completely autonomously as they need grid electricity to cover some of their peaks. Trying to increase the size of the systems to be able to cover their peaks would create an oversizing of batteries or huge amounts of EE, as the transmission capacity of the island connection is limited.

From Figure 55, it is derived that the system with the lowest COE is 2375PV+12*100WT+12BATT, while the one with the lowest WC is 4375PV+23BATT. The 2375PV+12*100WT+12BATT hybrid in total achieves better performance in more indexes than the 4375PV+23BATT, thus it is preferred as the most appropriate solution for this adoption rate.

Results for all combinations and adoption rates, more analytically can be found on Appendix 1.

6.6. Results Summary and Discussion

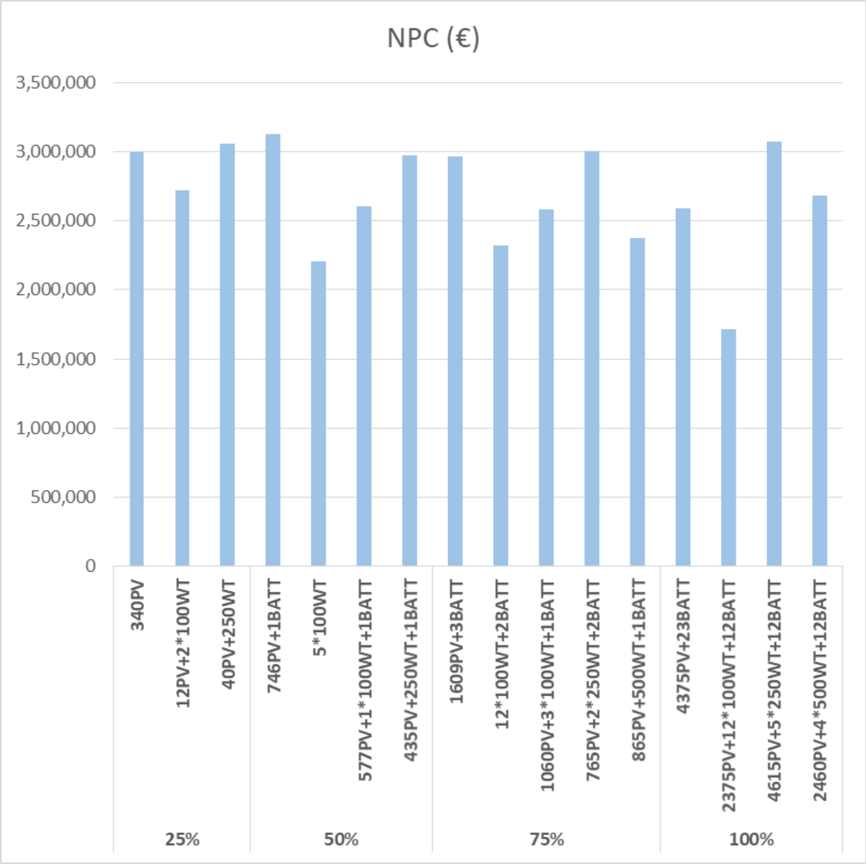
This section includes an accumulative comparison of the feasible solutions of the previous sections. This is done in order to investigate the connection and influence in between the different examined indexes and reach to conclusions regarding the performance of these systems. Results are presented in graphical form in Figures 56-62 and can be found in form of table in Appendix 2.

Regarding the wind-based combinations for 25, 50 and 75% adoption rates that did not achieve feasible results, on most cases either the COE or the NPC, exceeded the one of the initial base case system. The reason for that is the limitation in electricity export and the high initial cost of the equipment. Export limitation also limits the revenue of the investment and cannot achieve the payback that is expected through the project lifetime. Thus, wind farms on islands and especially bigger ones need strong connections to grid. Although batteries provide sufficient results for systems of small size or limitations, as proceeding to larger scale other more massive solutions such as pumped hydro prove to be more effective and financially better.

From Figures 56, 57 and 61 seems that COE is mostly affected by NPC and GS. On each of the examined adoption rates, combinations with the highest GS and the lowest NPC have also achieved the lowest COE. Referring back to the formulas that Homer uses, the reason for this behaviour is obvious, as for the calculation of NPC there are used GS, GI and CC. Additionally, COE is calculated as a function of NPC. So that is the main reason of COE with GI, GS, and CC. Moreover, another factor that affects results are the grid sale (0.1145 €/kWh) and purchase (wind: 0.09945, PV: 0.08, hybrid: 0.147€/kWh) prices.

For lower adoption rates (25, 50%) the NPC is mostly affected by GI, CC and this happens because GS are relatively low and small amounts of surplus are sold. This situation reverses at the higher adoption rates where GS have their maximum prices with GI reaching very small values (Figures 60, 61). From these facts, it could be said that NPC at highest adoption rates is more GS-dependant, while for the lowest ones more GI-dependant. This explains why for 25, 50 and 75% where the GS are low there is a strong connection between NPC and CC. At the 100% rate, GS become almost zero and the GS become maximum as seen in Figures 56, 58, 60, 61.

Another finding is that the component that affects the most the NPC is batteries. Storage adoption results to the increase of CC, the decrease of GS, the decrease of GI and the decrease of EE. Their use in this specific case study is necessary, due to the legislation limit of transmission (equal or less than 20% of the rated generation capacity). If batteries were not used, large amounts of electricity would be curtailed resulting to a money loss. Money would be lost because this electricity could not be sold and could not be used in periods of low generation and high demand either.



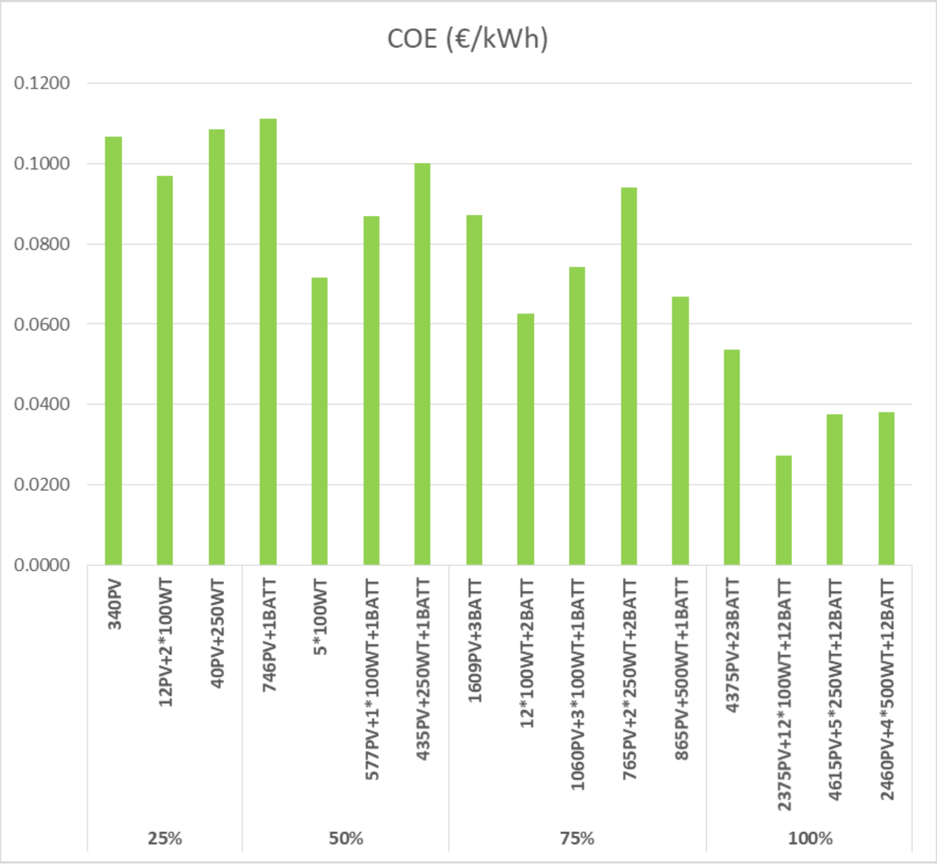
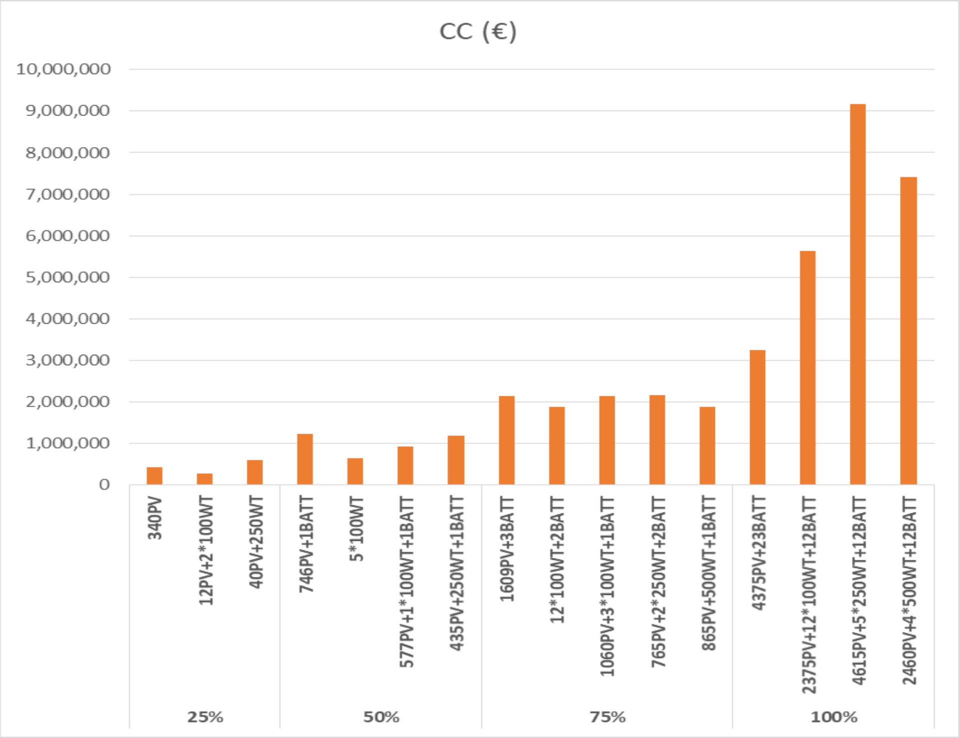


Figure 56(Left): NPC for the feasible solutions, for each adoption rate.

Figure 57 (Right): COE for the feasible solutions, for each adoption rate.



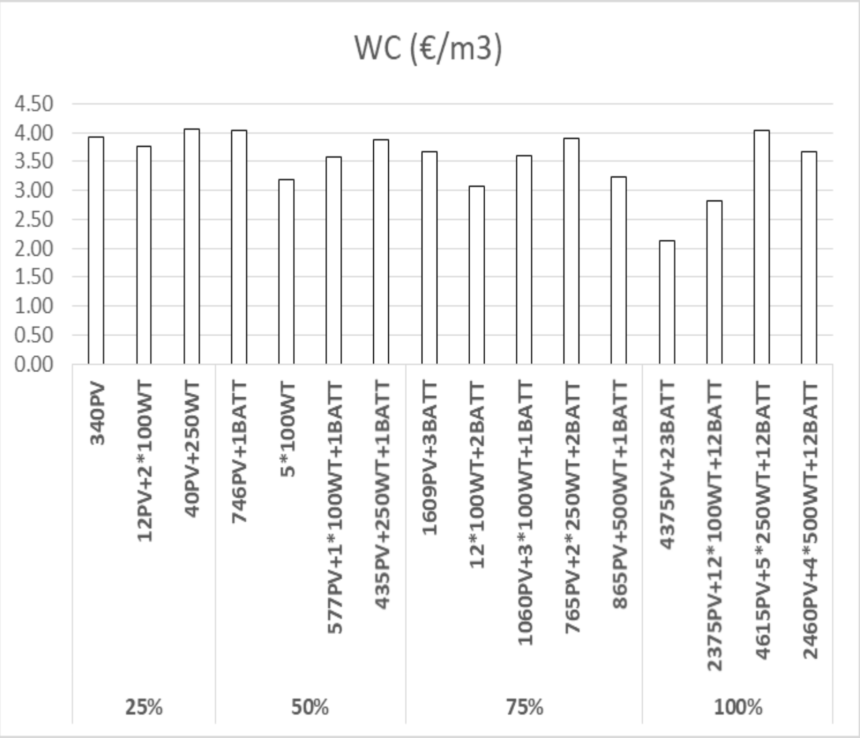
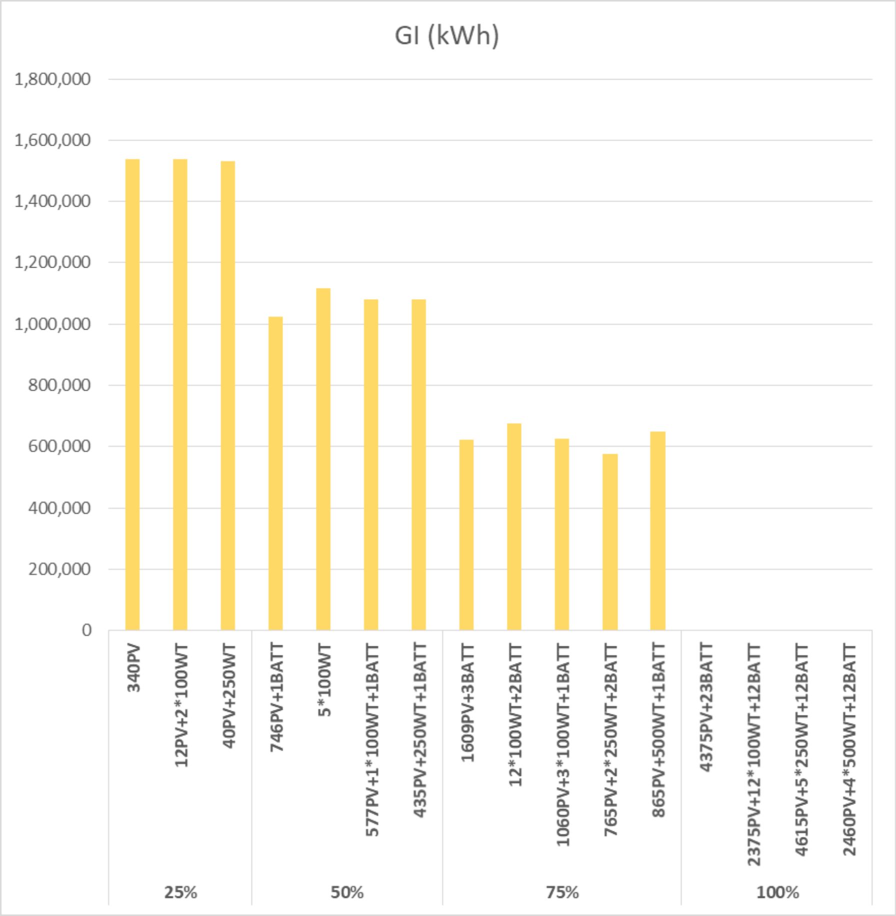


Figure 58 (Left): Initial CC for all the feasible combinations, for each adoption rate.

Figure 59 (Right): WC for all the feasible combinations, for each adoption rate.



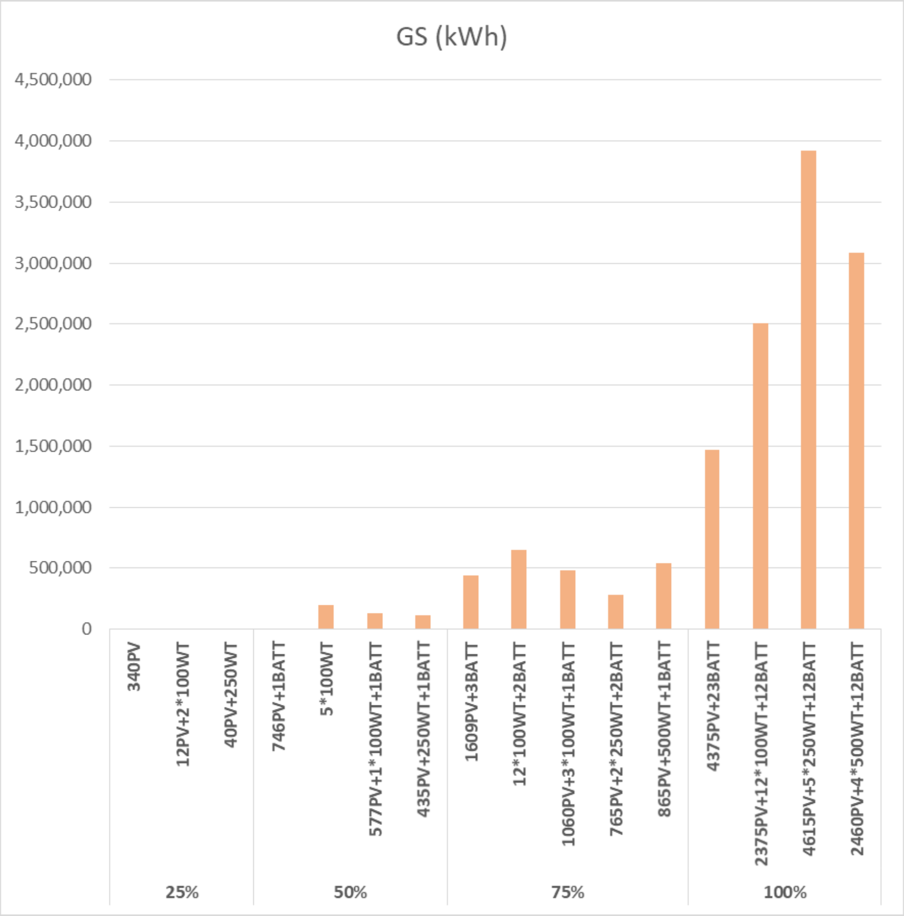


Figure 60 (Left): GI for all the feasible solutions, for each adoption rate.

Figure 61 (Right): GS for all the feasible solutions for each adoption rate.

Another parameter worth mentioning is the WC of the RO desalination unit on the island. As shown in Figures56, 59, the WC has a very strong connection with NPC. This happens because the quantity of water produced by the RO desalination unit is regarded as a fixed price, thus the factors that most affect WC are the same that affect NPC and COE consequently. For this reason, lowest NPC systems have also the lowest WC.

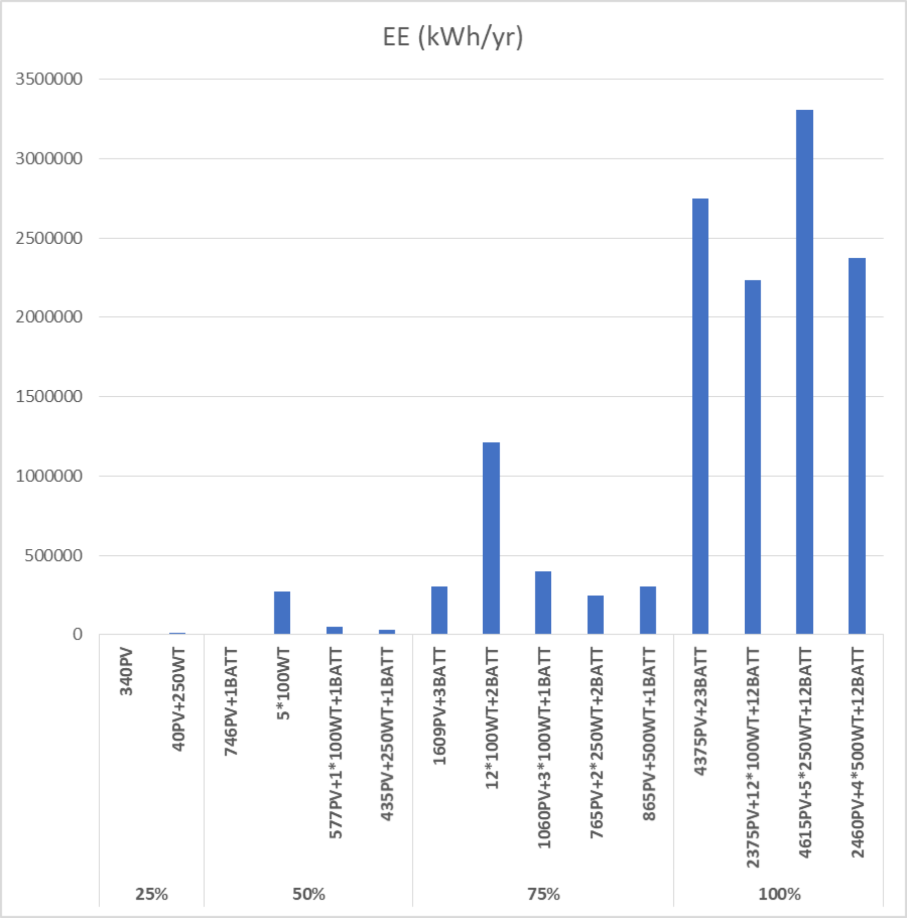


Figure 62: EE for all the feasible combinations, for each adoption rate.

EE is another index that was examined for each of the combinations. For the highest adoption rates, it reached its maximum and it was generally observed that in wind-based systems the amounts of excess energy were higher. The best performance was observed in PV systems. The most possible explanation has to do with the nature of the resources in the area, the battery capacity and the seasonal load fluctuation. To be more specific, wind turbines reach their top performance during winter, when the load on island on a 24/7 basis is low. This means that, batteries store the amount of energy their capacity allows, and the rest of the surplus is dumped at this period of the year. Batteries discharge only when the wind velocities drop down to the point that generated power becomes lower than the load and batteries are allowed to discharge. Besides that, if the period that the batteries are allowed to discharge the load is low and this period is short in duration, the discharge is not full.

On the other hand, PV are active during the day for a specific period of time, giving the batteries the opportunity to discharge at the low-light periods and be available to store energy the next day. All the average monthly (wind speed, solar radiation, load) profiles can be found in Appendix 3.

6.7. Sensitivity Analysis

The purpose of this Sensitivity Analysis is to study the possible effects on performance of the chosen system assuming a number of alterations that might happen in of the project lifetime. The four major assumptions that this sensitivity analysis is base on, are:

1. The adoption rate of renewables on the island will be 100% by 2027. This assumption is based on the incentives given by the State to foster renewables, mentioned on Chapter 2.

2. The island will have been connected to the mainland's grid. This assumption is based on the plans of the IPTO to connect islands of the nearby area by 2023, as also mentioned in Chapter 2.

3. The island, being connected, will be regarded as following the energy consumption trends of the mainland. For this reason, there will be used the energy consumption forecasts provided by IPTO for 2027 in (IPTO, 2017).
4. The water consumption on the island will continue increasing on the same pace as during the last decade, according to the rates provided by (Southern Aegean Municipality Administration, 2014).

Specifically, regarding the assumptions mentioned there will be examined the different scenarios for the chosen 100% renewables adoption combination. Having taken as granted the increase in water consumption, there will be examined the minimum (17.93%), average (19.91%) and maximum (21.8%) electrical load increase forecast scenarios. This will be done for the case that the batteries of the island are allowed to sale power to the grid and for the case that they are prohibited.

The grid connection capacity extension, and given the fact that no information is available, will be regarded as double of the currently existing one (2100 kW). Thus, the maximum energy export capacity is not known if is going to be regarded as 20% per connection or in total. For that reason, there are taken two different cases corresponding to these possibilities.

Water consumption increase is taken as granted, as according to the (Southern Aegean Municipality Administration, 2014), it increases about 12% every year and it is expected to continue at the same rate, due to the consumer behaviour change. The average consumer, when water is available and at low price tends to consumer more water, behaving carelessly. Their prediction is based on similar case studies from areas with the same characteristics, that such units operated and brought the same results.

As show in Table 12, applying the expected increase to the current average monthly water consumption values, an insufficiency during the summer months is created. This insufficiency is because the 700 m^3/h water generation capacity of the RO desalination unit cannot cover the daily demand. Although, this remains under the 2500 m^3 tank capacity. Thus, it is assumed that no further incrementations on the system are necessary, but it is assumed that on summer period the RO unit operates at its maximum of 23.5 h on daily basis.

Table 12: Predicted increase in water consumption and energy used by the RO desalination unit.

Month	10-Year Projection of Daily Demand Increase in water consumption (m^3)	Monthly Consumption (m^3)	Operation hours (h)	Energy Consumption per day (kWh/d)
January	357.6	11086.9	12.0	1620.19
February	345.6	9677.0	11.6	1565.67
March	424.0	13144.9	14.2	1920.94
April	555.6	16667.3	18.6	2516.88
May	519.9	16116.7	17.4	2355.22
June	1053.3	31597.7	23.5	3172.50
July	1754.0	54373.8	23.5	3172.50
August	1820.0	56419.8	23.5	3172.50
September	482.4	14472.8	16.2	2185.49
October	354.1	10978.6	11.9	1604.36
November	322.7	9681.0	10.8	1461.90
December	310.7	9630.7	10.4	1407.38

Tables 13 and 14 contain the results of the sensitivity analysis. On Table 14, the line containing information for the base case system was omitted because on the initial system battery sales to grid were not allowed. As it is displayed on both tables, with the attempted increase of the electric and the RO unit load the ReF in any case does not remain 100%. Especially on the battery sales to grid scenario it drops to 85-87%, because part of the energy stored, now is sold to the grid. This change is also obvious to the EE, where with the same export capacity and by allowing battery sales it becomes higher than the initial. On the battery prohibited sales case, it becomes lower at all cases.

On all scenarios, the initial CC remains the same as no further implications are done on the system.

GS become significantly higher and result to increased profit in the case of allowed battery sales. Either with the same or with double grid capacity GI remain the same both on the case of allowing and prohibiting battery sales. Although, comparing these two, it is obvious that in the battery export prohibition case the GI are increased. That is because battery is regulated by Homer to sell its surplus when this is possible instead of storing it for periods of demand higher than generation.

These have great impact on the most important index of the system, the NPC. The lowest NPC values are observed in the case of double export capacity with prohibited battery sales to the grid. This happens because GI are maintained low and the GS increase by some 10hundred thousands of kWh/year.

This difference is also obvious to COE and WC apart from the NPC. For both prices, when the grid sale capacity is doubled, they drop, with the most obvious decreases being recorded on the battery allowed sales case, where the profits from energy sale are higher and the NPC lower. WC on both battery sales scenarios and in the case of the same grid capacity as initially, is almost the same.

This leads to two different alternatives for the island in the future (if these scenarios apply to the situation until then). The first alternative is if the export capacity is allowed to double in future, it would be more profitable to allow energy from battery to be sold to the grid. Otherwise, they should continue using the battery-stored energy locally with higher NPC and electricity, water costs. A third option would be to continue using battery-stored energy locally to remain as green as possible. This would be an intermediate solution as it would not increase profit and at the same time, it would not increase the expenses significantly.

Table 13: Results for the 100% system behaviour, prohibiting battery sales to the grid.

	Index	**ReF (%)**	**NPC (€)**	**COE (€/kWh)**	**CC (€)**	**EE (kWh/yr.)**	**GI (kWh)**	**GS (kWh)**	**WC (€/m3)**
Initial System		100	1,712,146	0.0274	5,640,250	2,234,296	428	2,507,284	2.81
Export Capacity	**Demand Scenario**								
Same Export Capacity	**Low Demand**	99.5	2,670,300	0.0398	5,640,250	1,755,241	23,131	2,053,703	3.66
	Average Demand	99.5	2,731,915	0.0405	5,640,250	1,725,165	27,086	2,027,030	3.72
	High Demand	99.4	2,798,565	0.0413	5,640,250	1,697,461	31,715	1,998,529	3.77
Double Export Capacity	**Low Demand**	99.6	1,116,990	0.0144	5,640,250	954,163	23,131	2,825,832	2.27
	Average Demand	99.5	1,202,844	0.0155	5,640,250	936,361	27,086	2,787,109	2.35
	High Demand	99.4	1,292,933	0.0166	5,640,250	920,509	31,715	2,746,957	2.43

Table 14: Results for the 100% system behaviour, allowing battery sales to the grid.

	Index	**ReF (%)**	**NPC (€)**	**COE (€/kWh)**	**CC (€)**	**EE (kWh/yr.)**	**GI (kWh)**	**GS (kWh)**	**WC (€/m3)**
Export Capacity	**Demand Scenario**								
Same Export Capacity	**Low Demand**	85.8	2,999,439	0.0399	5,640,250	2,379,677	778,020	2,644,982	3.66
	Average Demand	85.6	3,076,159	0.0407	5,640,250	2,366,865	797,976	2,626,801	3.72
	High Demand	85.3	3,153,097	0.0414	5,640,250	2,353,995	818,386	2,608,967	3.78
Double Export Capacity	**Low Demand**	87.8	1,200,635	0.0137	5,640,250	1,451,621	778,020	3,539,141	2.05
	Average Demand	87.6	1,296,361	0.0148	5,640,250	1,448,346	797,976	3,511,514	2.13
	High Demand	87.3	1,392,240	0.0158	5,640,250	1,444,973	818,386	3,484,264	2.20

7. Final Remarks

7.1. Conclusions

The literature review that was conducted revealed that there are plenty of data available in publications regarding studies in renewable energy resources and desalination in the area of Aegean Sea in Greece. The data include information related to the energy systems of islands and more specifically connection characteristics and statistics of operation and prices of APS units. The electrical demand profile used in this dissertation was derived from one of these studies and altered to fit to the current case study. The island that it was derived from has similar characteristics regarding the population, activities and tourism, in order to ensure that the form of demand profile follows the same pattern regarding daily and seasonal fluctuations.

Desalination is often investigated using estimations, as on most cases there are no accurate and detailed data for water consumption on islands. Thus, on this dissertation there was followed the same procedure of estimating the water consumption and then the energy demand of the RO desalination unit. There were used statistical data regarding human and animal populations and crop areas on island. Form the calculation and after applying an overconsumption factor of +20% that is suggested on most studies, there was found that the already installed RO unit is adequate currently. Adequacy still exists after an eventual increase of the water consumption by 12% annually, after a 10-years period. On that case though, at periods of high demand (i.e. during summer months) the unit has to operate at its maximum continuously. An alternative to avoid that would be the increase of tank storage size.

Regarding the renewables implication study, there was found that for a 25% adoption rate the best combination, in terms of examined indexes, would be a 12kW PV

+2*100kW wind turbines hybrid, for a 50% adoption rate a 5*100kW wind turbine wind farm, for 75% a 12*100 kW wind turbine+2 CELLCUBE 200kW/400kWh VRB and for 100% a hybrid system consisted of 2375kW PV+12*100 kW wind turbines+12 CELLCUBE 200kW/400kWh VRB. From the results it is obvious that in order to advance from 50% to 75% and finally 100%, it is necessary to increase the wind turbine capacity and add storage gradually and add PV capacity, accordingly for the 100% rate. The scalability of this system allows for gradual adoption of renewables on the island, if the initial capital does not allow to proceed to 100% adoption at once, by achieving simultaneously the best performance. In the proposed systems calculation, there was also included the load of the RO unit, which means that water can be produced on-site with very limited cost, when comparing to the initial that was dependant on grid imported electricity.

The key limitation in calculations of the energy systems of this study was the maximum of 20% of rated generation capacity export limitation. This limitation is set by Greek laws, probably to ensure the security of grids that are not designed to accept energy from district energy sources but for distributing energy to consumers. Although, this limitation, confines the grid sales, leading to very slow revenue for the designed systems, preventing them from exploiting their full financial and energy potentials.

This argument was confirmed by the sensitivity analysis that was conducted and examined the behaviour of the 100% adoption proposed system if the load on island would follow the incremental trend of the mainland in energy demand and given that the water consumption was to increase. By the analysis results, there was found that only if this 20% export confinement was raised the system of the island would be able to achieve lower NPC, COE, WC and GS, despite the load increase. This analysis also showed that by enabling battery sales to grid, the true question becomes if the islanders are willing to sacrifice their energy autarky for profit, as the ReF decreases but the profits from GS increase a lot.

Finally, it was concluded that in order to solve both the energy and water problem of Greek Islands of the Aegean Sea the first and most important step is to upgrade the network by establishing larger capacity connections using underwater cables. These connections would allow the energy trade between islands or between islands and the mainland. In that way, the islands could more actively contribute to the efforts of the country to decommission carbon and petrol and base its generation on sustainable green resources.

7.2. Project Limitations

1. The whole project is based on estimations of the load profile of the island, using measured data for another one. Thus, deviations from reality might exist.

2. The same applies for water consumption and the energy requirements of the desalination unit.

3. An estimation was also done regarding the number of visitors on the island throughout the year, due to lack of accurate data.

4. On the water demand estimation, it was assumed that the purified water will be used for livestock irrigation. This might not be true in reality.

5. The whole project is undertaken on the condition that the legal framework does not change within the project lifetime. This includes tariffs, surplus export capacity and possible taxation increases.

6. The consumer behaviour is assumed as not being affected by unforeseeable/ unpredictable events that may cause severe changes, like a financial crisis,

war, etc. The same applies for financial sizes such as inflation that are regarded to follow the same change patterns over the examined period.

7. The sensitivity analysis conducted, assumes that the adoption of renewables will continue growing in Greece over the next years, so the 100% adoption scenario is feasible and has a logical basis.

8. Sensitivity analysis is also assuming that the inhabitants of the island will continue consuming more water over the years, following the currently incremental trend. This might not happen as the water consumption might reach a plateau in the future.

9. Another assumption regarding sensitivity analysis is that the mainland will be connected with the island by 2025, with an underwater cable with the same capacity as the existing one.

10. Homer assumes that the load profile and weather will not change significantly over the project lifetime, which might not be exactly correct.

7.3. Proposed Future Work

1. The most important and urgent task for future work based on this thesis is the acquisition of accurate data. This could be done after the installation of measurement equipment on the island that will measure the energy and maybe water consumption.

2. A possible focus of future work, being based on this thesis is the investigation of possible alternatives that will be able to exploit the large quantities of excess electricity. Towards this course there can be suggested three directions:

   a. The connection of Ano with Kato Koufonisi, so the latter will be electrified. The investigation should also cover the possible exploitation of the island itself as an energy generator-island for the surrounding area.

   b. The design of a unit that will produce ice. As mentioned in Section 5.2, the primary occupation in the area is fishing. Ice for fish is being supplied by Paros. Ano Koufonisi could use its excess electricity not only to cover its own needs in ice, but also to make profit by selling it to other islands in the area.

   c. The investigation of an organised marina that will provide shelter for sailing boats. Many of these marinas have docks with pillars with plugs and water taps for replenishing the boat batteries and water tanks. This would also introduce the island with a new form of tourism, the sail tourism. Thus, the research relative to such a project could be worth investigating.

3. A field on possible future research would also be on a district heating/cooling system for the island, on community scale.

4. Electric vehicles in the islands of Aegean Sea are also being investigated and it would be worth looking up to, on this specific case where surplus could cover such implementations. Alternative to batteries on that case, Vehicle-to-Grid technologies adoption could be investigated.

5. An Environmental Impact Assessment of the proposed solutions, which would also aim to minimise the footprint of such implications could be worth investigating.

8. References

Hellenic Constitution, 2016. *Article 7 of Law 4414/2016,* Athens: Greek Government Gazette.

IGME, 1983. *Geological Map of Greece 1:500.000 (second edition),* Athens: Greek Institute of Geology and Mineral Exploration.

Aggarwal, V., 2018. *https://news.energysage.com.* [Online]
Available at: https://news.energysage.com/what-are-the-most-efficient-solar-panels-on-the-market/
[Accessed 02 June 2018].

Alevar, V. & Zacho, M., n.d. *White Paper 229: Battery Technology for Data Centers: VRLA vs. Li-ion,* s.l.: Schneider Electric.

Alexakis, A., 2003. *Desalination.* 1st ed. Athens: Michalis Sideris Publications.

Alsgeghri, A., Sharief, S. A., Rabbani, S. & Aitzhan, N. Z., 2015. Design and Cost Analysis of a Solar Photovoltaic Powered Reverse Osmosis Plant for Masdar Institute. *Energy Procedia,* Issue 15, pp. 319-324.

Andriosopoulos, K., Galariotis, E. & Spyrou, S., 2017. Contagion, volatility persistence and volatility spill-overs: The case of energy markets during the European financial crisis. *Energy Economics,* 66(August 2017), pp. 217-227.

Andritsos, N. et al., 2013. *Geothermal Energy Use, Country Update for Greece.* Pisa, Italy, European Geothermal Congress 2013.

Aolaritei, L., Bolognani, S. & Dorfler, F., 2017. A distributed voltage stability margin for power distribution networks. *IFAC-Papers Online,* 50(1), pp. 13240-13245.

AP, 2017. *Work on Israel-Cyprus-Greece electricity link to start in 2018,* Jericho: The Times of Israel.

Aquino, T., Roling, M., Baker, C. & Rowland, L., 2017. *Battery Energy Storage Technology Assessment* , Fort Collins, CO: Platte River Power Authority.

Artelaris, P., 2017. Geographies of crisis in Greece: A social well-being approach. *Geoforum,* 84(August 2017), pp. 59-69.

Atwell, C., 2018. *6 Promising Energy Storage Options to Tie into the Grid: Renewable energy storage solutions have shown remarkable progress in recent years, as the following list demonstrates..* [Online] Available at: http://www.powerelectronics.com/alternative-energy/6-promising-energy-storage-options-tie-grid
[Accessed 05 July 2018].

Bertsiou, M., Feloni, E., Karpouzos, D. & Baltas, E., 2017. Water management and electricity output of a Hybrid Renewable Energy System (HRES) in Fournoi Island in Aegean Sea. *Renewable Energy,* I(118), pp. 790-798.

Blatsios, P. & Feichtinger, A., 2016. *CellCube – a storage system based on the vanadium redox flow technology,* s.l.: Tesco Engineering-Gildemeister.

Brlek, T. I. et al., 2016. *The quality analyses of olive cake fuel pellets – Mathematical approach,* Beograd: Hem. Ind..

Centre for Renewable Energy Resources, 2017. *Renewables in Greek Islands,* Athens: CRES.

Christodoulakis, N., 2017. *The Investment Gap in Greece 2008-2017.* Athens, Greek Industry Conference Society Publications.

Cisneros Ramirez, C. & Racalde, C., 2015. Small-Scale of Water Production Using Renewable Energy: Economic Evaluation. *Energy Procedia,* Issue 75, pp. 956-962.

CNN Greece, 2018. How is going to be conducted the sale of DEI owned lignite units in Greece. *CNN Greece Newsroom,* 31 March, p. [online].

CRES, 2014. *Map of APS and Grids on Islands.* [Online] Available at: http://www.rae.gr/old/sub3/3B/3b3.htm#%CE%9D%CE%97%CE%A3%CE%99%CE%A9%CE%A4%CE%99%CE%9A%CE%9F
[Accessed 03 July 2018].

CRES, 2018. *CRES Renewables Diadrastic Map.* [Online] Available at: http://www.rae.gr/geo/
[Accessed 15 June 2018].

Dagoumas, A. & Kitsios, F., 2014. Assessing the impact of the economic crisis on energy poverty in Greece. *Sustainable Cities and Society,* 13(October 2014), pp. 267-278.

Damianidis, M., Katsaros, G., Tolis, M. & Stergiopoulos, F., 2011. *Guide for Design and Installation of Photovoltaic Pannels.* 1st ed. Thessaloniki: Thechnical Chamber of Greece-Regular Energy Comitee.

Electric Energy Market Operator, 2018. *Prices for Energy and CHP (Photovoltaics Excempt).* [Online] Available at: http://www.lagie.gr/systima-eggyimenon-timon/ape-sithya/adeiodotiki-diadikasia-kodikopoiisi-nomothesias-ape/periechomena/times-energeias-apo-ape-sithya-plin-fb/
[Accessed April 2018].

Electric Energy Market Operator, 2018. *Prices for Energy from Photovoltaics Installed on Buildings.* [Online] Available at: http://www.lagie.gr/systima-eggyimenon-timon/ape-sithya/adeiodotiki-diadikasia-kodikopoiisi-nomothesias-ape/periechomena/times-energeias-apo-ape-sithya-plin-fb/times-energeias-apo-fb-se-ktiria/ [Accessed April 2018].

Electrical Energy Market Operator, 2018. *Prices of Energy from Photovoltaics (not in special tariffs).* [Online] Available at: http://www.lagie.gr/systima-eggyimenon-timon/ape-sithya/adeiodotiki-diadikasia-kodikopoiisi-nomothesias-ape/periechomena/times-energeias-apo-ape-sithya-plin-fb/times-energeias-apo-fb-ektos-eidikon-programmaton/ [Accessed April 2018].

Energiewende Team, 2016. Lignite in the Greek energy system: facts and challenges. *Energy Transition: The Global Energiewende,* 09 February, p. [online].

ENERGY RESPONSE SOLUTIONS, 2017. *Energy Storage System Safety: Comparing Vanadium Redox Flow and Lithium-Ion Based Systems (White Paper),* [online]: ENERGY RESPONSE SOLUTIONS.

Energy Storage Association, 2018. *Compressed Air Energy Storage (CAES).* [Online] Available at: http://energystorage.org/compressed-air-energy-storage-caes [Accessed 17 June 2018].

Energypress Team, 2018. Deviation of Greece from its 2018 goal according to Eurostat's research findings. *Energy Press,* 07 February, p. [online].

Eriksson, E. V. & Gray, E. M., 2017. Optimization and integration of hybrid renewable energy hydrogen fuel cell energy systems – A critical review. *Applied Energy,* Issue 202, pp. 347-364.

Euaggelopoulou, S., 2013. *Economotechnic Ananysis and Performance Evaluation of Desalination Plant,* Pireaus, Athens: University of Pireaus.

EurObserv'ER, 2007. Photovoltaic energy barometer 2007. *Systèmes solaires Le journal des énergies renouvelables n° 178*, 4, pp. 49-70.

EurObserv'ER, 2018. *Photovoltaic Energy Barometer 2010-2018,* s.l.: EurObserv'ER.

European Commission, 2017. *https://ec.europa.eu.* [Online] Available at: https://ec.europa.eu/inea/en/news-events/newsroom/tilos-project-scoops-two-eu-sustainable-energy-awards
[Accessed 21 June 2017].

EuroStat, 2016. *http://appsso.eurostat.ec.europa.eu.* [Online] Available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en
[Accessed 31 May 2018].

EWEA Staff, 2010. *Cumulative installed capacity per EU Member State 1998 - 2009 (MW),* [online]: European Wind Energy Association.

EWEA Staff, 2017. *European Statistics Archive,* [online]: European Wind Energy Association.

Fahmy, F. H., Ahmed, N. M. & Farghally, H. M., 2012. Optimization of Renewable Energy Power System for Small Scale Brackish Reverse Osmosis Desalination Unit and a Tourism Motel in Egypt. *Smart Grid Renewable Energy,* Issue 3, pp. 43-50.

Farret, F. A. & Simoes, M. G., 2006. CHAPTER 15: MICROPOWER SYSTEM MODELLING WITH HOMER. In: T. Lambert, P. Gilman & G. Lilienthal, eds. *Integration of Alternative Sources of Energy.* s.l.:John Wiley & Sons, pp. 379-418.

Franklyn, L., 2018. *HOMER Energy Conducts Training at Greenland's National Utility.* [Online] Available at: http://microgridnews.com/category/homer-energy/homer-pro-microgrid-software/
[Accessed 28 June 2018].

German, F. & Newton, M., 2010. *Making money from renewable energy,* s.l.: FARREL & CO.

Giogiakas, P., 2018. *www.tanea.g.* [Online]
Available at: http://www.tanea.gr/news/greece/article/5572920/15-ellhnika-nhsia-ginontai-prasina-me-strofh-sthn-katharh-energeia/
[Accessed 08 June 2018].

Gkikas, P. & Tchobanoglous, G., 2009. Sustainable use of water in the Aegean Islands. *Journal of Environmental Management,* Issue 90, pp. 2601-2611.

Global Energy Network Institute, 2017. *www.geni.org.* [Online]
Available at: http://www.geni.org/globalenergy/library/renewable-energy-resources/world/europe/solar-europe/solar-greece.shtml
[Accessed 2017].

Greek Regulatory Energy Authority, 2018. *Non-Connected Islands System.* [Online]
Available at: http://www.rae.gr/site/categories_new/electricity/market/mdn.csp
[Accessed 12 June 2018].

HELAPCO, 2013. *Photovoltaics-A practical installation guide.* 1st ed. Thesalloniki: Hellenic Association of Photovoltaic Companies.

HELAPCO, 2017. *Temporary 2017 Photovoltaics Market Data,* Athens: Hellenic Association of Photovoltaic Companies.

Hellenic Association of Tourism (EOT), 2013. *Study on the Development of Southern Aegean Municipality,* Athens: Hellenic Ministry of Tourism.

Hellenic Distribution Electricity Network Operator, 2017. *Informative Report on Energy Generation from Renewables in Non-Connected Islands for November 2017,* Athens: Hellenic Distribution Electricity Network Operator.

Hellenic Distribution Electricity Network Operator, 2018. *Report for Energy Generation and Consumption in Non-Connected Greek Islands for May 2018,* Athens: HEDNO.

Hellenic Government Gazette, 2010. *Law 3851,* Athens: Hellenic Parliament Publications.

Hellenic Scientific Wind Energy Association, 2017. *Greek Energy 2017 Report,* Athens: Hellenic Scientific Wind Energy Association.

Hellenic Statistic Authority, 2017. *Tourist Movement To Greece in year 2017,* Athens: ELSTAT.

Hellenic Wind Energy Association, 2017. *Statistics for Wind Energy in Greece for year 2017,* Athens: Hellenic Wind Energy Association.

Hellenic Wind Energy Scientific Association, 2018. *Conference for Awareness Regarding Investments in Wind Energy.* Athens, Hellenic Wind Energy Scientific Association.

Hoffman, J., 2017. *United Nations Conference on Trade and Development.* [Online] Available at: http://unctad.org/en/pages/newsdetails.aspx?OriginalVersionID=1516 [Accessed 16 June 2018].

HOMER Pro HELP, 2018. *Homer 3.11.* [Online] Available at: https://www.homerenergy.com/products/pro/ [Accessed 03 July 2018].

Hyland, M. J., n.d. *Microgrids: Back to Future?,* Arlington, Virginia: IEEE Standards Association.

Iliopoulou, C., Kepaptsoglou, K. & Schinas, O., 2018. Energy supply security for the Aegean islands: A routing model with risk and environmental considerations. *Energy Policy,* Volume 113, pp. 608-620.

Independetnt Power Transmission Operator, 2017. *www.admie.gr.* [Online] Available at: http://www.admie.gr/en/transmission-system/system-development/erga-eyropaikoy-tameioy-perifereiakis-anaptyxis/project/article/2825/ [Accessed 22 May 2017].

Institute of Agriculture and Tourism POREC, 2008. *MARKET OF ENERGY FROM OLIVE RESIDUES,* Porec: Intelligent Energy.

International District Energy Association , 2017. *Features and Benefits.* [Online] Available at: https://www.districtenergy.org/microgrids/about-microgrids97/features [Accessed 28 June 2018].

International Energy Association, 2017. *Energy Policies of IEA Countries: Greece 2017,* s.l.: OECD/IEA.

Ioannidou, M. & Argyros, N. C., 2011. *Economometric study and evaluation of wind farms construcion in Greece.* 1st ed. Athens: National Technical University of Athens.

IPTO, 2016. *Pricing of Energy from Renewables.* [Online] Available at: http://www.desmie.gr/ape-sithya/adeiodotiki-diadikasia-kodikopoiisi-nomothesias-ape/periechomena/timologisi-energeias-apo-ape/ [Accessed 05 July 2018].

IPTO, 2017. *Energy Sufficiency Study for the period 2017-2027,* Athens: IPTO.

Ismail, I. M. et al., 2015. Effective utilization of excess energy in standalone hybrid renewable energy systems for improving comfort ability and reducing cost of energy: A review and analysis. *Renewable and Sustainable Energy eviews,* Issue 42, pp. 726-734.

ITA Corporation, 2006. *Proposal for Systems Able to Cover Water Demand in Arid Greek Islands of Cyclades and Dodecanese,* Athens: ITA Corporation.

Kalaitzoglou, A., 2016. Inconsistency of State depletes Renewable Investments. *Liberal*, 15 February, p. 54.

Kaldellis, J. K., Gkikaki, A., Kaldelli, E. & Kapsali, M., 2012. Investigating the energy autonomy of very small non-interconnected islands. A Case Study: Agathonisi, Greece. *Energy for Sustainable Development*, 16(19 August 2012), pp. 476-485.

Kaldellis, J. K. & Kavadias, K. A., 2001. Optimal wind-hydro solution for Aegean Sea islands' electricity-demand fulfilment. *Applied Energy,* I(70), pp. 335-354.

Kaldellis, J. K. & Konduli, E. M., 2007. The water shortage problem in the Aegean archipelago islands: ost-effective desalination prospects. *Desalination,* I(216), pp. 123-138.

Kaldellis, J. K. & Konduli, E. M., 2007. The water shortage problem in the Aegean Archipelago islands:cost-effective desalination prospects. *Desalination,* Issue 216, pp. 123-138.

Karachaliou, P., 2010. *Dissertation: Desalination technologies and application prospects on Greek Islands*, Athens: National Technical University of Athens (NTUA).

Karagiannis, I. C. & Soldatos, P. G., 2007. Current status of water desalination in the Aegean Islands. *Desalination,* I(203), pp. 56-61.

Kartalidis, A., Georgopoulou, M., Arampatzis, G. & Asimakopoulos, D., 2011. *DESALINATION IN GREEK ISLANDS BY USING RES.* Rhodes, CEST 2011.

Katsifis, D., 2015. *Technoeconomic Analysis of Hybrid renewable Energy System*, Patras: Univeristy of Patras.

Koroneos, C. J. & Fytikas, M., 1999. *Energy potential of geothermal energy in Greece.* Basel, Switzerland, Switzerland Proceedings.

Koufonisia Municipality, S. A. I. A., 2016. *History.* [Online] Available at: http://www.koufonisia.gr/?page_id=941 [Accessed 03 July 2018].

Koutroupis, N., 1993. UPDATE OF GEOTHERMAL ENERGY DEVELOPMENT IN GREECE. *Geothermics,* 5/6(21), pp. 881-890.

Kovaios, A., 2017. *Koufonisi: Another 100 cubic metres added in the desalination unit capacity* [Interview] (16 December 2017).

Levi, D., 2018. *Conversion efficiencies of best research solar cells worldwide from 1976 through 2018 for various photovoltaic technologies. Efficiencies determined by certified agencies/laboratories.,* Gloden, CO: National Renewable Energy Resources Laboratory.

Liaggou, C., 2018. *The Cyclades grid connection project was inaugurated..* [Online] Available at: http://www.kathimerini.gr/954679/article/oikonomia/ellhnikh-oikonomia/egkainiasthke-to-ergo-ths-hlektrikhs-diasyndeshs-kykladwn [Accessed 03 July 2018].

Lianos, N., 2018. *Koufonisi: Caution on water...plus another desalination unit..* [Online]
Available at: https://www.naxospress.gr/arthro/koinonia/koyfonisia-prosohi-sto-nero-alla-kai-nea-monada-afalatosis
[Accessed 10 July 2018].

Maiers, M., 2017. *cellcube: Vanadium Redox Flow Batteries- Ideal for Microgrid Applications,* Albany, NY: NY-Best.

Manolakos, D., Papadakis, G., Papantonis, D. & Kyritsis, S., 2001. A simulation-optimisation programme for designing hybrid energy systems for supplying electricity and fresh water through desalination to remote areas Case study: the Merssini village, Donoussa island, Aegean Sea, Greece. *Energy,* I(26), pp. 679-704.

Margaris, K., 2008. *Network of Sustainable Islands (DAFNI),* Athens: Interdisciplinary Institute of Environmental Studies.

Matzarakis, A. P. & Katsoulis, V. D., 2005. Sunshine duration hours over the Greek region. *Theoretical and Applied Climatology,* Issue June, pp. 107-120.

Mendrinos, D., Choropanitis, I., Polyzou, O. & Kyratsas, K., 2010. Exploring for geothermal resources in Greece. *Geothermics*, 1(39), pp. 124-137.

Mentis, D., 2011. *Desalination using Renewable Energy Sources in the arid Aegean Islands*, Athens: National Technical University of Athens.

Michalakakou, G., Psiloglou, B., Samantouris, M. & Nomidis, D., 2002. Application of renewable energy sources in the Greek islands of the South Aegean Sea. *Renewable Energy,* 26(1), pp. 1-19.

Ministry of Agricultural Development and Food, 2006. *Water Situation on islands in the South Aegean Sea district,* Athens: Hellenic Government.

Ministry of Agriculture, F. a. R. A. o. C., 2015. *Water Requirements of Livestock.* [Online]
Available at: http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm
[Accessed 03 July 2018].

Mohanty, P., Muneer, T. & Kolhe, M., 2016. *Solar Photovoltaic System Applications: A Guide-Book for Offgrid Electrification.* 1st ed. e-book: Springer Publications Switzwerland.

Moumouris, J. C. & Potolias, C., 2013. A multi-criteria methodology for energy planning and developing renewable energy sources at a regional level: A case study Thassos, Greece. *Energy Policy,* Volume 52, pp. 522-530.

Moutafis, P., 2008. *Coverage of Demand for Energy and Water using Wind Turbines and Desalination for Island of Sikinos,* Athens: Nationala Technical University of Athens.

Municipality of South Aegean, 2016. *www.pnai.gov.gr.* [Online] Available at: http://www.pnai.gov.gr/
[Accessed 03 July 2018].

National Observatory of Athens, 2018. *http://www.meteo.gr/.* [Online] Available at: http://www.meteo.gr/
[Accessed 15 June 2018].

National Observatory of Athens, 2018. *www.meteo.gr.* [Online] Available at: http://www.meteo.gr/wind_climatology_for_meteo.cfm
[Accessed 14 June 2018].

Naxos Press, 2018. *CAUTION: Water...and the new desalinationunit.* [Online] Available at: https://www.naxospress.gr/arthro/koinonia/koyfonisia-prosohi-sto-nero-alla-kai-nea-monada-afalatosis
[Accessed 03 July 2018].

Nederland Maritiem Land, 2016. *Tidal Energy Fish Impact: Method development to determine the impact of open water tidal energy converters on fish,* Horntje: Nederland Maritiem Land.

NEMA, 2014. *MICROGRIDS, MACROBENEFITS: How to talk to decisionmakers about building your own electrical power system,* s.l.: National Electrical Manufacturers Association.

Nydreos-Sakouelos, P., 2010. *Desalination Units in Greece: Carbon Footprint,* Volos: University of Thessaly.

Oktay, Z., 2006. Olive Cake as a Biomass Fuel for Energy Production. *Energy Sources,* 4(28), pp. 329-339.

Oram, B., 2014. *Total Dissolved Solids and Water Quality.* [Online] Available at: https://www.water-research.net/index.php/water-treatment/tools/total-dissolved-solids
[Accessed 27 June 2018].

Paliatsos, A. G., Kambezidis, H. D. & Nastos, P. T., 2004. *The spatial distribution of precipitation trends in Greece.* Mitilene, Lesvos, 7th Pan-Hellenic Geographical Conference, University of Aegean.

Papamanolis, N., 2015. The first indications of the effects of the new legislation concerning the energy performance of buildings on renewable energy applications in buildings in Greece. *International Journal of Sustainable Built Environment,* 1(4), pp. 391-399.

PPC Renewables S.A., 2017. *www.ppcr.gr.* [Online] Available at: https://www.ppcr.gr/el/announcements/news/290-european-investment-bank-backs-renewable-energy-investment-across-greek-islands
[Accessed 21 December 2017].

Probio Energy International, 2018. *https://probio-energy.com.* [Online] Available at: https://probio-energy.com/products-from-processes/agriwaste/olive-cake/
[Accessed 16 June 2018].

Public Power Corporation of Greece S.A., 2017. *Financial Report of 2017,* Athens: Public Power Corporation of Greece S.A..

Rabinovich, A. & Kambas, M., 2018. *Cyprus, Israel seek gas-sharing formula to unlock East Med energy hub,* New York: Reuters Bussiness News.

Rassai, N. et al., 2018. Effect of the particle size of pulverized olive cake on combustion parameters in Stirling engine in Morocco. *Case Studies in Thermal Engineering,* Volume 1.

Regional Agency of Central Macedonia, 2013. *Market of Olive Residues for Energy,* s.l.: Intelligent Energy Europe.

Rinkesh, R., 2017. *Conserve Energy Future.* [Online] Available at: https://www.conserve-energy-future.com/pros-and-cons-of-hydrogen-energy.php
[Accessed 17 June 2018].

Salah, M. & Boxer, B., 2017. *Mediterranean Sea,* s.l.: Bittanica Encyclopedia.

Saltelli, A., 2002. Sensitivity Analysis for Importance Assessment. *RISK ANALYSIS: An International Journal,* 3(22), pp. 579-592.

Sinha, S. & Chandel, S. S., 2014. Review of software tools for hybrid renewable energy systems. *Renewable and Sustainable Energy Reviews,* Volume 32, pp. 192-205.

Skyllas-Kazacos, M. & McCann, J. F., 2015. Chapter 10 – Vanadium redox flow batteries (VRBs) for medium- and large-scale energy storage. In: M. S. T. M. L. Chris Menictas, ed. *A volume in Woodhead Publishing Series in Energy.* 2014: Woodhead Publishing, p. 329–386.

Southern Aegean Municipality Administration, 2014. *Bussiness Plan fro Agricultural Development in Koufonisia Islands 2014-2020,* Athens: Ministry of Aegean.

Southern Aegean Municipality, 2014. *Bussiness Plan for Agriculteral Development of Donousa Island 2014-2020,* Athens: Ministry of Aegean.

Stamatopoulos, D., 2014. *Dissertation: "Design of a Hybrid Energy System in Donousa Island using Homer Pro",* Athens: National Technical University of Athens.

Swapnil, D., Sarvaiya, J. N. & Sheshari, B., 2013. Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World-A Review. *Energy Procedia,* Volume 33, pp. 311-321.

Teloglou, T., 2016. *"Stories" documentary series: The role of lignite in Greece.* Athens: SKAI TV.

The Enineering ToolBox, 2010. *Farm-Livestock Water Consumption.* [Online] Available at: https://www.engineeringtoolbox.com/farm-use-animals-water-consumption-d_1588.html
[Accessed 03 July 2018].

Ton, D. T. & Smith, M. A., 2012. *The U. S. Deprartment of Energy's Microgrid Initiative,* Washington: United States of America Department of Energy.

Tsipras, A., Netanyahu, B. & Anastasiades, N., 2017. *Greece-Cyprus-Israel Trilateral Summit, Thessaloniki 15.06.2017, Joint Declaration.* Thessaloniki, Israeli Government, Cypriot Government, Greek Government.

Tzanes, G. T. et al., 2017. PHAROS: An Integrated Planning Tool for Meeting the Energy and Water Needs of Remote Islands using RES-based Hybrid Solutions. *Energy Procedia,* Volume 142, pp. 2586-2591.

Tzen, E., 2010. *Desalination using Renewable Energy Sources,* Athens: Agricultural University of Athens.

Tzen, E., 2015. *Desalination Technology in Greek Islands,* Athens: Hellenic Center for Renewable Energy Sources (CRES).

U.S. NREL, 2018. *HOMER Energy.* [Online] Available at: https://www.homerenergy.com/products/pro/index.html
[Accessed 28 June 2018].

U.S. Office of Energy Efficiency & Renewable Energy, 2018. *Fuel Cell Technologies Office Accomplishments and Progress.* [Online] Available at: https://www.energy.gov/eere/fuelcells/fuel-cell-technologies-office-accomplishments-and-progress
[Accessed 17 June 2018].

Vassileiadis, C., 2014. *Techoeconomic Analysis and Design of an Energy System for Gavdos Island,* Patras: Universisty of Patras, Laboratory of Generation Transmission and Utilisation of Energy.

Vlahakis, A., 2010. *Recent Changes in the Structure of Greek Wind Power Support Policies: Is enough being done to avert the wrath of Aeolus' sack of winds?,* Zurich: SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH.

Voutchkov, N., 2013. *Desalination Engineering: Planning and Design.* 1st ed. New York: Mc Graw Hill.

Warmburg, B. M., 2006. *MSc Thesis: Sustainable Energy for Islands: Opportunities versus Constraints of a 100%Renewable Electricity Systems: El Hierro (Canary Islands) and Flores (Azores) case studies,* Lund, Sweden: The International Institute for Industrial Environmental Economics.

WATEREUSE Association, 2011. *WHITE PAPER: Seawater Desalination Power Consumption,* s.l.: WATEREUSE Association Desalination Commitee.

Watkins, B., 2014. *Lithium or Vanadium: In Energy Storage, It's No Contest.* [Online] Available at: https://www.renewableenergyworld.com/articles/2014/07/lithium-or-vanadium-in-energy-storage-its-no-contest.html
[Accessed 17 June 2018].

Windfinder, 2018. *www.windfinder.com.* [Online] Available at: https://www.windfinder.com/#9/52.5170/13.4000 [Accessed 15 June 2018].

Windflow Technology Ltd., 2016. *Windflow Technology Ltd. Annual Report 2016,* New Zealand: Windflow Technology Ltd..

WWF Greece, 2018. *www.wwf.gr.* [Online] Available at: http://www.wwf.gr/news/2083-15-2 [Accessed 16 May 2018].

www.conserve-energy-future.com, 2017. *Cost of Wind Energy.* [Online] Available at: https://www.conserve-energy-future.com/windenergycost.php [Accessed 05 July 2018].

www.kalliergo.gr, 2018. *Farmer's Guide.* [Online] Available at: https://www.kalliergo.gr/ [Accessed 03 July 2018].

www.marinetraffic.com, 2018. *www.marinetraffic.com.* [Online] Available at: https://www.marinetraffic.com/en/ais/home/centerx:25.4/centery:38.3/zoom:6 [Accessed 16 June 2018].

www.renergyuk.com, 2018. *www.renergyuk.com.* [Online] Available at: http://www.renergyuk.com/olive-cake/ [Accessed 16 June 2018].

Zervos, A. & Moutafis, P., 2008. *Covering of energy and water demand using wind energy and desalination in Sikinos Island,* Athens: National Technical Univesity of Athens.

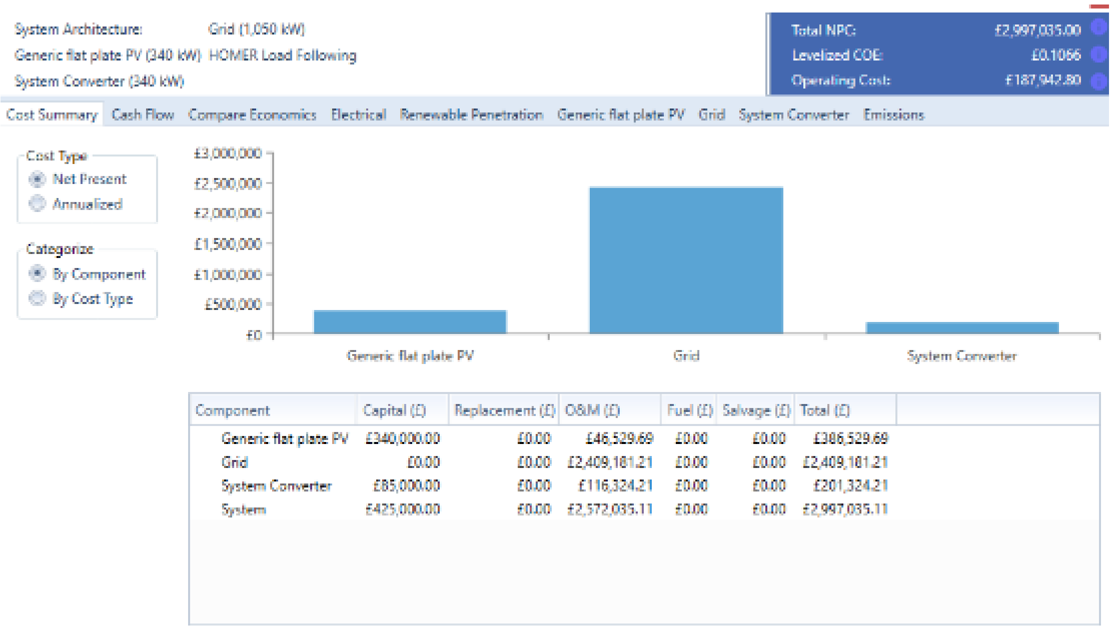
Zotalis, K., Dialynas, E. G., Mammasis, N. & Angelakis, A. N., 2014. Desalination Technologies: Hellenic Experience. *Water*, 6(2014), pp. 1134-1150.

9. Appendixes

Appendix 1:

25% Adoption Scenario

340PV:



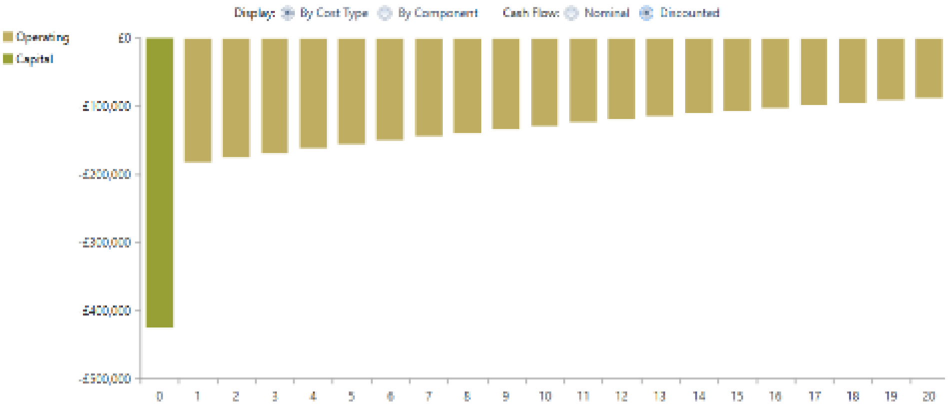
System Architecture: Grid (1,050 kW)
Generic flat plate PV (340 kW) HOMER Load Following
System Converter (340 kW)

Cost Type: ● Net Present ○ Annualized

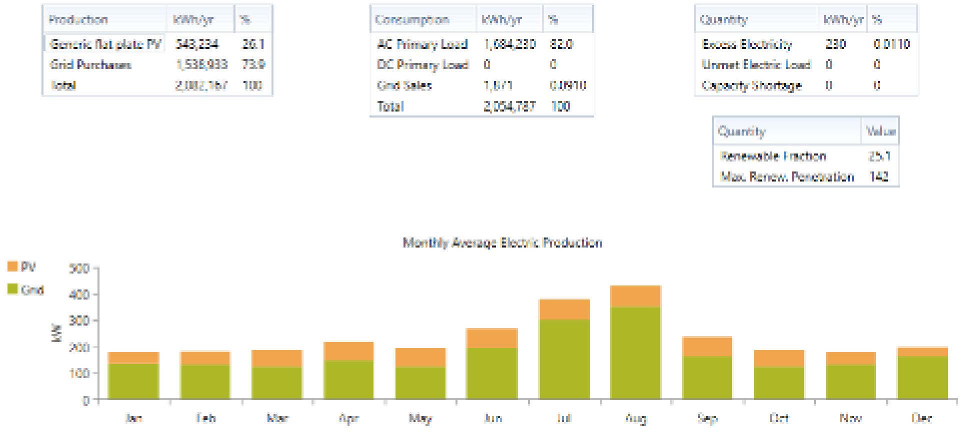
Categorize: ● By Component ○ By Cost Type

Component	Capital (£)	Replacement (£)	O&M (£)	Fuel (£)	Salvage (£)	Total (£)
Generic flat plate PV	£340,000.00	£0.00	£46,529.69	£0.00	£0.00	£386,529.69
Grid	£0.00	£0.00	£2,409,181.21	£0.00	£0.00	£2,409,181.21
System Converter	£85,000.00	£0.00	£116,324.21	£0.00	£0.00	£201,324.21
System	£425,000.00	£0.00	£2,572,035.11	£0.00	£0.00	£2,997,035.11

Cost Summary



Cash Flow



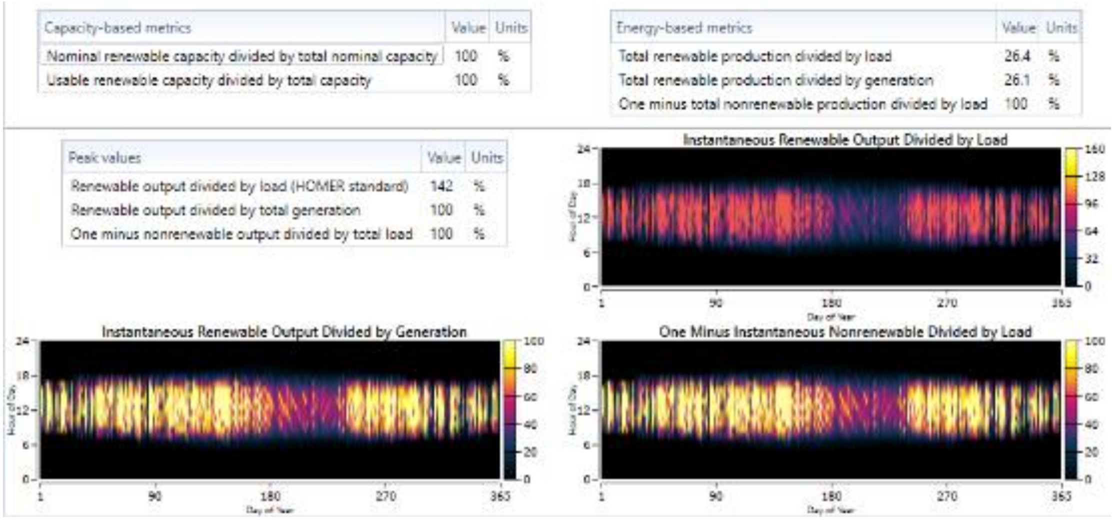
Production	kWh/yr	%
Generic flat plate PV	543,234	26.1
Grid Purchases	1,538,933	73.9
Total	2,082,167	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	82.0
DC Primary Load	0	0
Grid Sales	1,871	0.0910
Total	2,054,787	100

Quantity	kWh/yr	%
Excess Electricity	230	0.0110
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	25.1
Max. Renew. Penetration	142

Electrical sizes

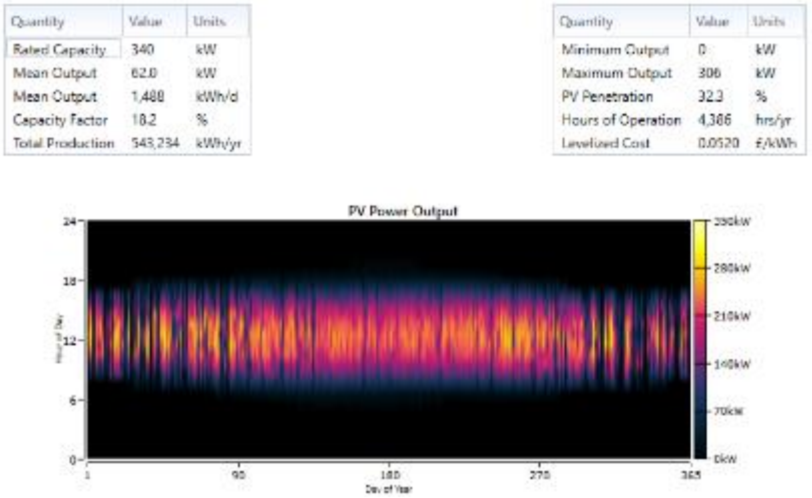


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	26.4	%
Total renewable production divided by generation	26.1	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	142	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

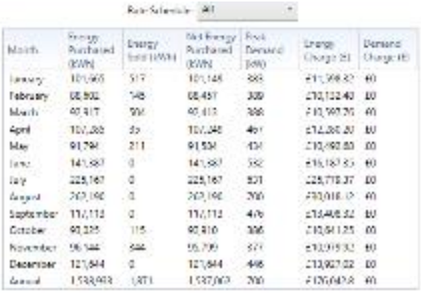
Renewable Penetration



Quantity	Value	Units
Rated Capacity	340	kW
Mean Output	62.0	kW
Mean Output	1,488	kWh/d
Capacity Factor	18.2	%
Total Production	543,234	kWh/yr

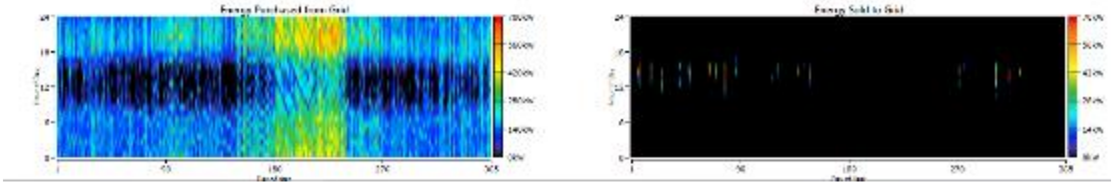
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	306	kW
PV Penetration	32.3	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	£/kWh

PV Output



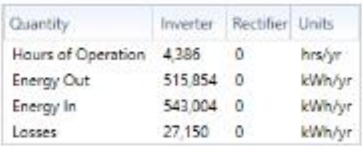
Rate Schedule: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (£)	Demand Charge (£)
January	101,665	517	101,148	388	£11,398.82	£0
February	88,902	145	88,457	389	£10,132.40	£0
March	90,917	504	90,413	388	£10,397.25	£0
April	107,283	35	107,248	461	£12,260.20	£0
May	91,794	211	91,534	434	£10,492.60	£0
June	141,587	0	141,587	532	£16,167.85	£0
July	225,167	0	225,167	501	£25,718.37	£0
August	262,190	0	262,190	700	£30,016.12	£0
September	117,112	0	117,112	476	£13,408.32	£0
October	90,325	115	90,210	386	£10,341.25	£0
November	56,344	644	55,700	377	£[illegible]	£0
December	121,644	0	121,644	446	£13,927.02	£0
Annual	1,538,933	1,871	1,537,062	700	£176,042.8	£0

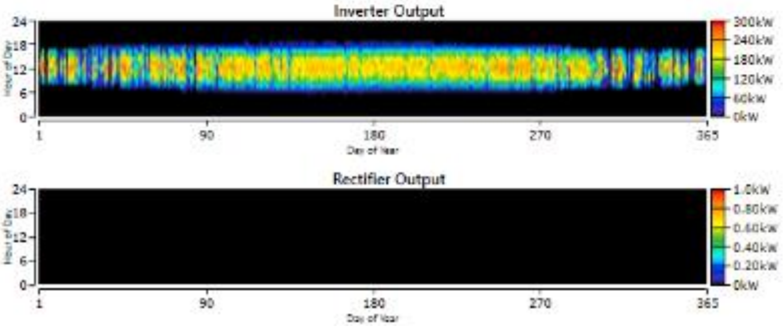


Grid Transactions

Quantity	Inverter	Rectifier	Units
Capacity	340	340	kW
Mean Output	58.9	0	kW
Minimum Output	0	0	kW
Maximum Output	291	0	kW
Capacity Factor	17.3	0	%

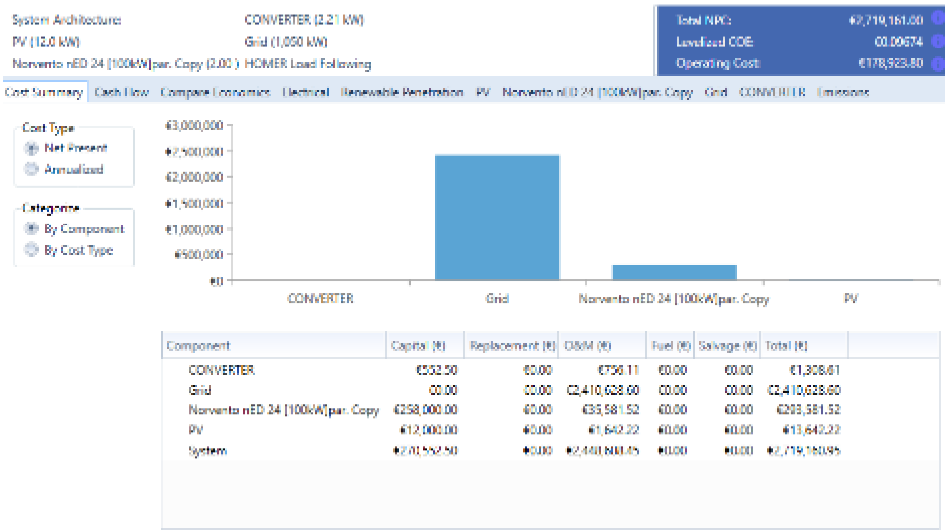


Quantity	Inverter	Rectifier	Units
Hours of Operation	4,386	0	hrs/yr
Energy Out	515,854	0	kWh/yr
Energy In	543,004	0	kWh/yr
Losses	27,150	0	kWh/yr



Converter Output

<u>12PV+2*100WT:</u>

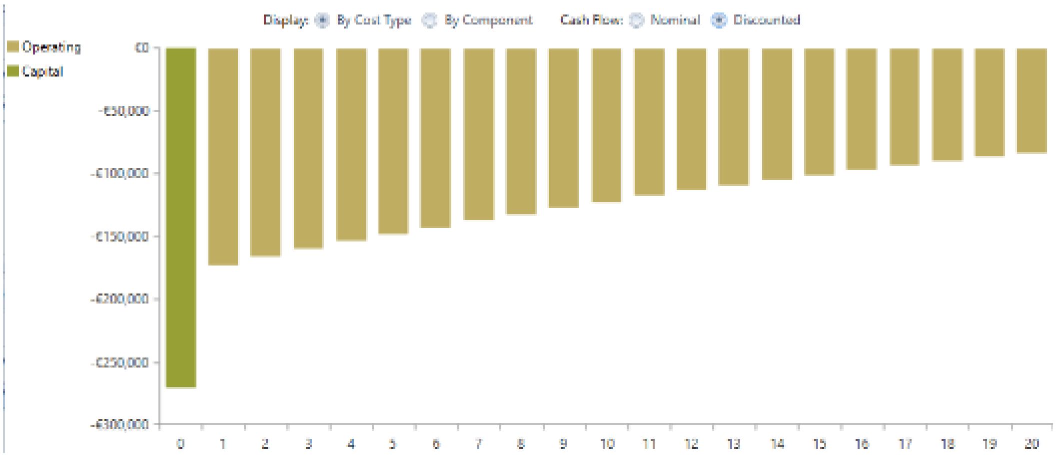


System Architecture: CONVERTER (2.21 kW)
PV (12.0 kW) Grid (1,050 kW)
Norvento nED 24 [100kW]par. Copy (2.00) HOMER Load Following

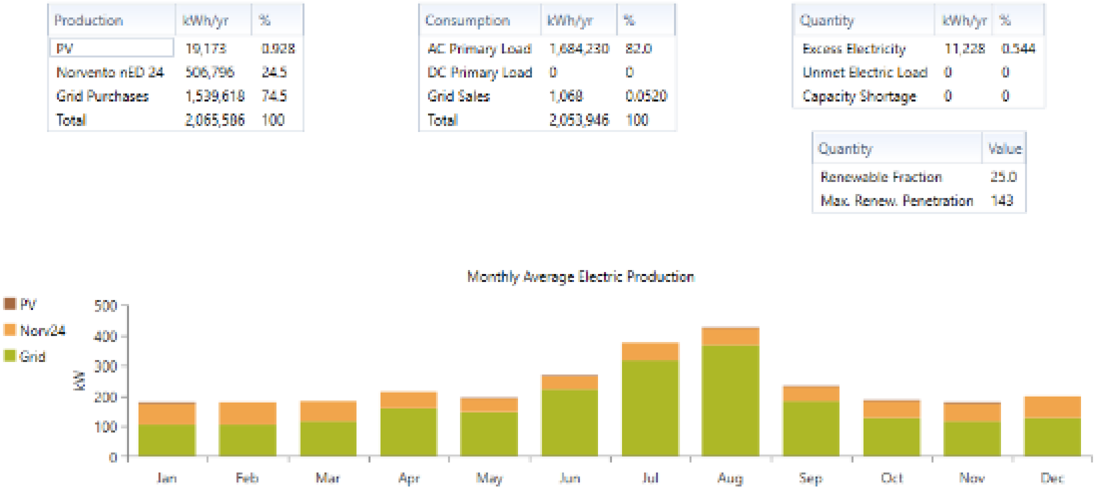
Total NPC: €2,719,161.00
Levelized COE: €0.00674
Operating Cost: €178,923.80

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CONVERTER	€552.50	€0.00	€756.11	€0.00	€0.00	€1,308.61
Grid	€0.00	€0.00	€2,410,628.60	€0.00	€0.00	€2,410,628.60
Norvento nED 24 [100kW]par. Copy	€258,000.00	€0.00	€35,581.52	€0.00	€0.00	€293,581.52
PV	€12,000.00	€0.00	€1,642.22	€0.00	€0.00	€13,642.22
System	€270,552.50	€0.00	€2,448,608.45	€0.00	€0.00	€2,719,160.95

Cost Summary



Cash Flow



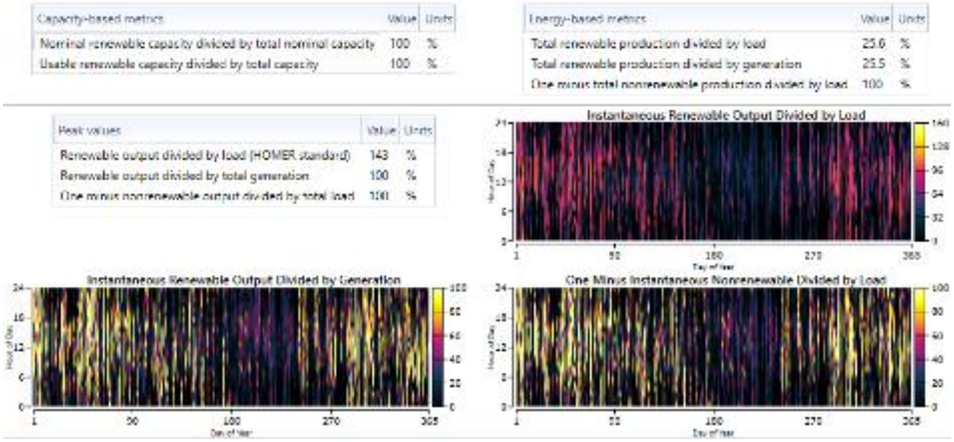
Production	kWh/yr	%
PV	19,173	0.928
Norvento nED 24	506,796	24.5
Grid Purchases	1,539,618	74.5
Total	2,065,586	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	82.0
DC Primary Load	0	0
Grid Sales	1,068	0.0520
Total	2,053,946	100

Quantity	kWh/yr	%
Excess Electricity	11,228	0.544
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	25.0
Max. Renew. Penetration	143

Electrical sizes

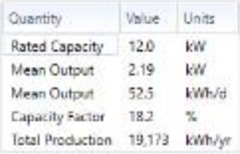


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

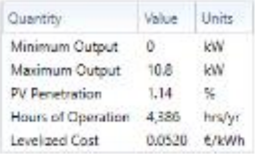
Energy-based metrics	Value	Units
Total renewable production divided by load	25.6	%
Total renewable production divided by generation	25.5	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	143	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

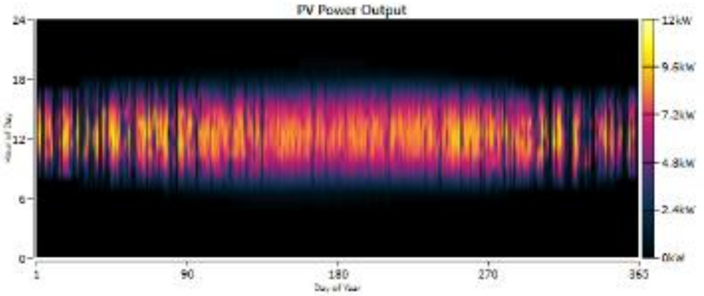
Renewable Penetration



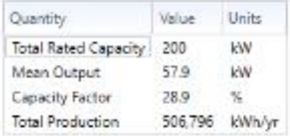
Quantity	Value	Units
Rated Capacity	12.0	kW
Mean Output	2.19	kW
Mean Output	52.5	kWh/d
Capacity Factor	18.2	%
Total Production	19,173	kWh/yr



Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	10.8	kW
PV Penetration	1.14	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

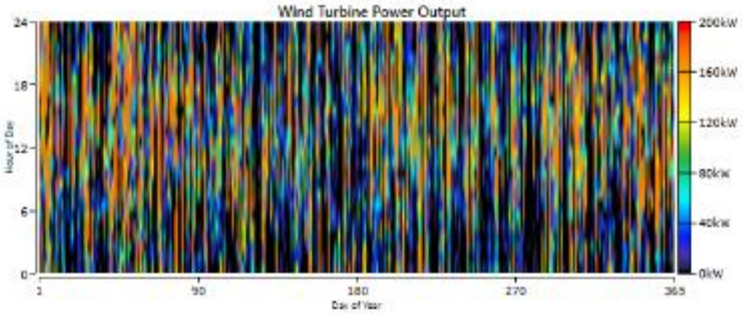


PV output



Quantity	Value	Units
Total Rated Capacity	200	kW
Mean Output	57.9	kW
Capacity Factor	28.9	%
Total Production	506,796	kWh/yr

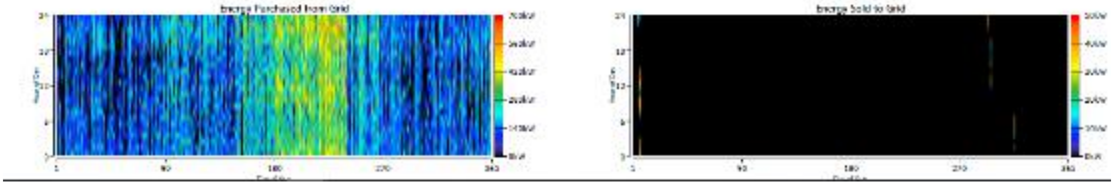
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	181	kW
Wind Penetration	30.1	%
Hours of Operation	6,206	hrs/yr
Levelized Cost	0.0423	€/kWh



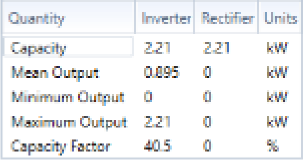
Wind Turbines' output

Rate Schedule: All

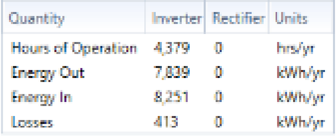
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (₦)	Demand Charge (₦)
January	70,870	603	70,273	398	₦8,961.00	₦0
February	60,679	0	60,679	375	₦7,917.52	₦0
March	80,181	0	80,181	377	₦10,093.52	₦0
April	115,220	0	115,220	451	₦13,191.59	₦0
May	108,142	0	108,142	383	₦12,485.72	₦0
June	162,907	0	160,907	502	₦18,472.27	₦0
July	224,351	0	224,351	569	₦26,800.82	₦0
August	273,090	0	273,090	661	₦31,335.07	₦0
September	132,075	0	132,075	487	₦15,121.06	₦0
October	97,145	335	96,030	368	₦11,087.06	₦0
November	83,108	156	82,955	379	₦9,487.55	₦0
December	97,258	0	97,258	470	₦11,134.02	₦0
Annual	1,589,618	1,098	1,588,530	661	₦176,148.1	₦0



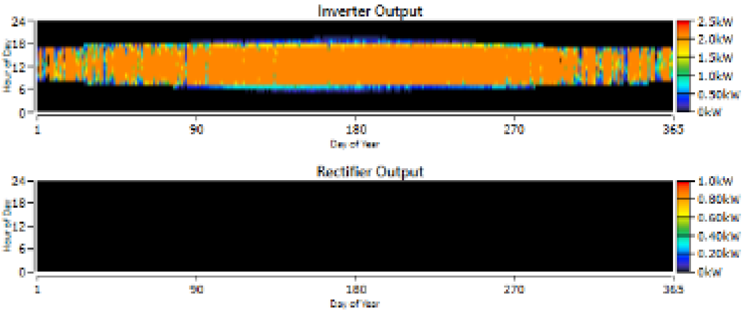
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	2.21	2.21	kW
Mean Output	0.895	0	kW
Minimum Output	0	0	kW
Maximum Output	2.21	0	kW
Capacity Factor	40.5	0	%

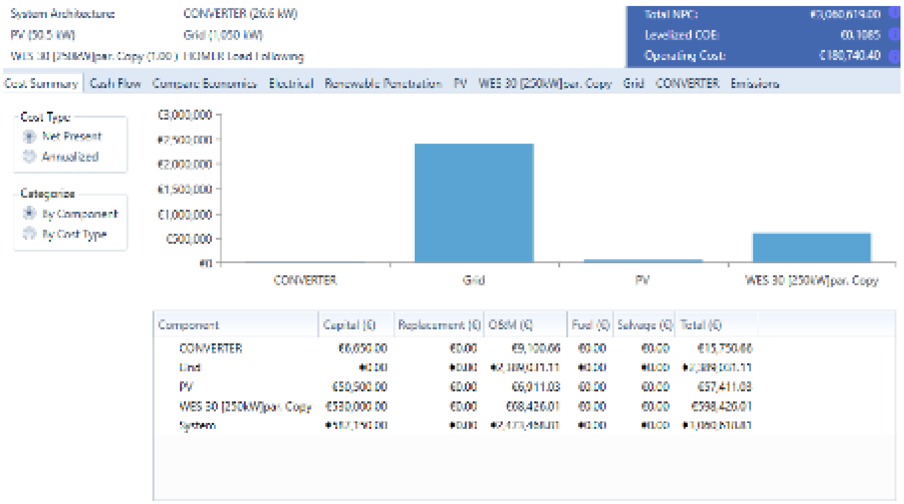


Quantity	Inverter	Rectifier	Units
Hours of Operation	4,379	0	hrs/yr
Energy Out	7,839	0	kWh/yr
Energy In	8,251	0	kWh/yr
Losses	413	0	kWh/yr



Converter output

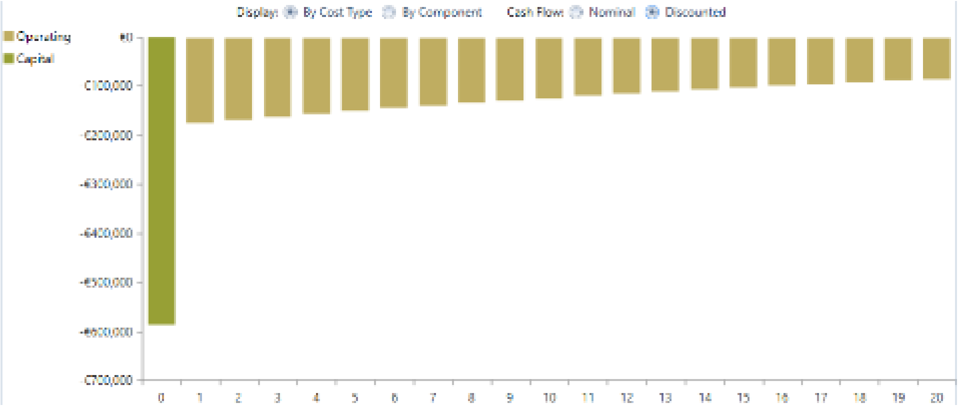
<u>40PV+250WT:</u>



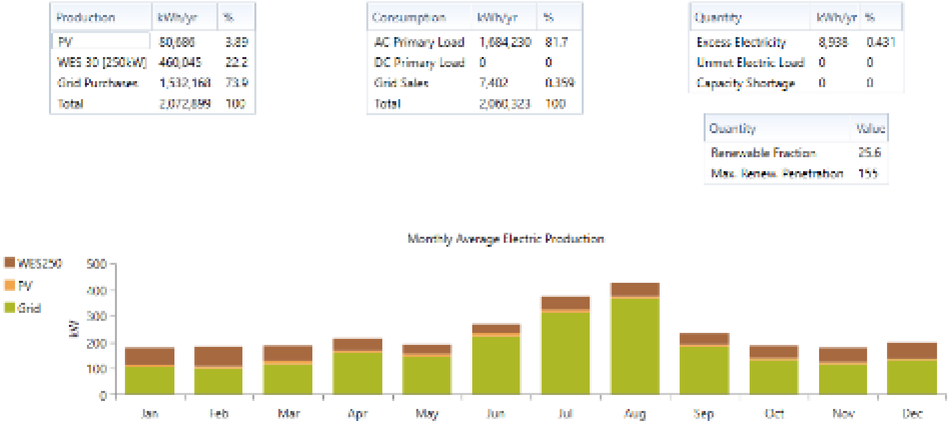
System Architecture:	CONVERTER (26.6 kW)	Total NPC: €3,060,619.00
PV (50.5 kW)	Grid (1,050 kW)	Levelized COE: €0.1085
WES 30 [250kW]par. Copy (1.00)	HOMER Load Following	Operating Cost: €180,740.40

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CONVERTER	€6,650.00	€0.00	€9,100.66	€0.00	€0.00	€15,750.66
Grid	€0.00	€0.00	€2,389,031.11	€0.00	€0.00	€2,389,031.11
PV	€50,500.00	€0.00	€6,911.03	€0.00	€0.00	€57,411.03
WES 30 [250kW]par. Copy	€530,000.00	€0.00	€68,426.01	€0.00	€0.00	€598,426.01
System	€587,150.00	€0.00	€2,473,468.81	€0.00	€0.00	€3,060,618.81

Cost Summary



Cash flow



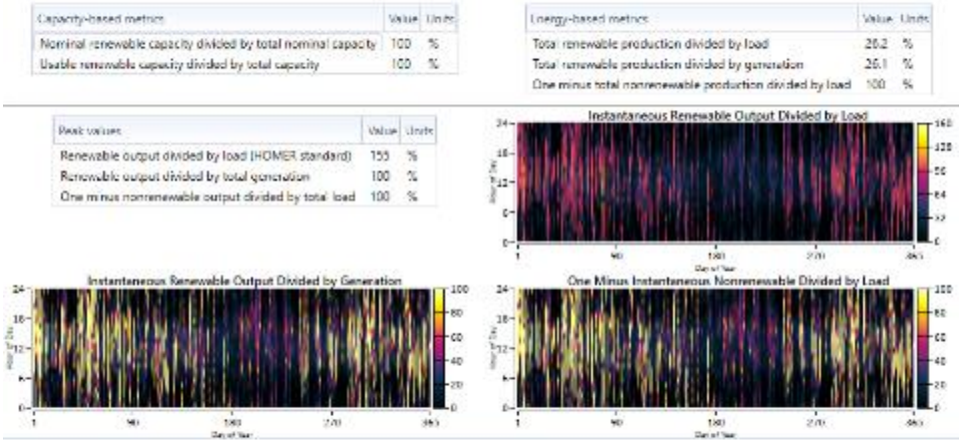
Production	kWh/yr	%
PV	80,686	3.89
WES 30 [250kW]	460,045	22.2
Grid Purchases	1,532,168	73.9
Total	2,072,899	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	81.7
DC Primary Load	0	0
Grid Sales	7,402	0.359
Total	2,060,323	100

Quantity	kWh/yr	%
Excess Electricity	8,938	0.431
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	25.6
Max. Renew. Penetration	155

Electrical sizes

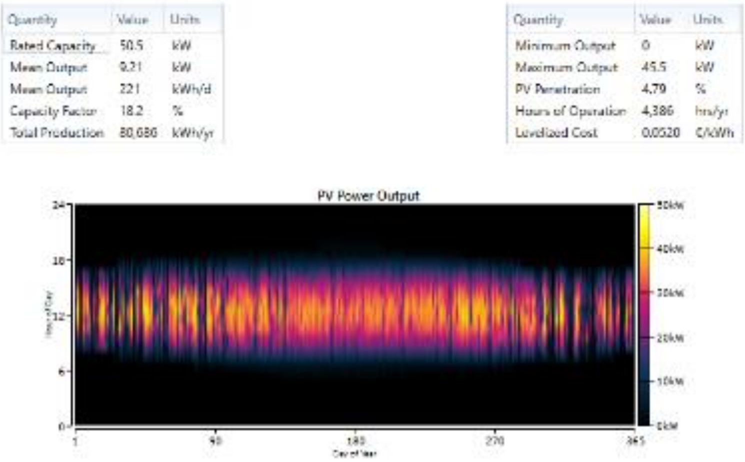


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	26.2	%
Total renewable production divided by generation	26.1	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	155	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

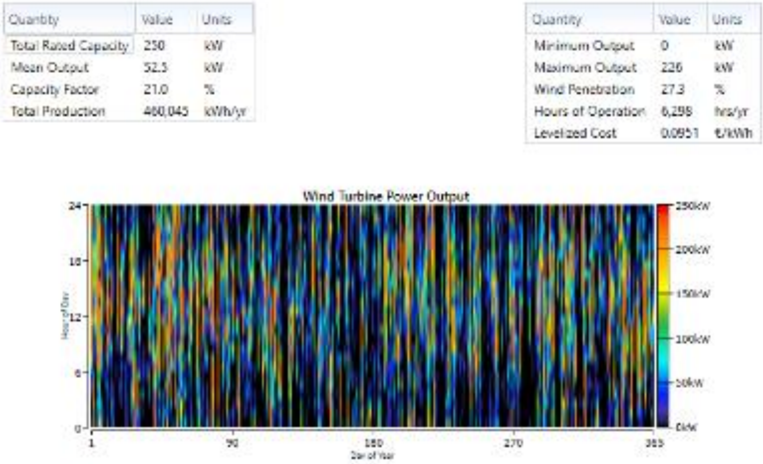
Renewable Penetration



Quantity	Value	Units
Rated Capacity	50.5	kW
Mean Output	9.21	kW
Mean Output	221	kWh/d
Capacity Factor	18.2	%
Total Production	80,686	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	45.5	kW
PV Penetration	4.79	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

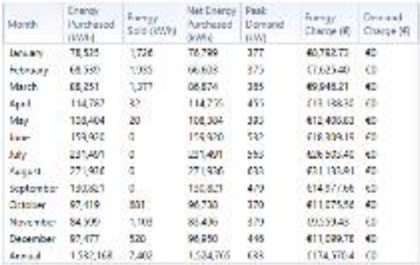
PV output



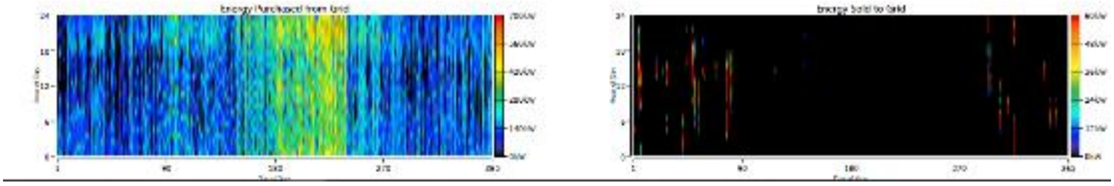
Quantity	Value	Units
Total Rated Capacity	250	kW
Mean Output	52.5	kW
Capacity Factor	21.0	%
Total Production	460,045	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	226	kW
Wind Penetration	27.3	%
Hours of Operation	6,298	hrs/yr
Levelized Cost	0.0951	€/kWh

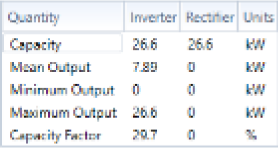
250 kW wind turbine output



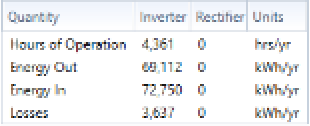
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (₹)	Demand Charge (₹)
January	78,525	1,726	76,799	377	₹9,782.73	₹0
February	68,530	1,935	66,608	375	₹7,625.40	₹0
March	68,251	1,377	66,874	385	₹9,948.21	₹0
April	114,787	32	114,755	455	₹13,188.32	₹0
May	108,404	20	108,384	393	₹12,400.83	₹0
June	159,920	0	159,920	532	₹18,309.15	₹0
July	221,481	0	221,481	553	₹26,505.40	₹0
August	271,936	0	271,936	633	₹31,193.91	₹0
September	150,821	0	150,821	479	₹14,577.66	₹0
October	97,419	689	96,730	370	₹11,075.58	₹0
November	84,509	1,103	83,406	379	₹9,553.48	₹0
December	97,477	520	96,950	446	₹11,099.78	₹0
Annual	1,532,168	7,402	1,524,765	633	₹174,570.4	₹0



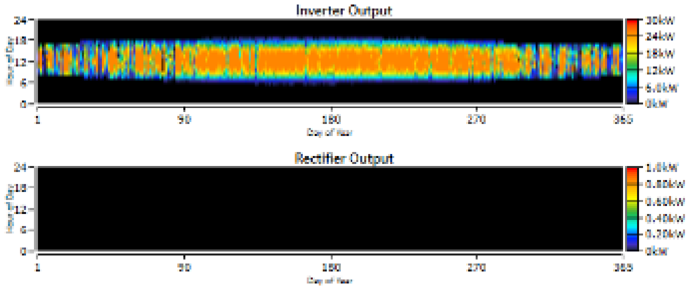
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	26.6	26.6	kW
Mean Output	7.89	0	kW
Minimum Output	0	0	kW
Maximum Output	26.6	0	kW
Capacity Factor	29.7	0	%



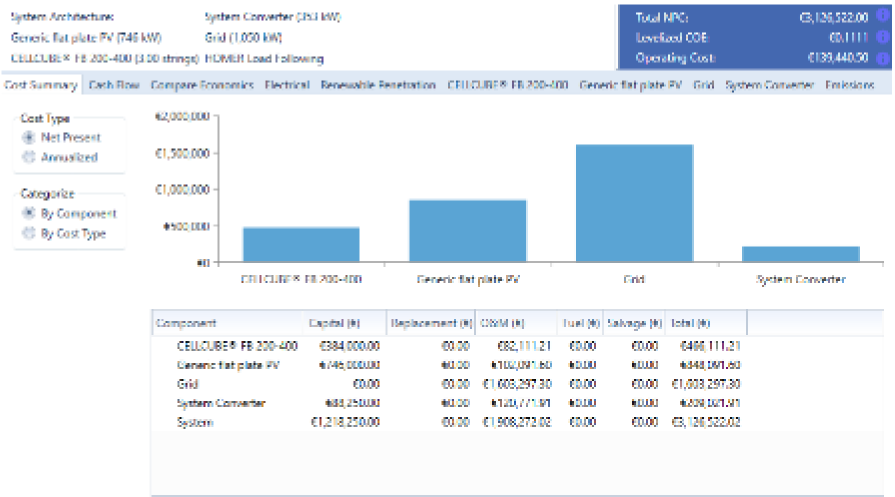
Quantity	Inverter	Rectifier	Units
Hours of Operation	4,361	0	hrs/yr
Energy Out	69,112	0	kWh/yr
Energy In	72,750	0	kWh/yr
Losses	3,637	0	kWh/yr



Converter output

50% Adoption Scenario

746PV+1BATT:

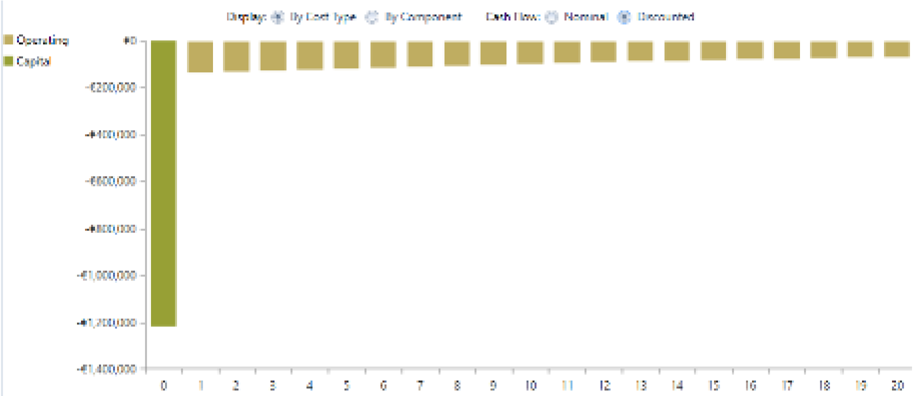


System Architecture:
Generic flat plate PV (746 kW)
CELLCUBE® FB 200-400 (3.00 strings)
System Converter (353 kW)
Grid (1,030 kW)
HOMER Load Following

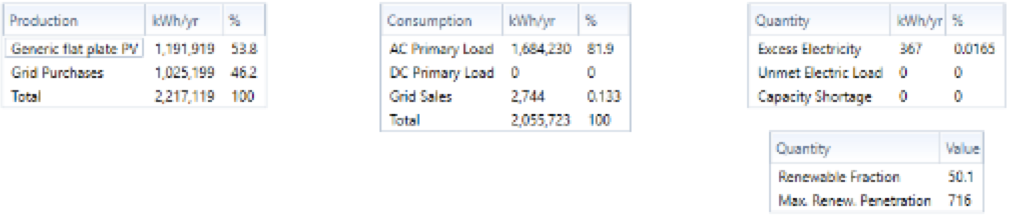
Total NPC:	€3,126,522.00
Levelized COE:	€0.1111
Operating Cost:	€139,440.50

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€384,000.00	€0.00	€82,111.21	€0.00	€0.00	€466,111.21
Generic flat plate PV	€746,000.00	€0.00	€102,091.60	€0.00	€0.00	€848,091.60
Grid	€0.00	€0.00	€1,603,297.30	€0.00	€0.00	€1,603,297.30
System Converter	€88,250.00	€0.00	€120,771.91	€0.00	€0.00	€209,021.91
System	€1,218,250.00	€0.00	€1,908,272.02	€0.00	€0.00	€3,126,522.02

Cost Summary



Cash flow

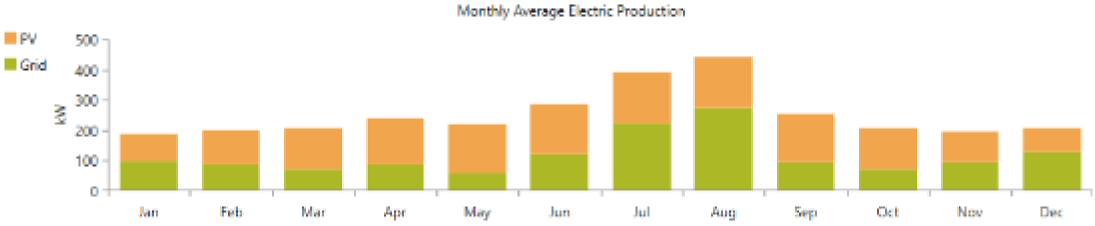


Production	kWh/yr	%
Generic flat plate PV	1,191,919	53.8
Grid Purchases	1,025,199	46.2
Total	2,217,119	100

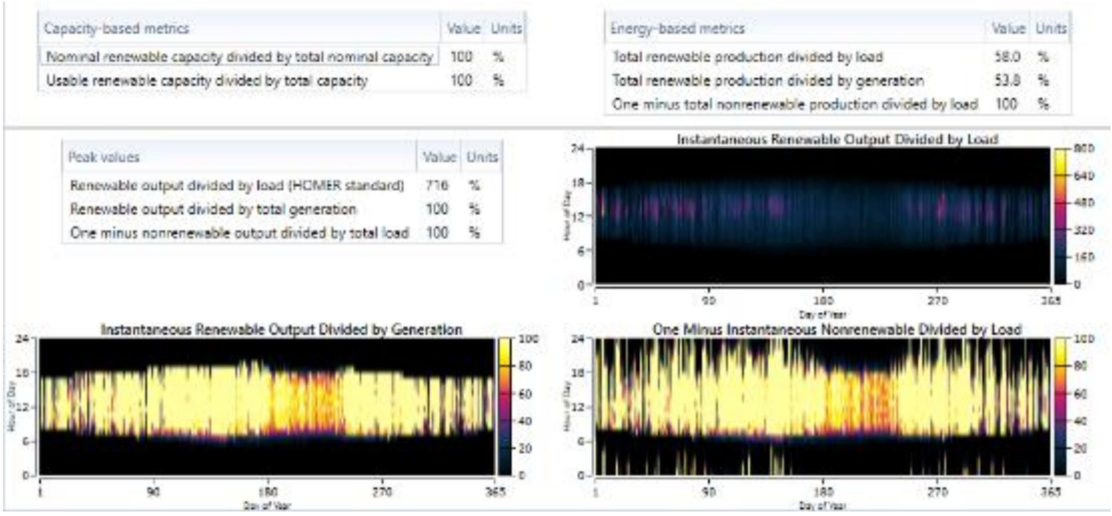
Consumption	kWh/yr	%
AC Primary Load	1,684,230	81.9
DC Primary Load	0	0
Grid Sales	2,744	0.133
Total	2,055,723	100

Quantity	kWh/yr	%
Excess Electricity	367	0.0165
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	50.1
Max. Renew. Penetration	716



Electrical sizes

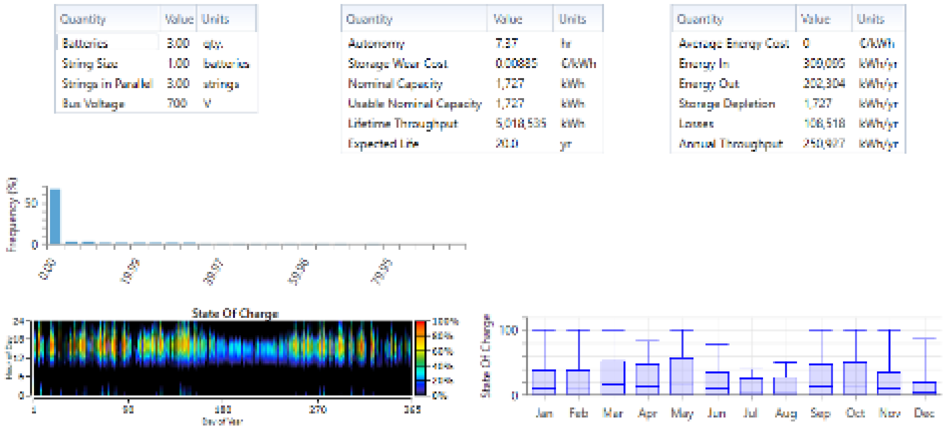


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	58.0	%
Total renewable production divided by generation	53.8	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	716	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

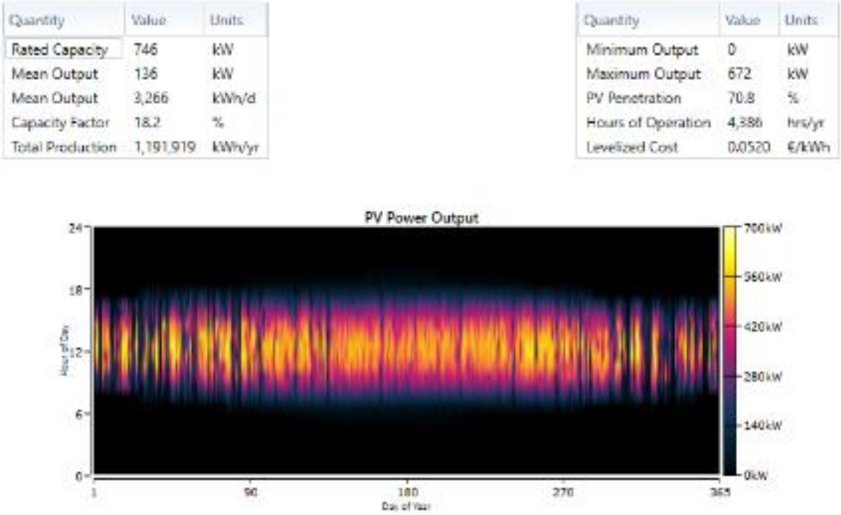


Quantity	Value	Units
Batteries	3.00	qty.
String Size	1.00	batteries
Strings in Parallel	3.00	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	7.37	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	1,727	kWh
Usable Nominal Capacity	1,727	kWh
Lifetime Throughput	5,018,535	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	309,095	kWh/yr
Energy Out	202,304	kWh/yr
Storage Depletion	1,727	kWh/yr
Losses	108,518	kWh/yr
Annual Throughput	250,977	kWh/yr

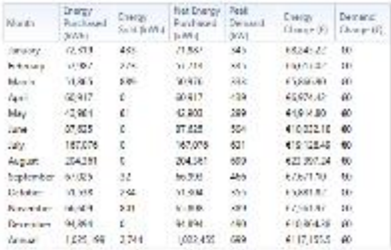
Battery usage

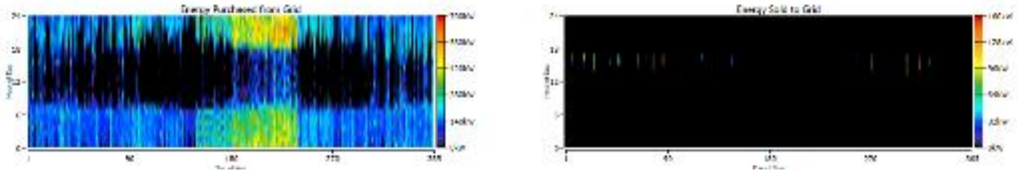


Quantity	Value	Units
Rated Capacity	746	kW
Mean Output	136	kW
Mean Output	3,266	kWh/d
Capacity Factor	18.2	%
Total Production	1,191,919	kWh/yr

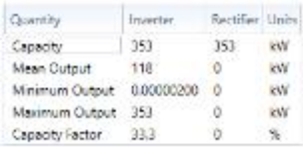
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	672	kW
PV Penetration	70.8	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

PV output

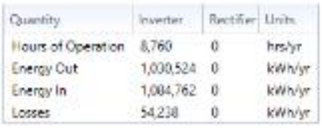




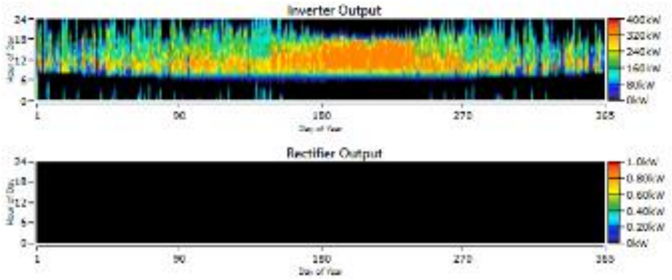
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	353	353	kW
Mean Output	118	0	kW
Minimum Output	0.00000200	0	kW
Maximum Output	353	0	kW
Capacity Factor	33.3	0	%

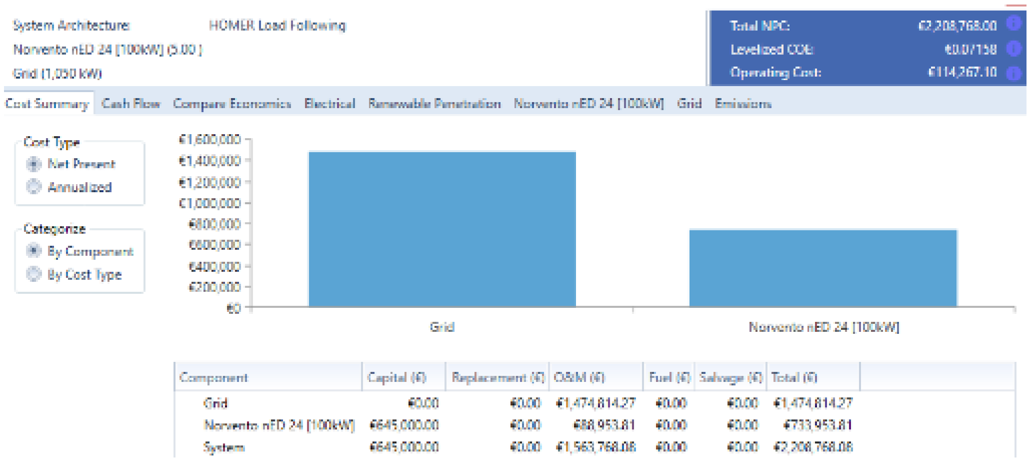


Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	1,030,524	0	kWh/yr
Energy In	1,084,762	0	kWh/yr
Losses	54,238	0	kWh/yr



Converter output

<u>5*100WT:</u>



System Architecture: HOMER Load Following
Norvento nED 24 [100kW] (5.00)
Grid (1,050 kW)

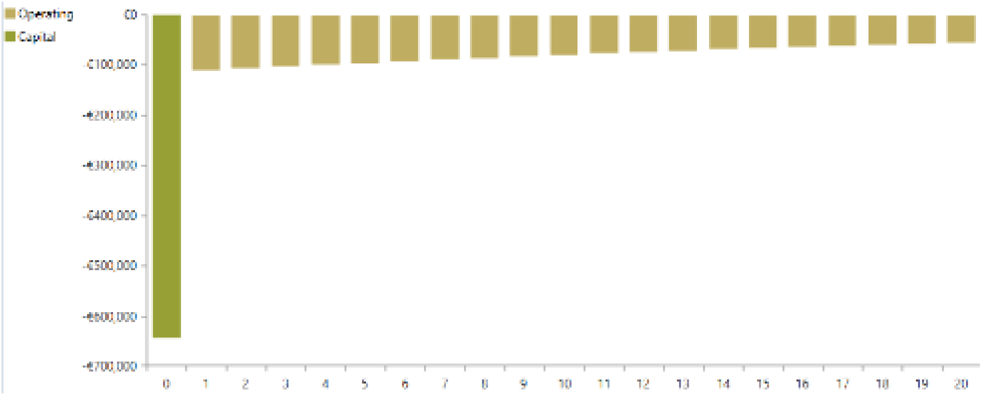
Total NPC: €2,208,768.00
Levelized COE: €0.07158
Operating Cost: €114,267.10

Cost Type: ● Net Present ○ Annualized

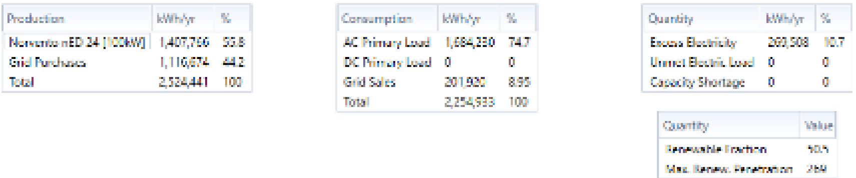
Categorize: ● By Component ○ By Cost Type

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
Grid	€0.00	€0.00	€1,474,814.27	€0.00	€0.00	€1,474,814.27
Norvento nED 24 [100kW]	€645,000.00	€0.00	€88,953.81	€0.00	€0.00	€733,953.81
System	€645,000.00	€0.00	€1,563,768.08	€0.00	€0.00	€2,208,768.08

Cost summary



Cash flow

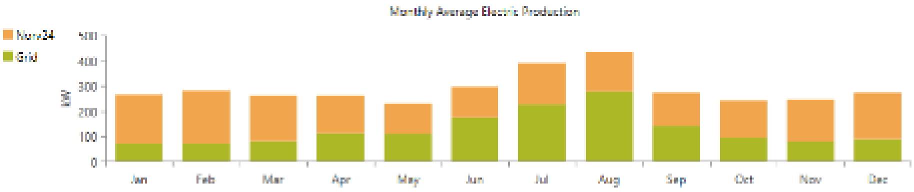


Production	kWh/yr	%
Norvento nED 24 [100kW]	1,407,766	55.8
Grid Purchases	1,116,674	44.2
Total	2,524,441	100

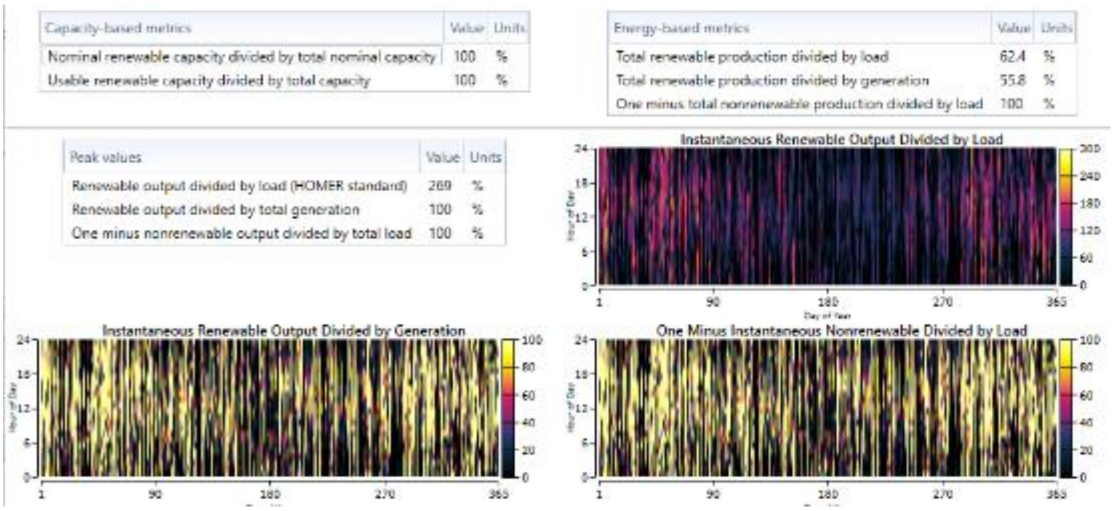
Consumption	kWh/yr	%
AC Primary Load	1,684,230	74.7
DC Primary Load	0	0
Grid Sales	201,920	8.95
Total	2,254,933	100

Quantity	kWh/yr	%
Excess Electricity	260,508	10.7
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	50.5
Max. Renew. Penetration	269



Cash flow



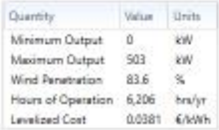
Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	62.4	%
Total renewable production divided by generation	55.8	%
One minus total nonrenewable production divided by load	100	%

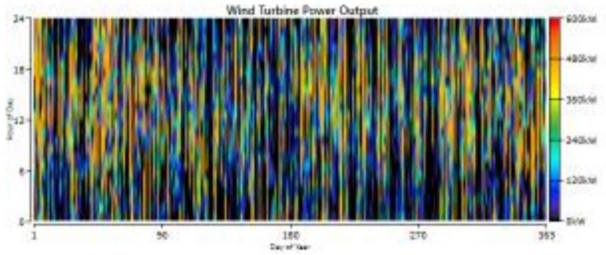
Peak values	Value	Units
Renewable output divided by load (HOMER standard)	269	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

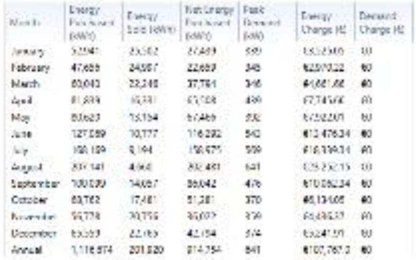
Quantity	Value	Units
Total Rated Capacity	500	kW
Mean Output	161	kW
Capacity Factor	32.1	%
Total Production	1,407,766	kWh/yr



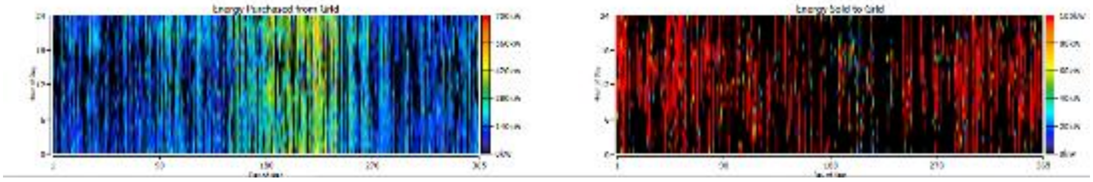
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	503	kW
Wind Penetration	83.6	%
Hours of Operation	6,206	hrs/yr
Levelized Cost	0.0381	€/kWh



100 kW wind turbines output

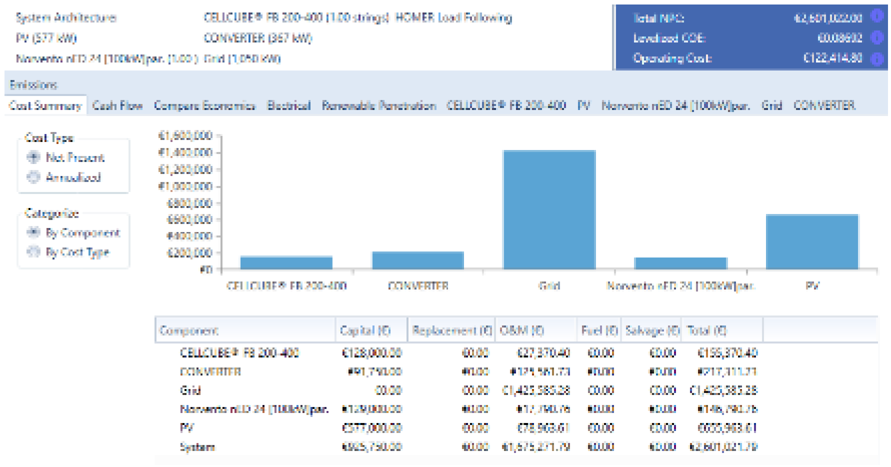


Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	52,941	25,502	27,469	559	€3,325.60	€0
February	47,655	24,967	22,689	346	€2,570.22	€0
March	60,043	22,248	37,761	346	€4,661.68	€0
April	81,699	16,331	65,368	489	€7,745.66	€0
May	83,623	15,154	67,469	532	€7,522.01	€0
June	127,059	10,777	116,282	542	€12,476.24	€0
July	168,169	9,194	158,975	559	€16,339.34	€0
August	207,141	4,664	202,481	641	€25,232.15	€0
September	100,039	14,057	86,042	476	€10,062.24	€0
October	68,762	17,481	51,281	370	€6,134.05	€0
November	56,778	20,756	36,022	379	€4,436.37	€0
December	65,363	22,165	42,154	574	€5,241.91	€0
Annual	1,118,974	201,820	914,754	641	€107,767.3	€0



Grid transactions

577PV+100WT+1BATT:

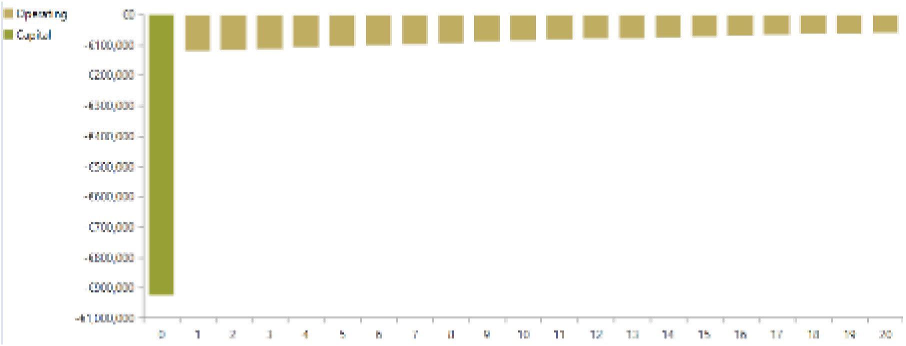


System Architecture CELLCUBE® FB 200-400 (1.00 strings) HOMER Load Following
PV (577 kW) CONVERTER (367 kW)
Norvento nED 24 [100kW]par. (1.00) Grid (1,050 kW)

Total NPC: €2,601,022.00
Levelized COE: €0.08692
Operating Cost: €122,414.80

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€128,000.00	€0.00	€27,370.40	€0.00	€0.00	€155,370.40
CONVERTER	€91,750.00	€0.00	€125,561.73	€0.00	€0.00	€217,311.73
Grid	€0.00	€0.00	€1,425,385.28	€0.00	€0.00	€1,425,385.28
Norvento nED 24 [100kW]par.	€129,000.00	€0.00	€17,790.76	€0.00	€0.00	€146,790.76
PV	€577,000.00	€0.00	€78,963.61	€0.00	€0.00	€655,963.61
System	€925,750.00	€0.00	€1,675,271.79	€0.00	€0.00	€2,601,021.79

Cost summary



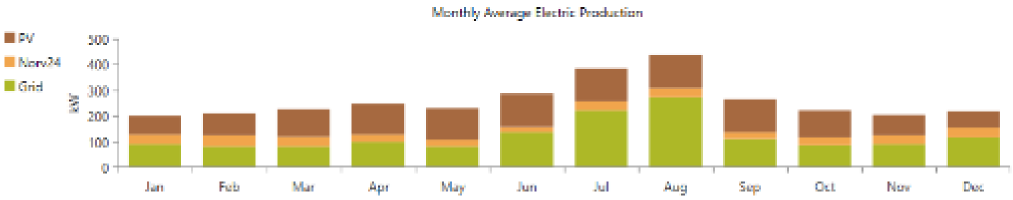
Cash flow

Production	kWh/yr	%
PV	921,900	40.3
Norvento nED 24 [100kW]par.	281,553	12.3
Grid Purchases	1,081,350	47.3
Total	2,284,803	100

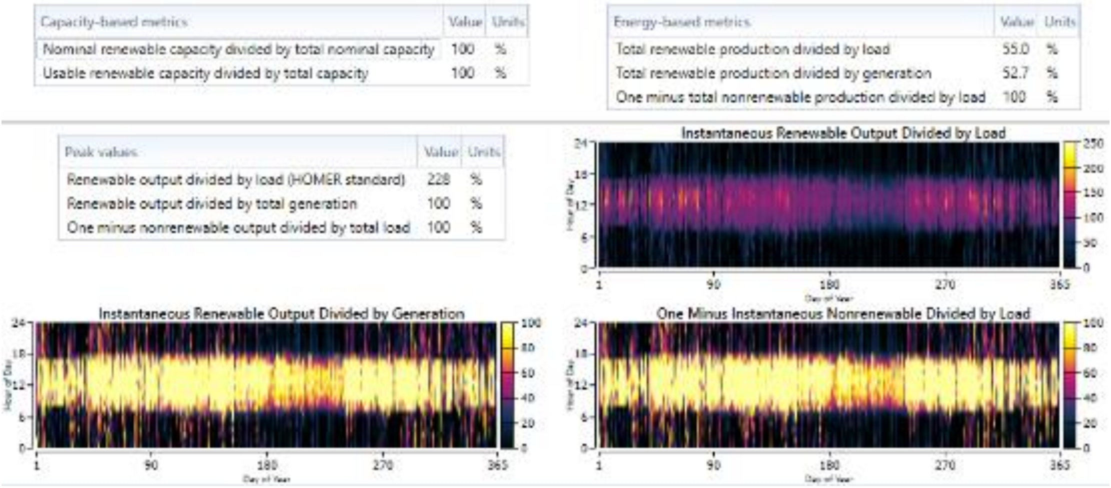
Consumption	kWh/yr	%
AC Primary Load	1,684,230	77.0
DC Primary Load	0	0
Grid Sales	133,564	6.11
Total	2,106,565	100

Quantity	kWh/yr	%
Excess Electricity	51,991	2.28
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	50.5
Max. Renew. Penetration	228



Electrical sizes

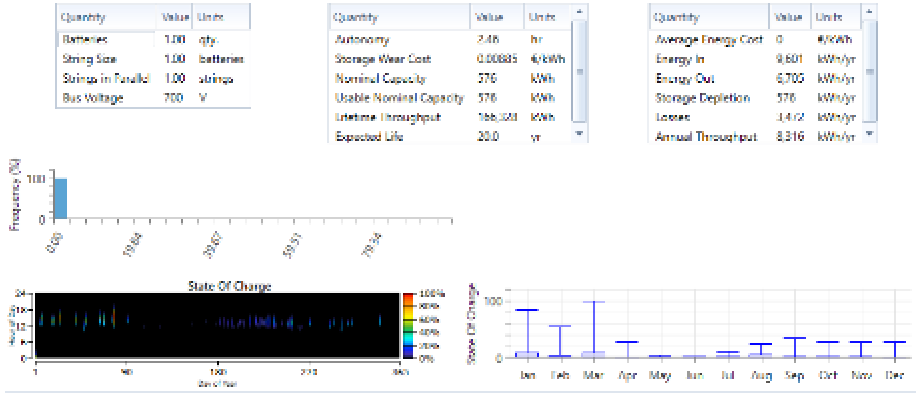


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	55.0	%
Total renewable production divided by generation	52.7	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	228	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

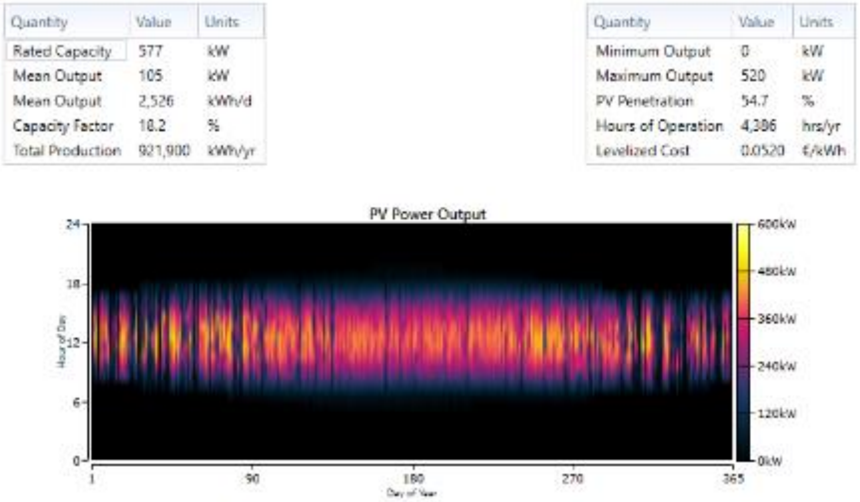


Quantity	Value	Units
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	2.46	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	576	kWh
Usable Nominal Capacity	576	kWh
Lifetime Throughput	166,320	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	9,601	kWh/yr
Energy Out	6,705	kWh/yr
Storage Depletion	576	kWh/yr
Losses	3,472	kWh/yr
Annual Throughput	8,316	kWh/yr

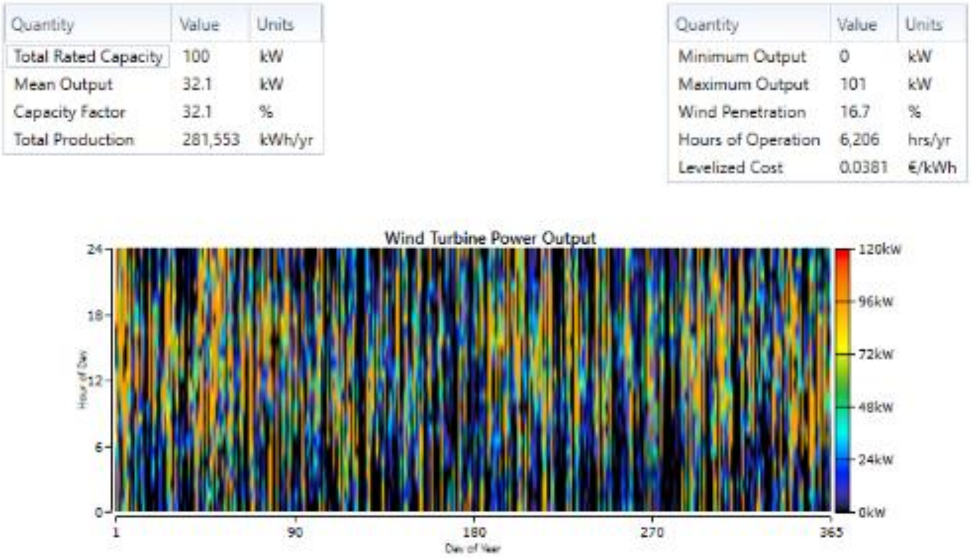
Battery usage



Quantity	Value	Units
Rated Capacity	577	kW
Mean Output	105	kW
Mean Output	2,526	kWh/d
Capacity Factor	18.2	%
Total Production	921,900	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	520	kW
PV Penetration	54.7	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

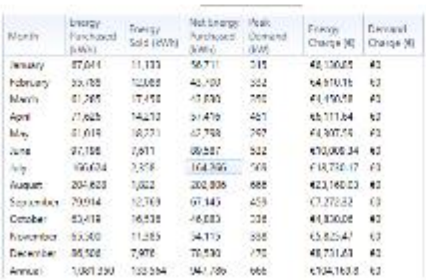
PV output



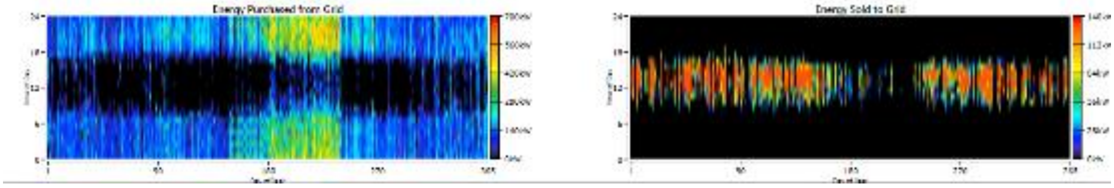
Quantity	Value	Units
Total Rated Capacity	100	kW
Mean Output	32.1	kW
Capacity Factor	32.1	%
Total Production	281,553	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	101	kW
Wind Penetration	16.7	%
Hours of Operation	6,206	hrs/yr
Levelized Cost	0.0381	€/kWh

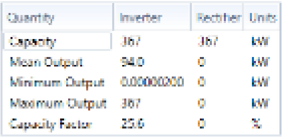
100 kW wind turbine output



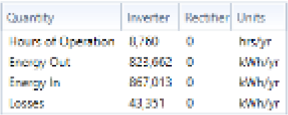
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	67,844	11,133	56,711	315	€6,130.05	€0
February	55,788	12,088	43,700	332	€4,910.15	€0
March	61,265	17,458	43,807	750	€4,490.58	€0
April	71,625	14,210	57,415	461	€6,111.84	€0
May	61,019	18,221	42,798	297	€4,307.55	€0
June	97,198	7,611	89,587	532	€10,008.34	€0
July	166,624	2,318	164,306	568	€18,730.17	€0
August	204,828	1,822	203,006	688	€23,160.03	€0
September	79,914	12,769	67,145	459	€7,272.82	€0
October	63,418	16,535	46,883	338	€4,830.06	€0
November	65,500	11,385	54,115	388	€5,825.47	€0
December	86,508	7,978	78,530	770	€8,731.63	€0
Annual	1,081,250	133,554	947,696	666	€104,163.8	€0



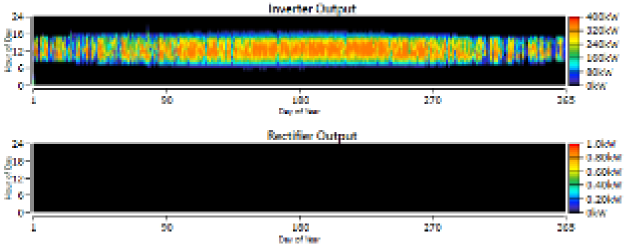
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	367	367	kW
Mean Output	94.0	0	kW
Minimum Output	0.00000200	0	kW
Maximum Output	367	0	kW
Capacity Factor	25.6	0	%

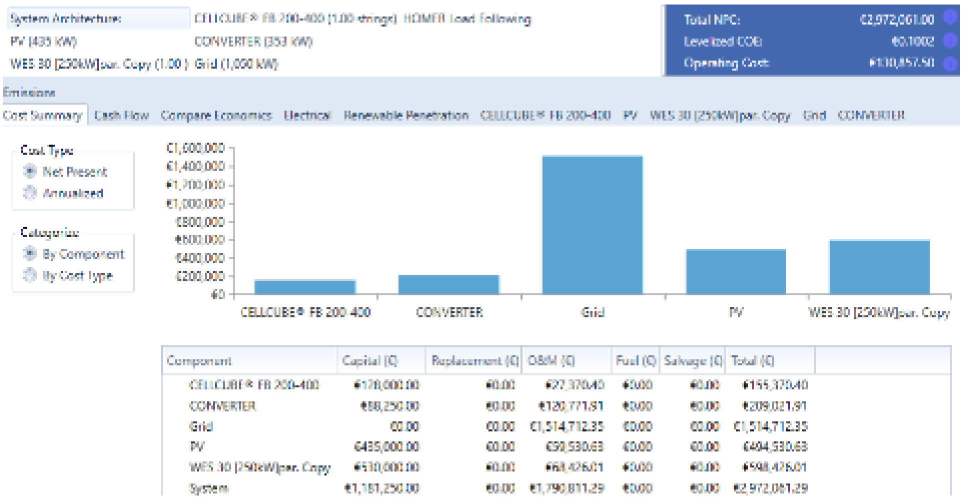


Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	823,662	0	kWh/yr
Energy In	867,013	0	kWh/yr
Losses	43,351	0	kWh/yr



Converter output

<u>435PV+250WT+1BATT:</u>



System Architecture:
PV (435 kW)
WES 30 [250kW]par. Copy (1.00)
CELLCUBE® FB 200-400 (1.00 strings)
CONVERTER (353 kW)
Grid (1,000 kW)
HOMER Load Following

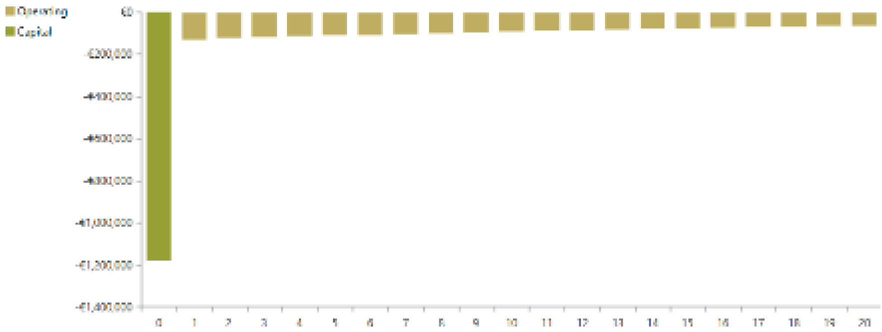
Total NPC: €2,972,061.00
Levelized COE: €0.1002
Operating Cost: €110,857.50

Cost Type
● Net Present
○ Annualized

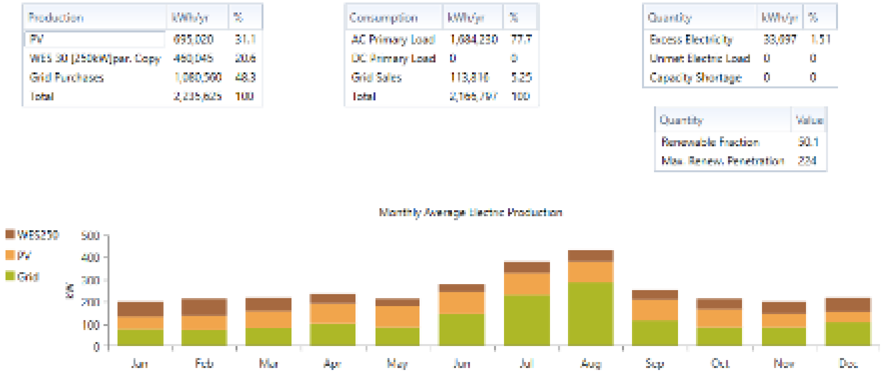
Categorize
● By Component
○ By Cost Type

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€128,000.00	€0.00	€27,370.40	€0.00	€0.00	€155,370.40
CONVERTER	€88,250.00	€0.00	€120,771.91	€0.00	€0.00	€209,021.91
Grid	€0.00	€0.00	€1,514,712.35	€0.00	€0.00	€1,514,712.35
PV	€435,000.00	€0.00	€59,530.63	€0.00	€0.00	€494,530.63
WES 30 [250kW]par. Copy	€530,000.00	€0.00	€68,426.01	€0.00	€0.00	€598,426.01
System	€1,181,250.00	€0.00	€1,790,811.29	€0.00	€0.00	€2,972,061.29

Cost summary



Cash flow



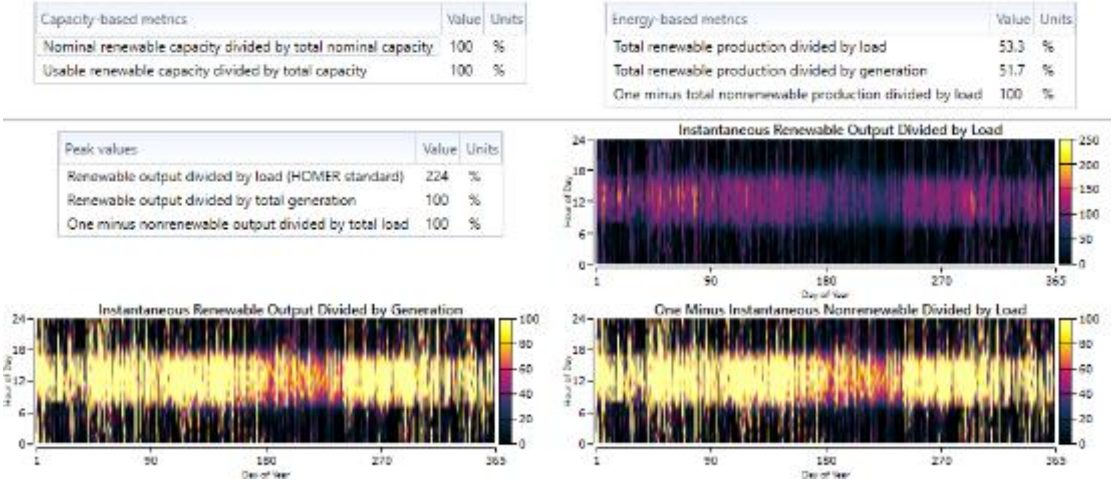
Production	kWh/yr	%
PV	695,020	31.1
WES 30 [250kW]par. Copy	460,045	20.6
Grid Purchases	1,080,560	48.3
Total	2,235,625	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	77.7
DC Primary Load	0	0
Grid Sales	113,816	5.25
Total	2,166,797	100

Quantity	kWh/yr	%
Excess Electricity	33,697	1.51
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	50.1
Max. Renew. Penetration	224

Electrical sizes

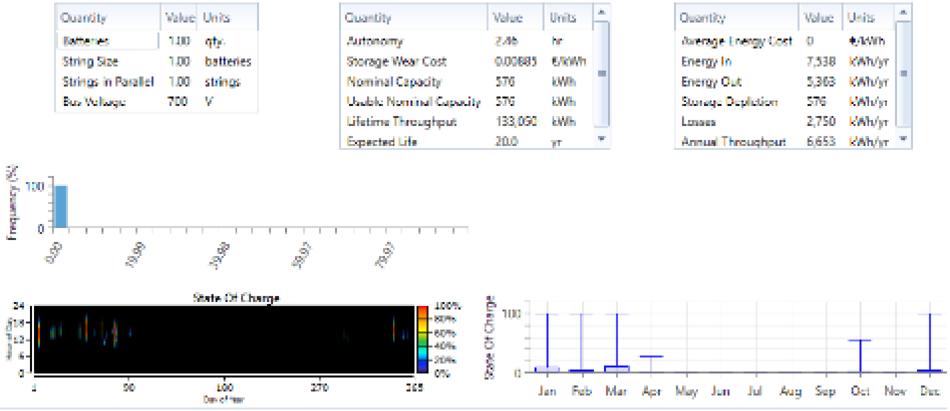


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	53.3	%
Total renewable production divided by generation	51.7	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	224	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

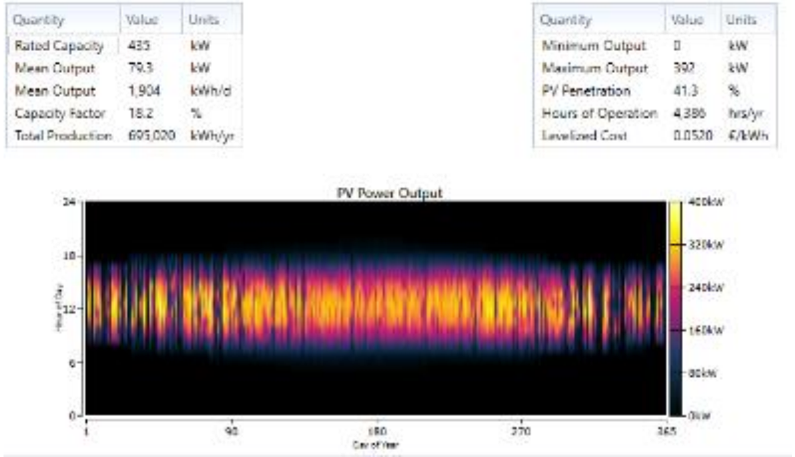


Quantity	Value	Units
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	2.46	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	576	kWh
Usable Nominal Capacity	576	kWh
Lifetime Throughput	133,050	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	7,538	KWh/yr
Energy Out	5,363	KWh/yr
Storage Depletion	576	KWh/yr
Losses	2,750	KWh/yr
Annual Throughput	6,653	KWh/yr

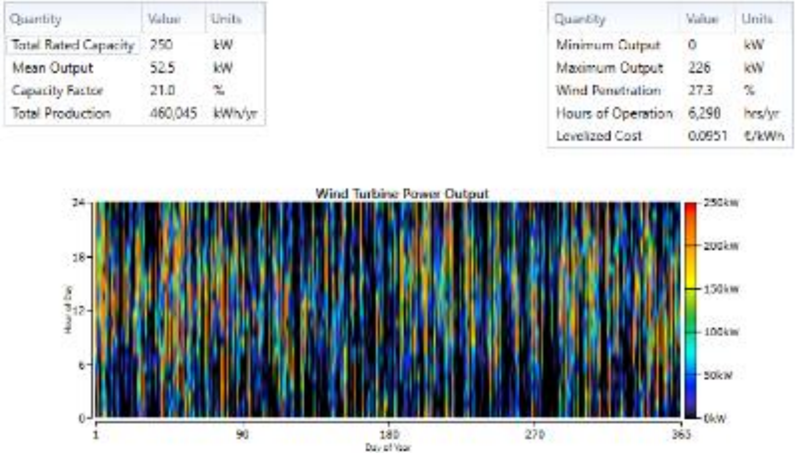
Battery usage



Quantity	Value	Units
Rated Capacity	435	kW
Mean Output	79.3	kW
Mean Output	1,904	kWh/d
Capacity Factor	18.2	%
Total Production	695,020	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	392	kW
PV Penetration	41.3	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

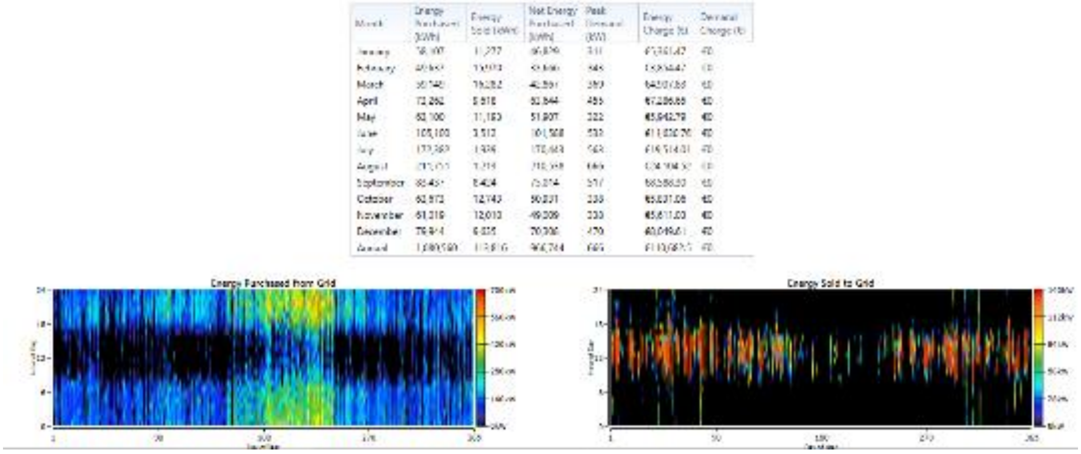
PV output



Quantity	Value	Units
Total Rated Capacity	250	kW
Mean Output	52.5	kW
Capacity Factor	21.0	%
Total Production	460,045	kWh/yr

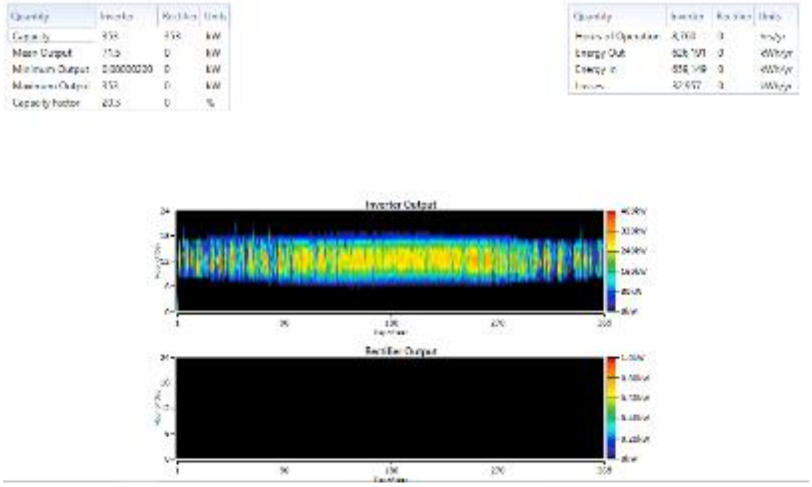
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	226	kW
Wind Penetration	27.3	%
Hours of Operation	6,298	hrs/yr
Levelized Cost	0.0951	€/kWh

250 kW wind turbine output



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	56,107	11,277	45,829	311	€3,361.42	€0
February	49,657	13,073	35,580	348	€3,504.47	€0
March	58,748	15,282	42,561	359	€4,507.88	€0
April	72,262	5,918	66,844	455	€7,286.85	€0
May	63,100	11,183	51,907	322	€5,942.79	€0
June	105,100	3,512	101,588	532	€11,032.70	€0
July	172,362	1,976	170,683	563	€19,514.01	€0
August	211,073	1,219	210,368	665	€24,304.57	€0
September	83,451	8,404	75,074	517	€8,588.53	€0
October	62,973	12,743	50,231	338	€5,831.08	€0
November	61,319	12,013	49,309	333	€5,611.03	€0
December	76,914	6,635	70,306	470	€8,049.61	€0
Annual	1,080,590	113,816	966,744	665	€110,682.5	€0

Grid transactions



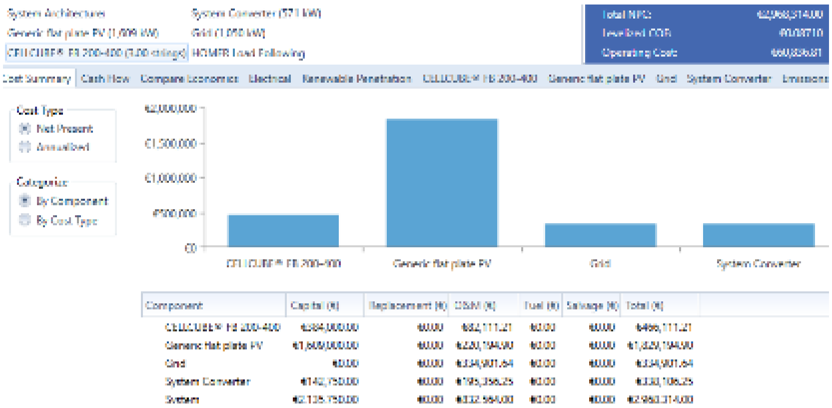
Quantity	Inverter	Rectifier	Units
Capacity	358	358	kW
Mean Output	71.5	0	kW
Minimum Output	0.00000030	0	kW
Maximum Output	358	0	kW
Capacity Factor	20.0	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	4,760	0	hrs/yr
Energy Out	626,191	0	kWh/yr
Energy In	659,149	0	kWh/yr
Losses	32,957	0	kWh/yr

Converter output

75% Adoption Scenario

1609PV+3BATT:

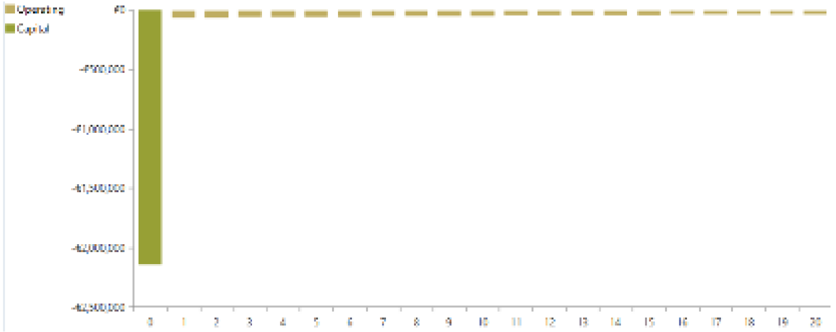


System Architecture
Generic flat plate PV (1,609 kW)
CELLCUBE® FB 200-400 (3.00 strings)
System Converter (571 kW)
Grid (1,050 kW)
HOMER Load Following

Total NPC €2,968,314.00
Levelized COE €0.03710
Operating Cost €60,826.81

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€384,000.00	€0.00	€82,111.21	€0.00	€0.00	€466,111.21
Generic flat plate PV	€1,609,000.00	€0.00	€220,194.90	€0.00	€0.00	€1,829,194.90
Grid	€0.00	€0.00	€334,901.64	€0.00	€0.00	€334,901.64
System Converter	€142,750.00	€0.00	€195,356.25	€0.00	€0.00	€338,106.25
System	€2,135,750.00	€0.00	€832,564.00	€0.00	€0.00	€2,968,314.00

Cost summary



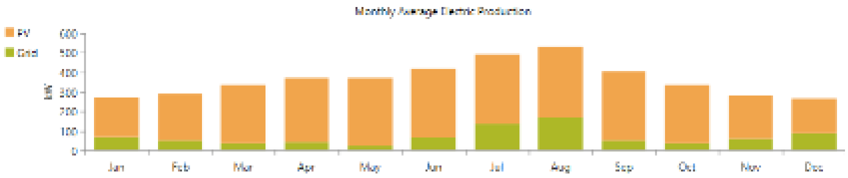
Cash flow

Production	kWh/yr	%
Generic flat plate PV	2,570,775	80.5
Grid Purchases	621,680	19.5
Total	3,192,456	100

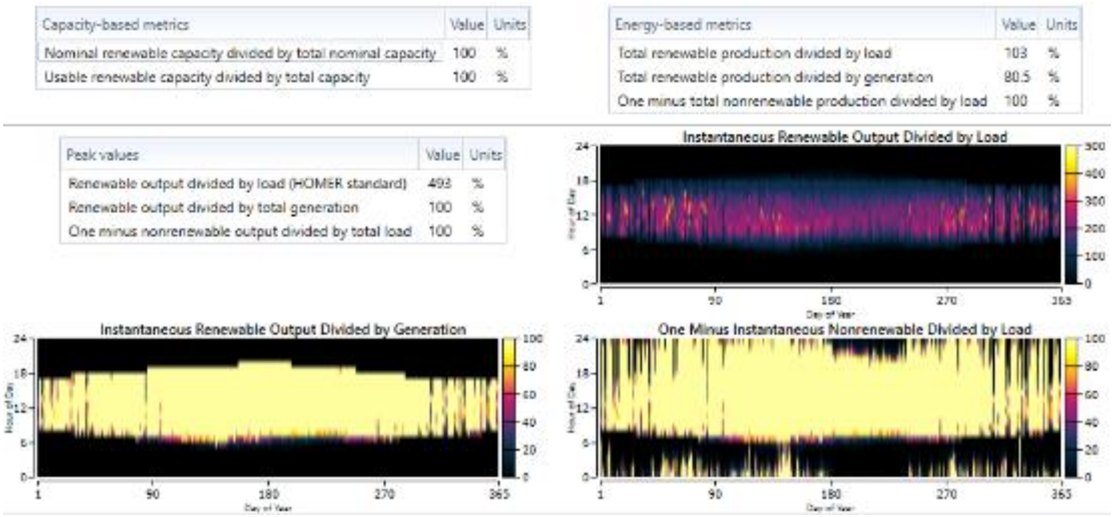
Consumption	kWh/yr	%
AC Primary Load	1,684,230	67.6
DC Primary Load	0	0
Grid Sales	437,305	17.6
Total	2,480,219	100

Quantity	kWh/yr	%
Excess Electricity	365,973	11.5
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	75.0
Max. Renew. Penetration	493



Electrical sizes



Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	103	%
Total renewable production divided by generation	80.5	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	493	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

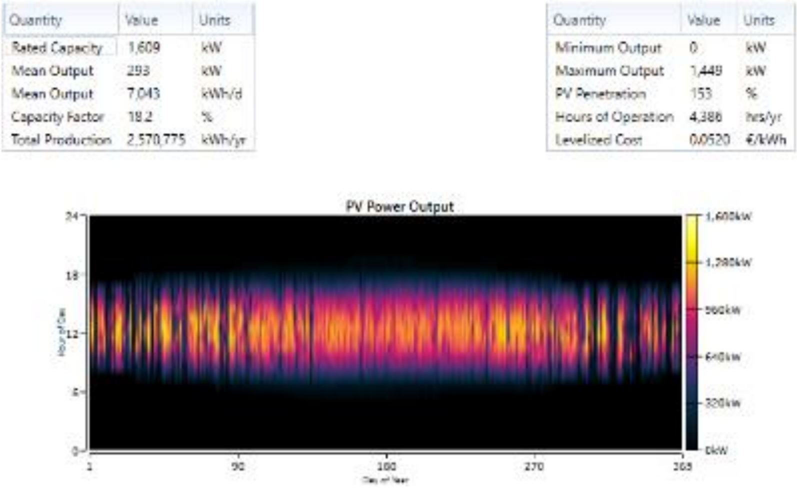
Renewable penetration

Quantity	Value	Units
Batteries	3.00	qty.
String Size	1.00	batteries
Strings in Parallel	3.00	strings
Bus Voltage	200	V

Quantity	Value	Units
Autonomy	7.37	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	1,727	kWh
Usable Nominal Capacity	1,727	kWh
Lifetime Throughput	11,059,640	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	683,748	kWh/yr
Energy Out	445,828	kWh/yr
Storage Depletion	1,727	kWh/yr
Losses	239,646	kWh/yr
Annual Throughput	552,982	kWh/yr

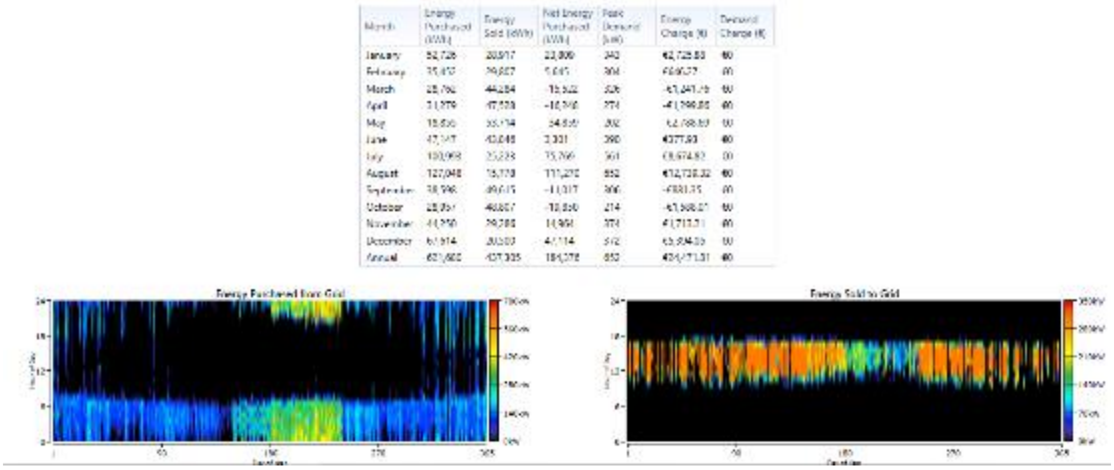
Battery usage



Quantity	Value	Units
Rated Capacity	1,609	kW
Mean Output	293	kW
Mean Output	7,043	kWh/d
Capacity Factor	18.2	%
Total Production	2,570,775	kWh/yr

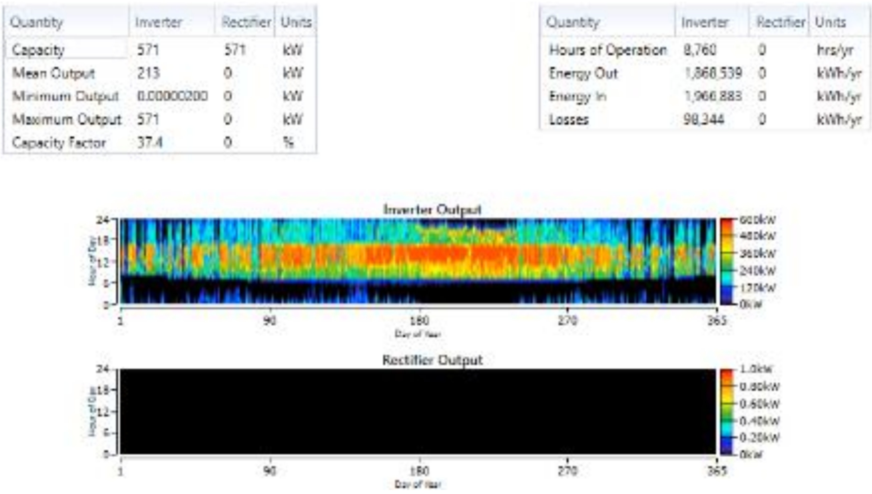
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,449	kW
PV Penetration	153	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

PV output



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	52,726	29,917	22,809	342	€2,725.83	€0
February	35,472	29,827	5,645	304	€696.77	€0
March	28,762	44,284	-15,522	326	-€1,841.75	€0
April	31,279	47,528	-16,248	274	-€1,299.85	€0
May	18,536	53,174	-34,638	302	-€2,788.89	€0
June	46,349	43,048	3,301	390	€377.93	€0
July	100,968	25,228	75,740	561	€8,674.82	€0
August	127,048	15,778	111,270	852	€12,738.32	€0
September	38,598	49,615	-11,017	306	-€881.75	€0
October	28,051	40,867	-12,816	214	-€1,568.07	€0
November	44,250	29,288	14,962	374	€1,713.21	€0
December	67,514	20,400	47,114	572	€5,904.35	€0
Annual	621,603	437,325	184,278	852	€24,471.31	€0

Grid transactions

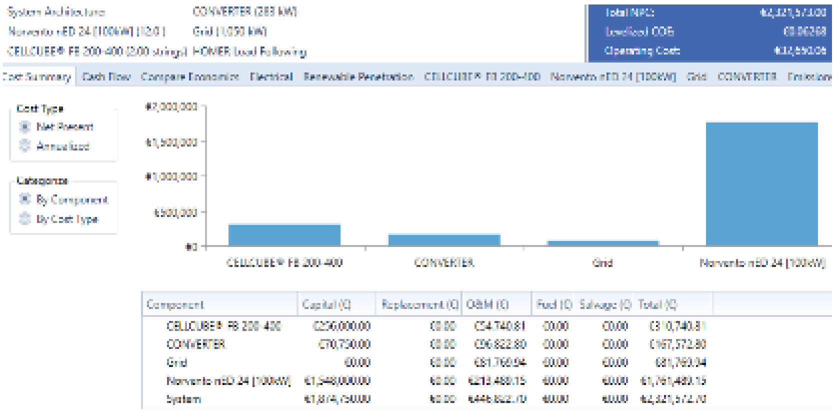


Quantity	Inverter	Rectifier	Units
Capacity	571	571	kW
Mean Output	213	0	kW
Minimum Output	0.00000200	0	kW
Maximum Output	571	0	kW
Capacity Factor	37.4	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	1,868,539	0	kWh/yr
Energy In	1,966,883	0	kWh/yr
Losses	98,344	0	kWh/yr

Converter output

12*100WT+2BATT:



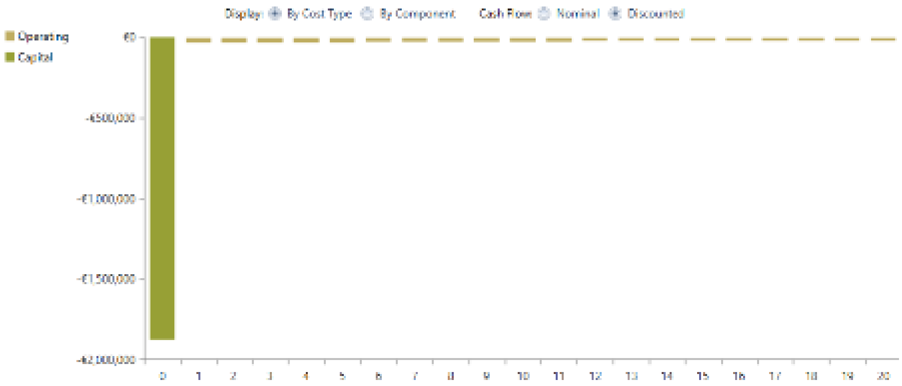
System Architecture

Norvento nED 24 [100kW] (12.0)	CONVERTER (283 kW)
CELLCUBE® FB 200-400 (2.00 strings)	Grid (1,050 kW)
	HOMER Load Following

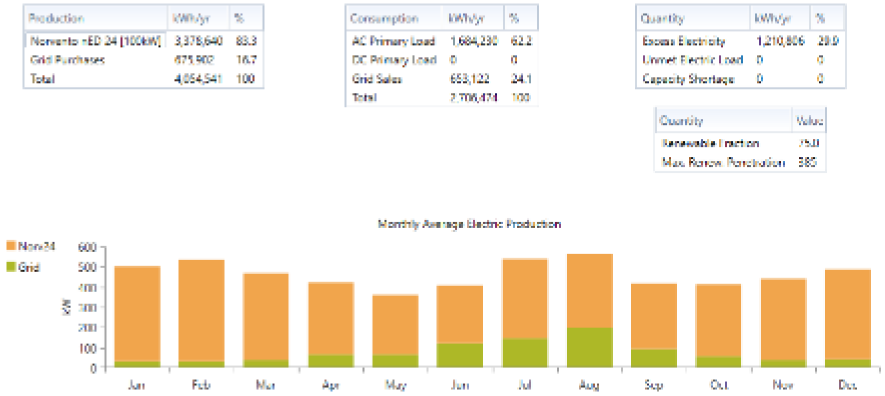
Total NPC:	€2,321,573.00
Levelized COE:	€0.06268
Operating Cost:	€32,650.06

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€256,000.00	€0.00	€54,740.81	€0.00	€0.00	€310,740.81
CONVERTER	€70,750.00	€0.00	€96,822.80	€0.00	€0.00	€167,572.80
Grid	€0.00	€0.00	€81,769.94	€0.00	€0.00	€81,769.94
Norvento nED 24 [100kW]	€1,548,000.00	€0.00	€213,489.15	€0.00	€0.00	€1,761,489.15
System	€1,874,750.00	€0.00	€446,822.70	€0.00	€0.00	€2,321,572.70

Cost summary



Cash flow



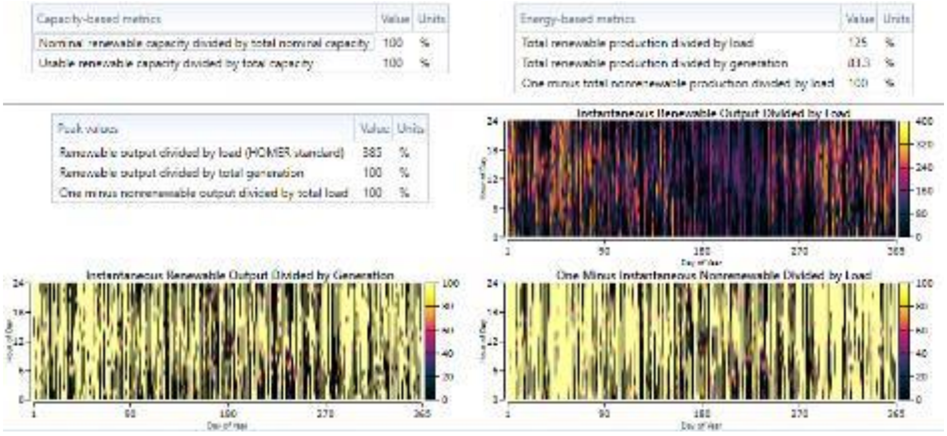
Production	kWh/yr	%
Norvento nED 24 [100kW]	3,378,640	83.3
Grid Purchases	675,902	16.7
Total	4,054,541	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	62.2
DC Primary Load	0	0
Grid Sales	653,122	24.1
Total	2,708,474	100

Quantity	kWh/yr	%
Excess Electricity	1,210,806	29.9
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	75.0
Max. Renew. Penetration	385

Electrical sizes

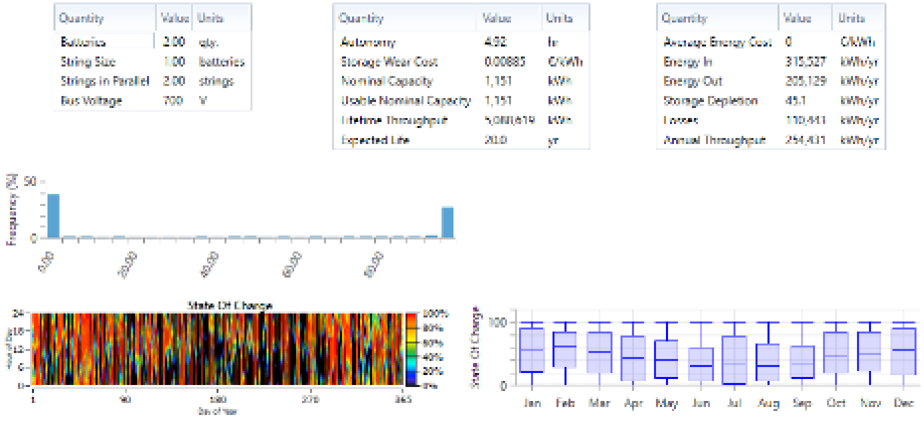


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	125	%
Total renewable production divided by generation	83.3	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	385	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

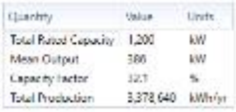


Quantity	Value	Units
Batteries	2.00	qty.
String Size	1.00	batteries
Strings in Parallel	2.00	strings
Bus Voltage	700	V

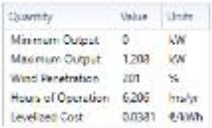
Quantity	Value	Units
Autonomy	4.92	hr
Storage Wear Cost	0.00885	C/kWh
Nominal Capacity	1,151	kWh
Usable Nominal Capacity	1,151	kWh
Lifetime Throughput	5,080,619	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	C/kWh
Energy In	315,527	kWh/yr
Energy Out	205,129	kWh/yr
Storage Depletion	45.1	kWh/yr
Losses	110,411	kWh/yr
Annual Throughput	254,431	kWh/yr

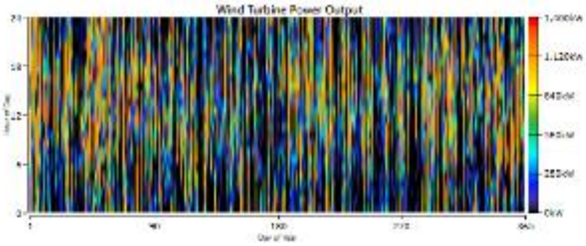
Battery usage



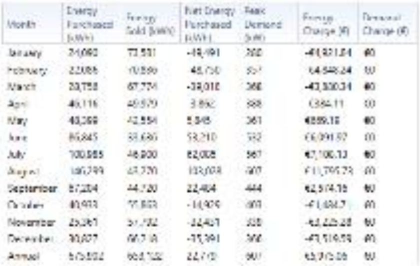
Quantity	Value	Units
Total Rated Capacity	1,200	kW
Mean Output	386	kW
Capacity Factor	32.1	%
Total Production	3,378,640	kWh/yr



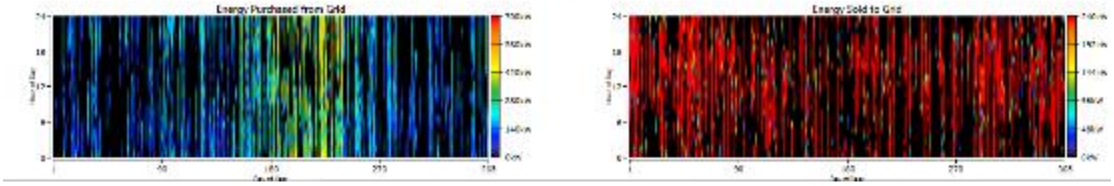
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,208	kW
Wind Penetration	201	%
Hours of Operation	6,206	hrs/yr
Levelized Cost	0.0381	€/kWh



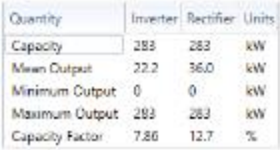
100 kW wind turbines output



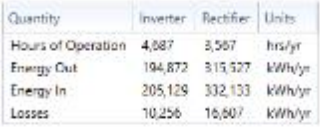
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	24,090	73,581	-49,491	300	-€4,921.84	€0
February	22,086	70,836	-48,750	357	-€4,848.24	€0
March	28,758	67,774	-39,016	366	-€3,330.34	€0
April	46,116	49,979	-3,862	388	-€384.11	€0
May	48,399	42,554	5,845	361	€589.18	€0
June	86,845	33,635	53,210	532	€6,091.97	€0
July	100,985	48,900	62,008	567	€7,106.13	€0
August	176,799	43,720	133,078	607	€11,795.73	€0
September	67,204	44,720	22,484	444	€2,574.15	€0
October	40,933	55,862	-14,929	403	-€1,484.7	€0
November	25,261	57,702	-32,441	338	-€3,225.28	€0
December	30,927	66,318	-35,391	366	-€3,519.59	€0
Annual	675,802	653,102	22,700	607	€5,775.06	€0



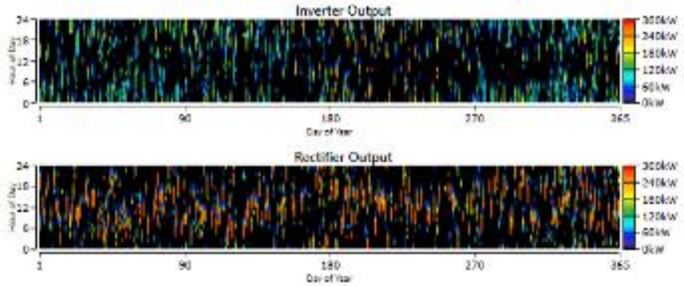
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	283	283	kW
Mean Output	22.2	36.0	kW
Minimum Output	0	0	kW
Maximum Output	283	283	kW
Capacity Factor	7.86	12.7	%

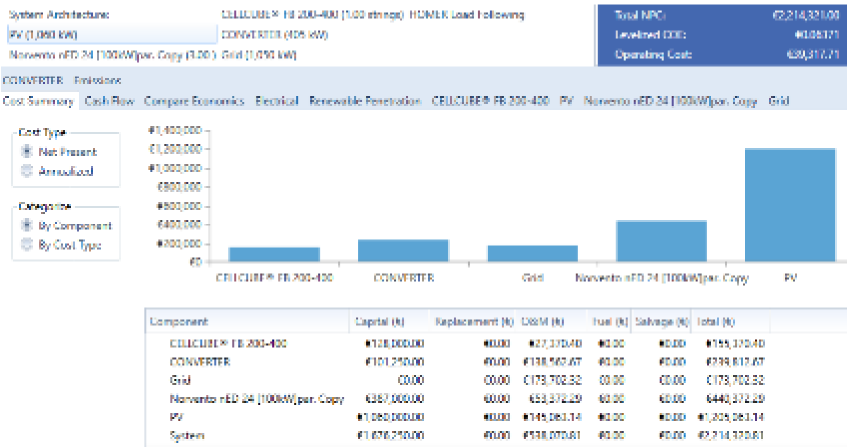


Quantity	Inverter	Rectifier	Units
Hours of Operation	4,687	3,567	hrs/yr
Energy Out	194,872	315,527	kWh/yr
Energy In	205,129	332,133	kWh/yr
Losses	10,256	16,607	kWh/yr



Converter output

<u>1060PV+3*100WT+1BATT:</u>

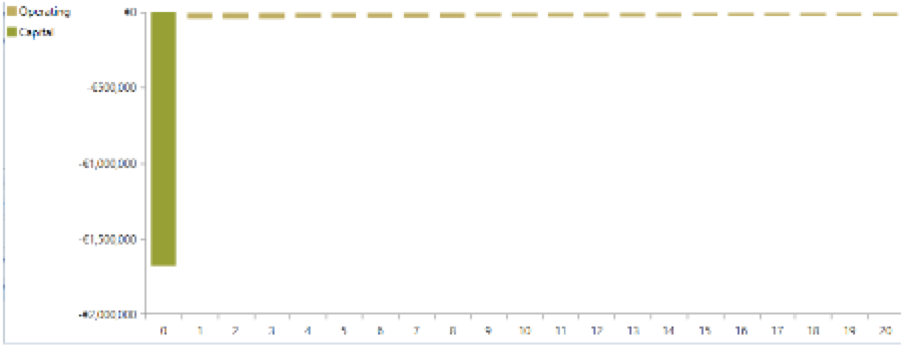


System Architecture: CELLCUBE® FB 200-400 (1.00 strings) HOMER Load Following
PV (1,060 kW) CONVERTER (405 kW)
Norvento nED 24 [100kW]par. Copy (3.00) Grid (1,050 kW)

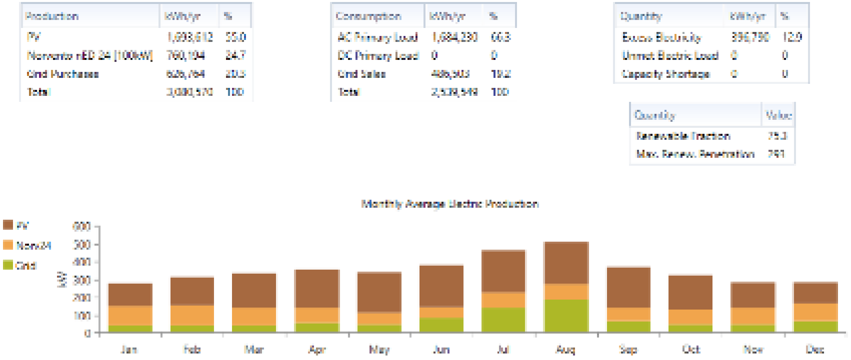
Total NPC: €2,214,321.00
Levelized COE: €0.08171
Operating Cost: €20,317.71

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€128,000.00	€0.00	€27,370.40	€0.00	€0.00	€155,370.40
CONVERTER	€101,250.00	€0.00	€138,562.67	€0.00	€0.00	€239,812.67
Grid	€0.00	€0.00	€173,702.32	€0.00	€0.00	€173,702.32
Norvento nED 24 [100kW]par. Copy	€387,000.00	€0.00	€53,372.29	€0.00	€0.00	€440,372.29
PV	€1,060,000.00	€0.00	€145,063.14	€0.00	€0.00	€1,205,063.14
System	€1,676,250.00	€0.00	€538,070.81	€0.00	€0.00	€2,214,320.81

Cost summary



Cash flow



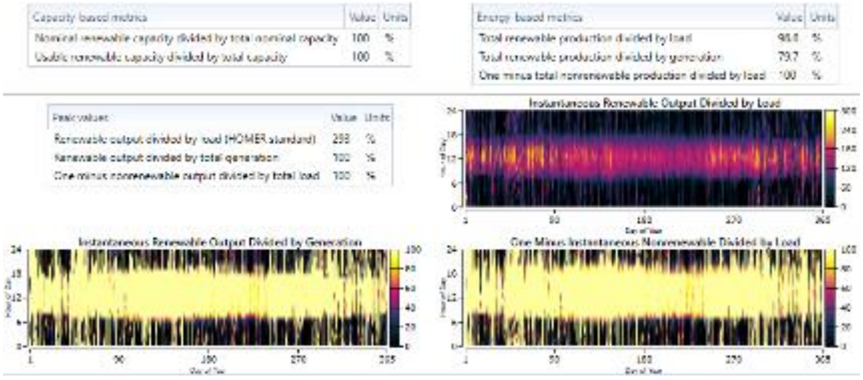
Production	kWh/yr	%
PV	1,693,612	55.0
Norvento nED 24 [100kW]	760,194	24.7
Grid Purchases	626,764	20.3
Total	3,080,570	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	66.3
DC Primary Load	0	0
Grid Sales	486,903	19.2
Total	2,539,549	100

Quantity	kWh/yr	%
Excess Electricity	396,790	12.9
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	75.3
Max. Renew. Penetration	791

Electrical sizes

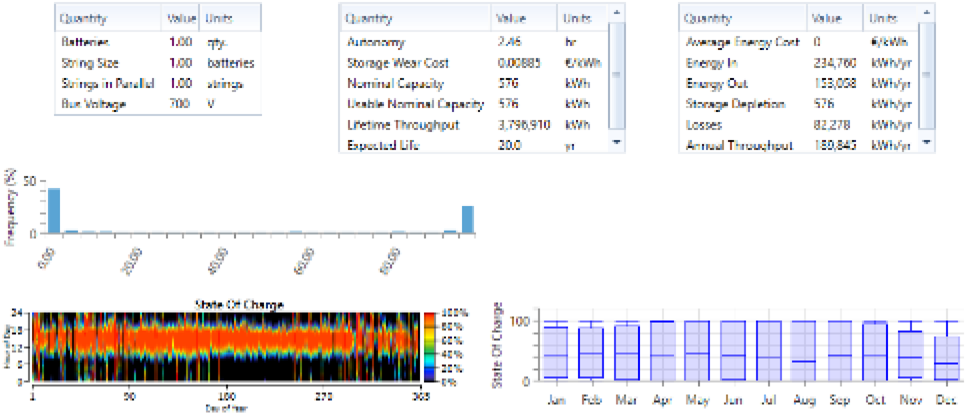


Capacity based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy based metrics	Value	Units
Total renewable production divided by load	98.8	%
Total renewable production divided by generation	79.7	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	298	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

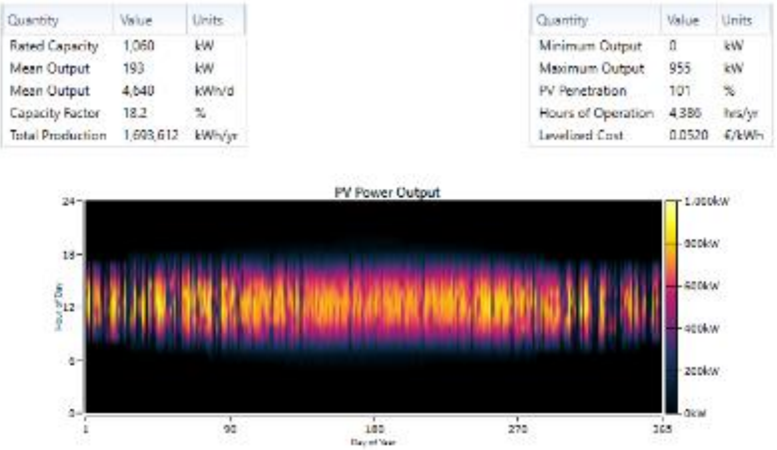


Quantity	Value	Units
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	2.46	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	576	kWh
Usable Nominal Capacity	576	kWh
Lifetime Throughput	3,796,910	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	234,760	kWh/yr
Energy Out	153,058	kWh/yr
Storage Depletion	576	kWh/yr
Losses	82,278	kWh/yr
Annual Throughput	180,845	kWh/yr

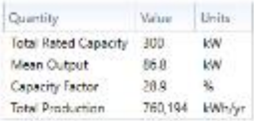
Battery usage



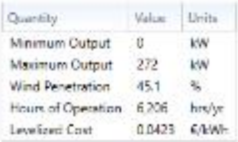
Quantity	Value	Units
Rated Capacity	1,060	kW
Mean Output	193	kW
Mean Output	4,640	kWh/d
Capacity Factor	18.2	%
Total Production	1,693,612	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	955	kW
PV Penetration	101	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

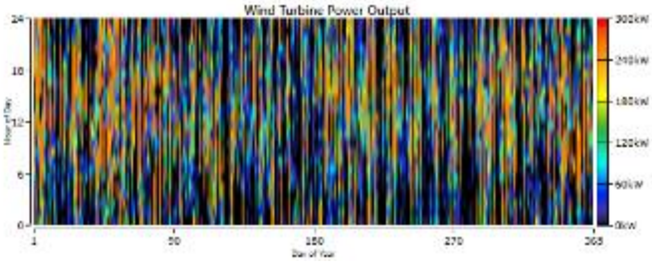
PV output



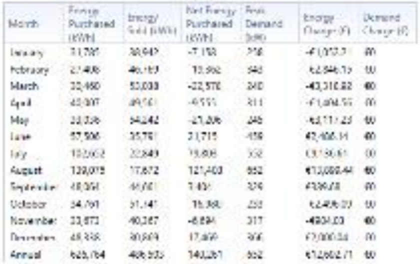
Quantity	Value	Units
Total Rated Capacity	300	kW
Mean Output	86.8	kW
Capacity Factor	28.9	%
Total Production	760,194	kWh/yr



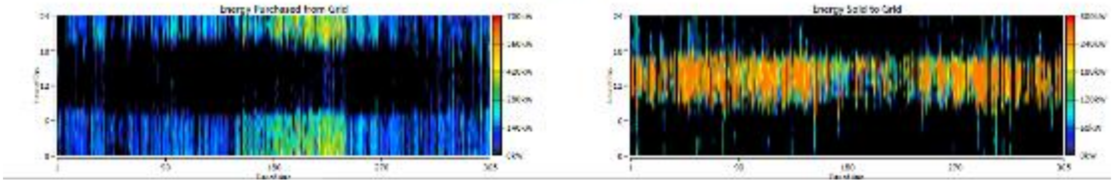
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	272	kW
Wind Penetration	45.1	%
Hours of Operation	6,206	hrs/yr
Levelized Cost	0.0423	€/kWh



100 kW wind turbines output



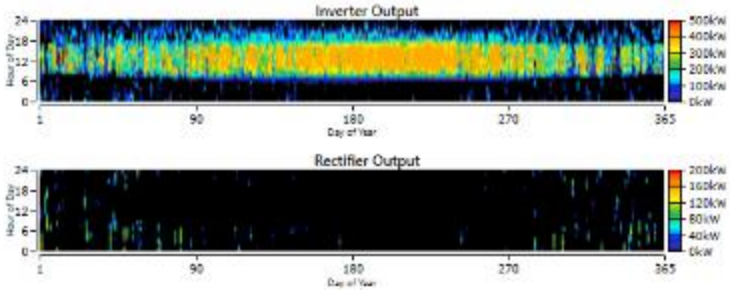
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	31,790	38,942	-7,152	236	-€1,017.21	€0
February	27,406	46,169	[illegible]	348	[illegible]	€0
March	30,460	53,038	-22,578	240	-€3,310.82	€0
April	40,007	49,561	-9,554	311	-€1,404.55	€0
May	33,036	54,242	-21,206	245	-€3,117.23	€0
June	57,506	35,791	21,715	458	€2,406.14	€0
July	102,652	22,843	79,808	332	€9,156.61	€0
August	139,075	17,672	121,403	552	€13,088.44	€0
September	48,068	40,661	7,407	329	€938.28	€0
October	34,791	51,147	[illegible]	233	[illegible]	€0
November	33,573	40,267	-6,694	317	-€804.03	€0
December	48,338	30,909	17,429	366	€2,000.34	€0
Annual	625,764	486,503	140,261	552	€12,602.71	€0



Grid transactions

Quantity	Inverter	Rectifier	Units
Capacity	405	405	kW
Mean Output	134	1.97	kW
Minimum Output	0	0	kW
Maximum Output	405	163	kW
Capacity Factor	33.0	0.487	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	7,925	555	hrs/yr
Energy Out	1,170,770	17,270	kWh/yr
Energy In	1,232,389	18,179	kWh/yr
Losses	61,619	909	kWh/yr



Converter output

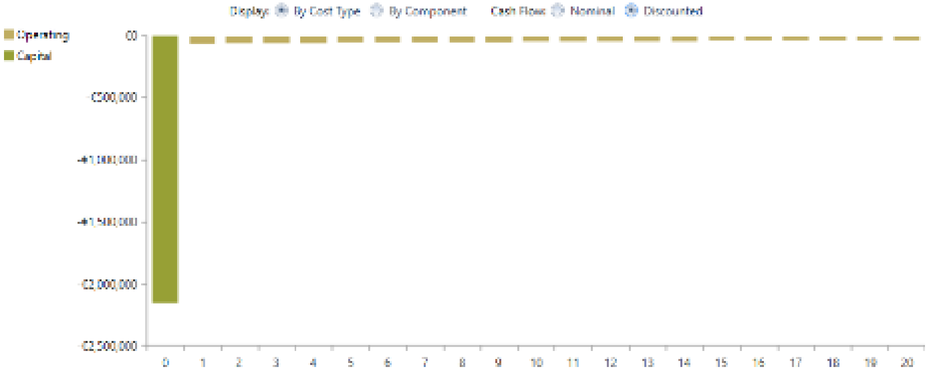
<u>765PV+2*250WT+2BATT:4</u>

System Architecture:	CELLCUBE® FB 200-400 (2.00 strings)	HOMER Load Following
PV (765 kW)	CONVERTER (300 kW)	
WES 30 [250kW]par. Copy (2.00)	Grid (1,050 kW)	

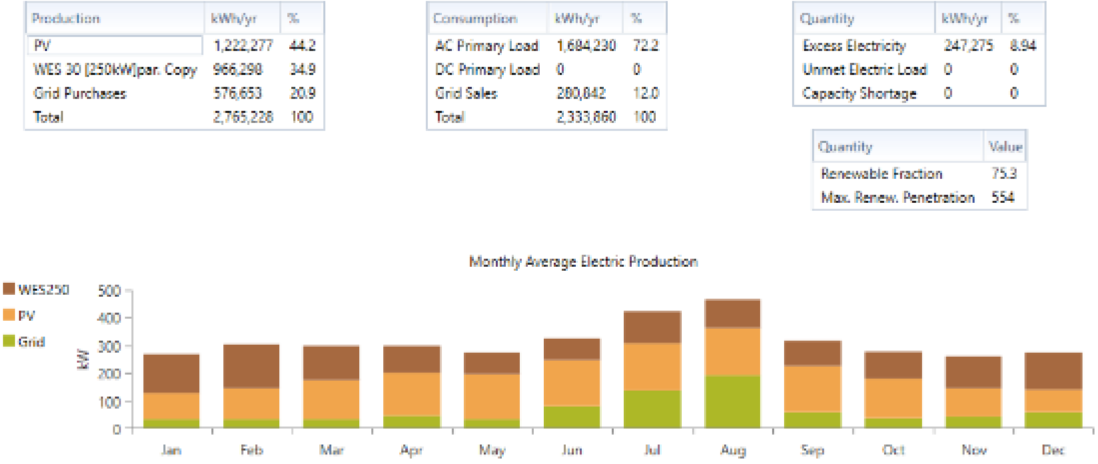
Total NPC:	€3,005,024.52
Levelized COE:	€0.09409
Operating Cost:	€52,039.61

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€256,000.00	€0.00	€54,740.81	€0.00	€0.00	€310,740.81
CONVERTER	€75,000.00	€0.00	€102,639.01	€0.00	€0.00	€177,639.01
Grid	€0.00	€0.00	€450,100.89	€0.00	€0.00	€450,100.89
PV	€765,000.00	€0.00	€104,691.79	€0.00	€0.00	€869,691.79
WES 30 [250kW]par. Copy	€1,080,000.00	€0.00	€116,852.02	€0.00	€0.00	€1,196,852.02
System	€2,176,000.00	€0.00	€829,024.52	€0.00	€0.00	€3,005,024.52

Cost summary



Cash flow



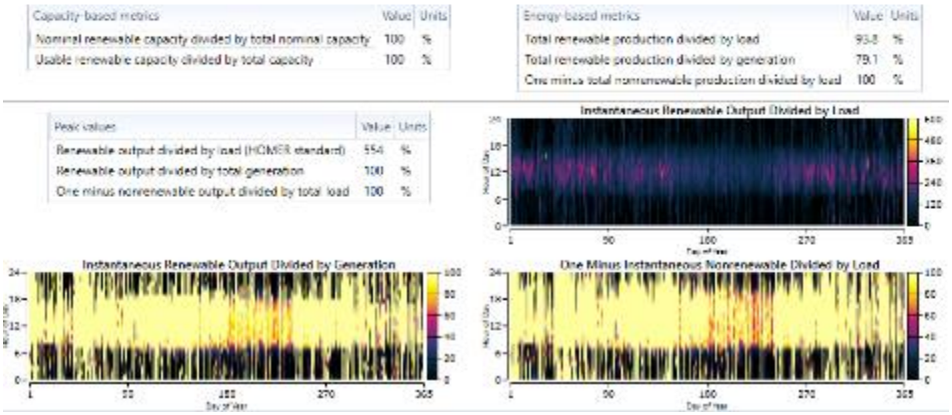
Production	kWh/yr	%
PV	1,222,277	44.2
WES 30 [250kW]par. Copy	966,298	34.9
Grid Purchases	576,653	20.9
Total	2,765,228	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	72.2
DC Primary Load	0	0
Grid Sales	280,042	12.0
Total	2,333,860	100

Quantity	kWh/yr	%
Excess Electricity	247,275	8.94
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	75.3
Max. Renew. Penetration	554

Electrical sizes



Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	93.8	%
Total renewable production divided by generation	79.1	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	554	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

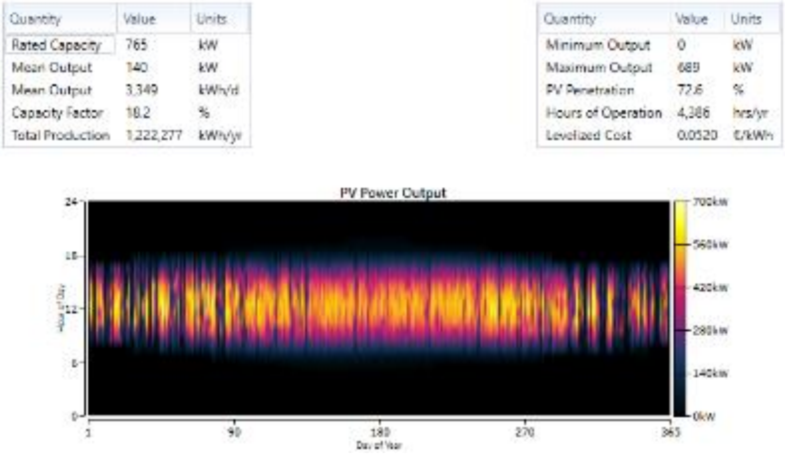
Renewable penetration

Quantity	Value	Units
Batteries	2.00	qty.
String Size	1.00	batteries
Strings in Parallel	2.00	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	4.02	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	1,151	kWh
Usable Nominal Capacity	1,151	kWh
Lifetime Throughput	6,301,087	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	388,348	kWh/yr
Energy Out	254,005	kWh/yr
Storage Depletion	1,151	kWh/yr
Losses	136,495	kWh/yr
Annual Throughput	315,054	kWh/yr

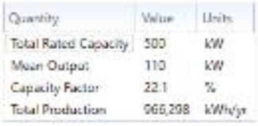
Battery usage



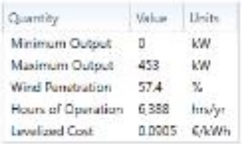
Quantity	Value	Units
Rated Capacity	765	kW
Mean Output	140	kW
Mean Output	3,349	kWh/d
Capacity Factor	18.2	%
Total Production	1,222,277	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	689	kW
PV Penetration	72.6	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

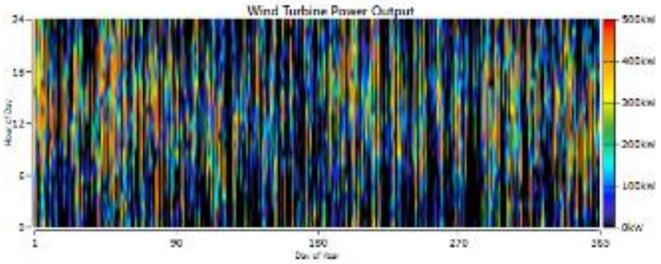
PV output



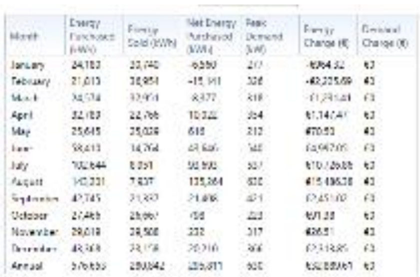
Quantity	Value	Units
Total Rated Capacity	500	kW
Mean Output	110	kW
Capacity Factor	22.1	%
Total Production	966,208	kWh/yr

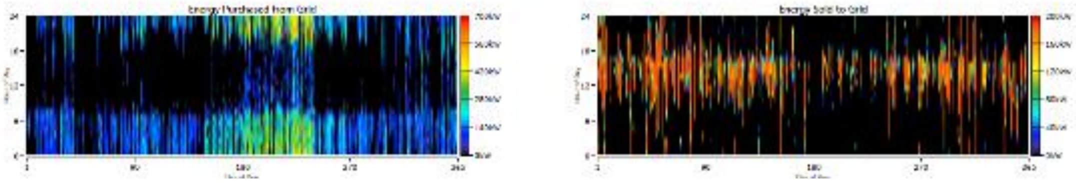


Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	453	kW
Wind Penetration	57.4	%
Hours of Operation	6,388	hrs/yr
Levelized Cost	0.0005	€/kWh

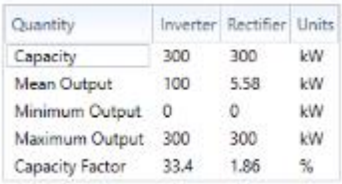


250 kW wind turbines output

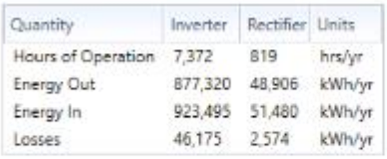




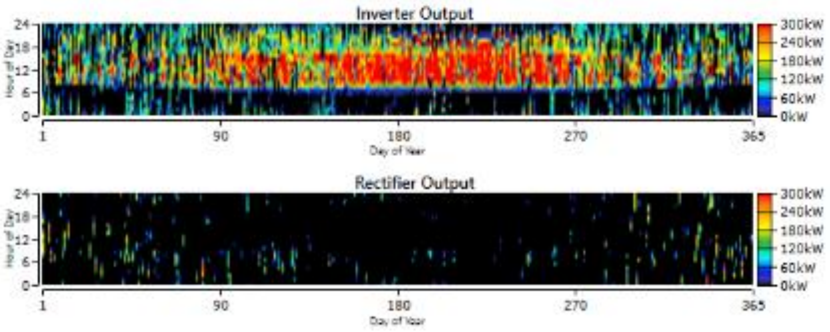
Grid transaction



Quantity	Inverter	Rectifier	Units
Capacity	300	300	kW
Mean Output	100	5.58	kW
Minimum Output	0	0	kW
Maximum Output	300	300	kW
Capacity Factor	33.4	1.86	%

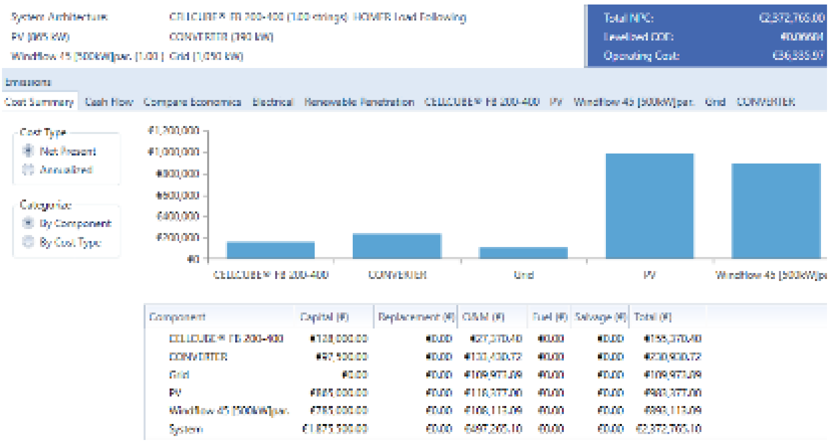


Quantity	Inverter	Rectifier	Units
Hours of Operation	7,372	819	hrs/yr
Energy Out	877,320	48,906	kWh/yr
Energy In	923,495	51,480	kWh/yr
Losses	46,175	2,574	kWh/yr



Converter output

865PV+500WT+1BATT:

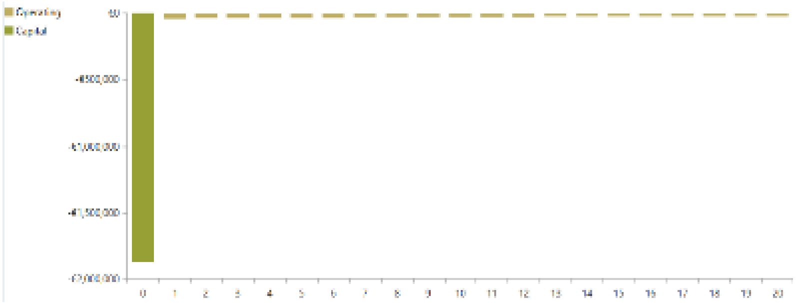


System Architecture:	CELLCUBE® FB 200-400 (1.00 strings) HOMER Load Following
PV (865 kW)	CONVERTER (390 kW)
Windflow 45 [500kW]par. (1.00)	Grid (1,050 kW)

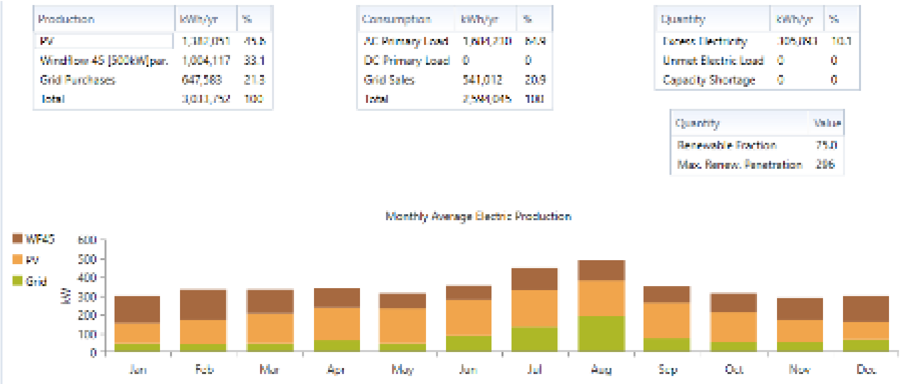
Total NPC:	€2,372,765.00
Levelized COE:	€0.06604
Operating Cost:	€36,335.97

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€128,000.00	€0.00	€27,370.40	€0.00	€0.00	€155,370.40
CONVERTER	€97,500.00	€0.00	€133,430.72	€0.00	€0.00	€230,930.72
Grid	€0.00	€0.00	€109,973.09	€0.00	€0.00	€109,973.09
PV	€865,000.00	€0.00	€118,377.00	€0.00	€0.00	€983,377.00
Windflow 45 [500kW]par.	€785,000.00	€0.00	€108,113.09	€0.00	€0.00	€893,113.09
System	€1,875,500.00	€0.00	€497,265.10	€0.00	€0.00	€2,372,765.10

Cost summary



Cash flow



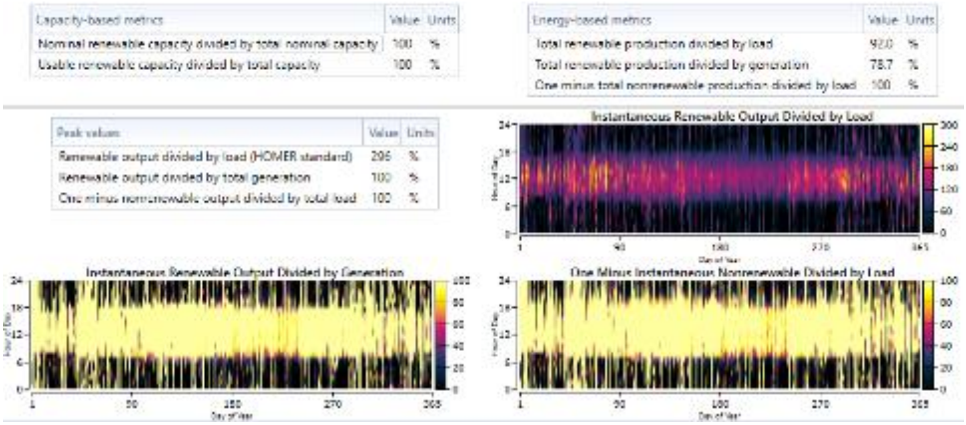
Production	kWh/yr	%
PV	1,382,051	45.6
Windflow 45 [500kW]par.	1,004,117	33.1
Grid Purchases	647,583	21.3
Total	3,033,752	100

Consumption	kWh/yr	%
AC Primary Load	[illegible]	[illegible]
DC Primary Load	0	0
Grid Sales	541,012	20.9
Total	2,594,045	100

Quantity	kWh/yr	%
Excess Electricity	[illegible]	10.1
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	75.0
Max. Renew. Penetration	286

Electrical sizes

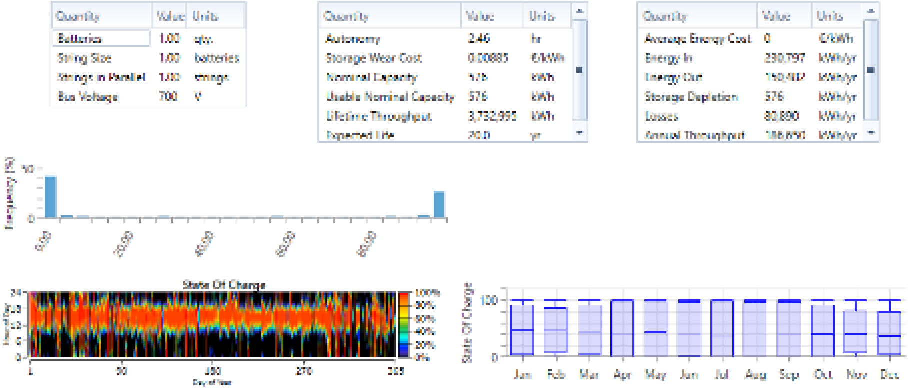


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	92.0	%
Total renewable production divided by generation	78.7	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	296	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

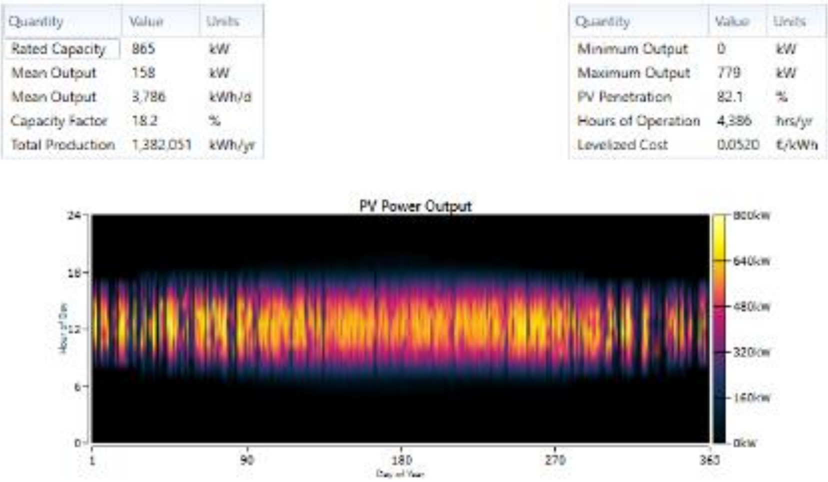


Quantity	Value	Units
Batteries	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	2.46	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	576	kWh
Usable Nominal Capacity	576	kWh
Lifetime Throughput	3,732,995	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	230,797	kWh/yr
Energy Out	150,482	kWh/yr
Storage Depletion	576	kWh/yr
Losses	80,890	kWh/yr
Annual Throughput	186,650	kWh/yr

Battery usage



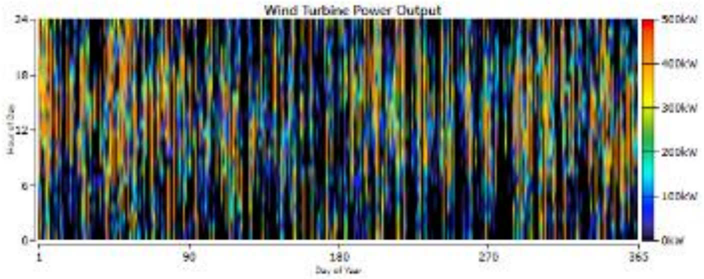
Quantity	Value	Units
Rated Capacity	865	kW
Mean Output	158	kW
Mean Output	3,786	kWh/d
Capacity Factor	18.2	%
Total Production	1,382,051	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	779	kW
PV Penetration	82.1	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh

PV output

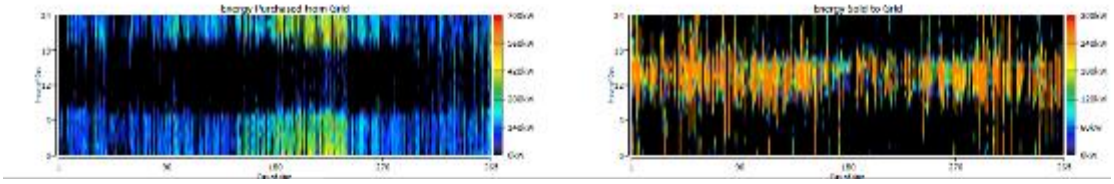
Quantity	Value	Units
Total Rated Capacity	500	kW
Mean Output	115	kW
Capacity Factor	22.9	%
Total Production	1,004,117	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	453	kW
Wind Penetration	59.6	%
Hours of Operation	5,336	hrs/yr
Levelized Cost	0.0650	€/kWh

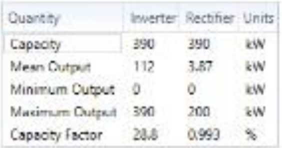


500 kW wind turbines output

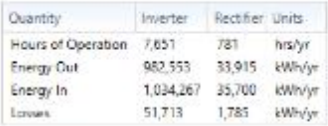
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	33,073	55,370	-22,297	253	-€2,277.71	€0
February	28,523	61,585	-33,062	330	-€4,880.17	€0
March	32,487	56,444	-23,957	247	-€2,521.74	€0
April	42,649	48,127	-5,477	354	-€925.16	€0
May	35,875	50,532	-14,657	246	-€2,199.52	€0
June	61,098	34,205	26,893	541	€3,070.24	€0
July	99,920	24,936	74,985	552	€9,581.08	€0
August	140,215	22,644	117,571	687	€12,906.44	€0
September	50,928	43,520	7,408	350	€943.30	€0
October	37,068	51,161	-14,093	242	-€2,092.45	€0
November	36,072	50,810	-14,738	330	-€2,157.65	€0
December	49,777	42,729	7,048	365	€952.13	€0
Annual	647,384	541,012	106,372	687	€8,035.27	€0



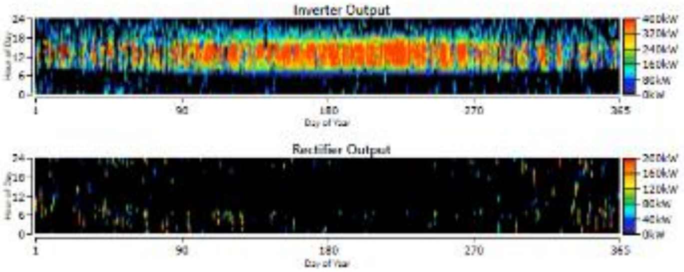
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	390	390	kW
Mean Output	112	3.87	kW
Minimum Output	0	0	kW
Maximum Output	390	200	kW
Capacity Factor	28.8	0.993	%



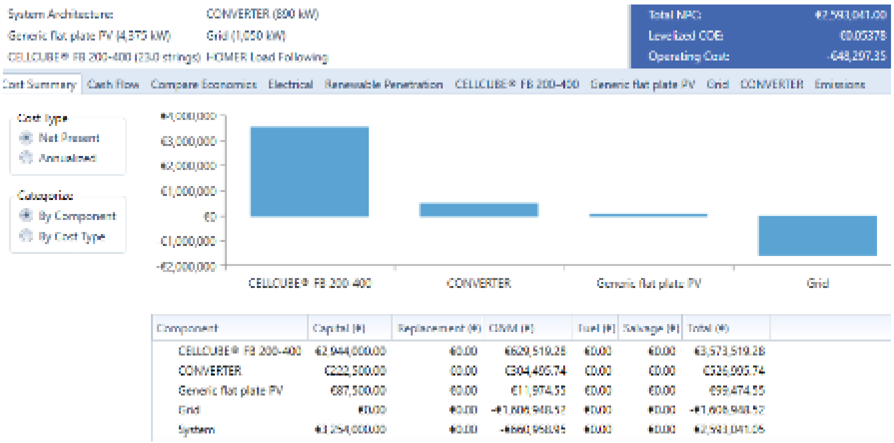
Quantity	Inverter	Rectifier	Units
Hours of Operation	7,651	781	hrs/yr
Energy Out	982,553	33,915	kWh/yr
Energy In	1,034,267	35,700	kWh/yr
Losses	51,713	1,785	kWh/yr



Converter output

100% Adoption Scenario

4375PV+23BATT:

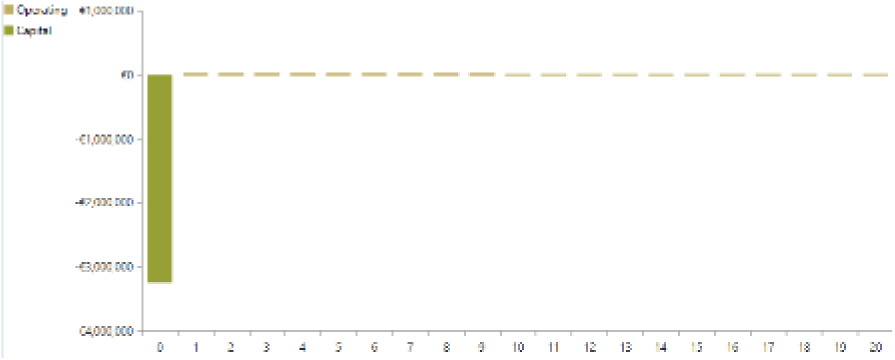


System Architecture: CONVERTER (890 kW)
Generic flat plate PV (4,375 kW) Grid (1,050 kW)
CELLCUBE® FB 200-400 (23.0 strings) HOMER Load Following

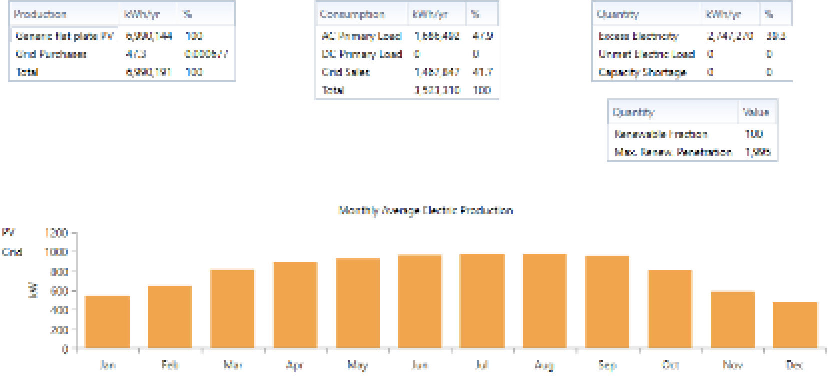
Total NPC: €2,593,041.00
Levelized COE: €0.05378
Operating Cost: -€48,297.35

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€2,944,000.00	€0.00	€629,519.28	€0.00	€0.00	€3,573,519.28
CONVERTER	€222,500.00	€0.00	€304,405.74	€0.00	€0.00	€526,905.74
Generic flat plate PV	€87,500.00	€0.00	€11,974.55	€0.00	€0.00	€99,474.55
Grid	€0.00	€0.00	-€1,606,948.52	€0.00	€0.00	-€1,606,948.52
System	€3,254,000.00	€0.00	-€660,958.95	€0.00	€0.00	€2,593,041.05

Cost summary



Cash flow



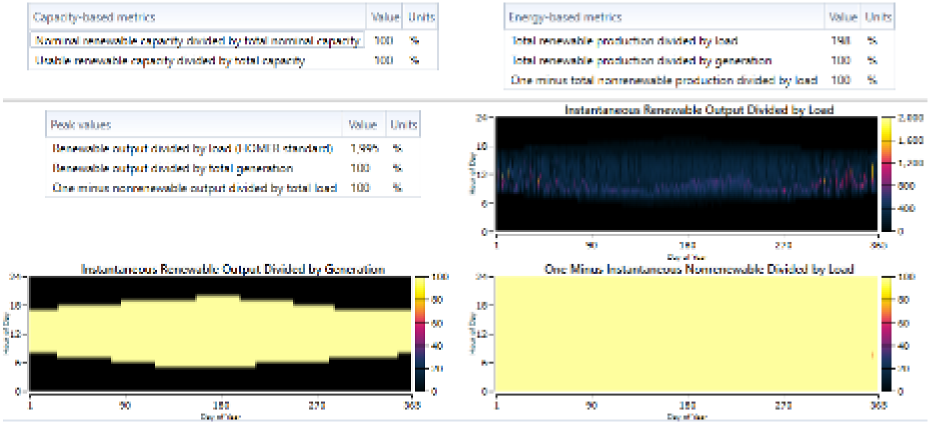
Production	kWh/yr	%
Generic flat plate PV	6,990,144	100
Grid Purchases	47.3	0.000677
Total	6,990,191	100

Consumption	kWh/yr	%
AC Primary Load	1,655,492	47.9
DC Primary Load	0	0
Grid Sales	1,457,847	41.7
Total	3,523,310	100

Quantity	kWh/yr	%
Excess Electricity	2,747,270	39.3
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	1,995

Electrical sizes

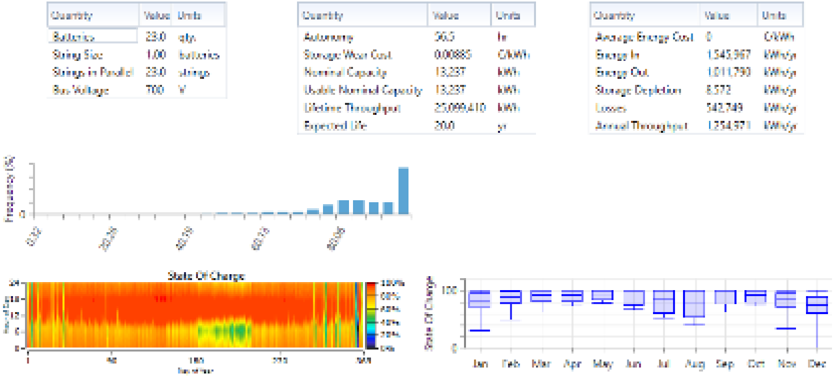


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	198	%
Total renewable production divided by generation	100	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	1,995	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

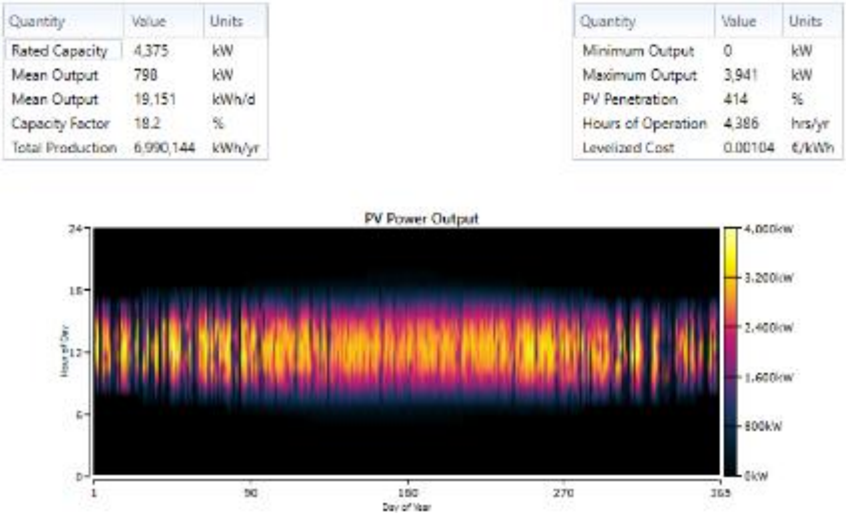


Quantity	Value	Units
Batteries	23.0	qty.
String Size	1.00	batteries
Strings in Parallel	23.0	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	96.5	hr
Storage Wear Cost	0.00885	¢/kWh
Nominal Capacity	13,237	kWh
Usable Nominal Capacity	13,237	kWh
Lifetime Throughput	25,099,410	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	¢/kWh
Energy In	1,545,967	kWh/yr
Energy Out	1,011,790	kWh/yr
Storage Depletion	8,572	kWh/yr
Losses	542,749	kWh/yr
Annual Throughput	1,254,971	kWh/yr

Battery usage

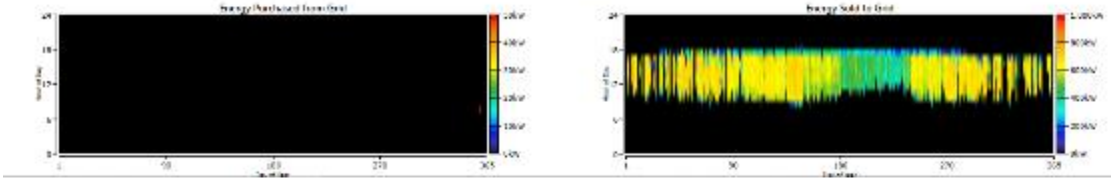


Quantity	Value	Units
Rated Capacity	4,375	kW
Mean Output	798	kW
Mean Output	19,151	kWh/d
Capacity Factor	18.2	%
Total Production	6,990,144	kWh/yr

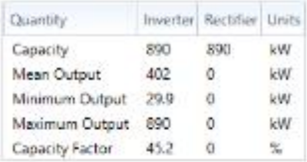
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	3,941	kW
PV Penetration	414	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.00104	¢/kWh

PV output

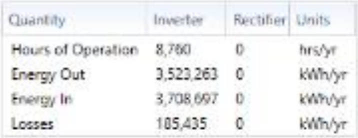
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	0	79,230	-79,230	0	-€5,338.39	€0
February	0	106,057	-106,057	0	-€8,484.56	€0
March	0	148,797	-148,797	0	-€11,581.5	€0
April	0	151,230	-151,230	0	-€12,099.0	€0
May	0	181,391	-181,391	0	-€14,507.5	€0
June	0	148,850	-148,850	0	-€11,506.7	€0
July	0	102,909	-102,909	0	-€8,212.73	€0
August	0	83,607	-83,607	0	-€6,688.57	€0
September	0	151,296	-151,296	0	-€12,100.5	€0
October	0	152,880	-152,880	0	-€12,270.3	€0
November	0	80,289	-80,289	0	-€7,063.11	€0
December	47	67,935	-67,888	47	-€5,269.60	€0
Annual	47	1,467,847	-1,467,800	47	-€117,452	€0



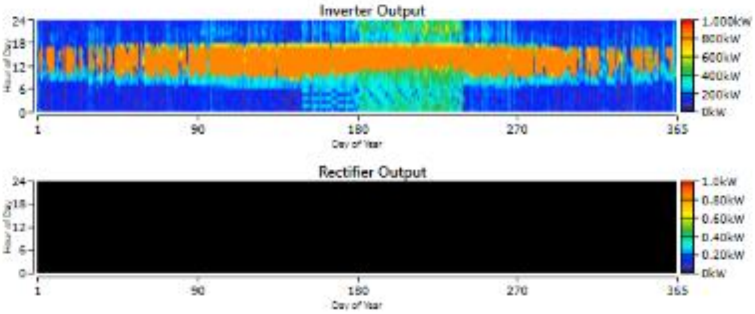
Grid transactions



Quantity	Inverter	Rectifier	Units
Capacity	890	890	kW
Mean Output	402	0	kW
Minimum Output	29.9	0	kW
Maximum Output	890	0	kW
Capacity Factor	45.2	0	%

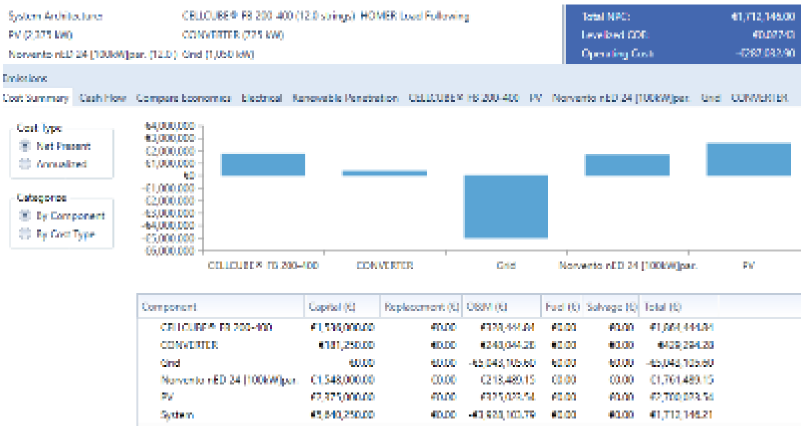


Quantity	Inverter	Rectifier	Units
Hours of Operation	8,760	0	hrs/yr
Energy Out	3,523,263	0	kWh/yr
Energy In	3,708,697	0	kWh/yr
Losses	185,435	0	kWh/yr



Converter output

2375PV+12*100WT+12BATT:

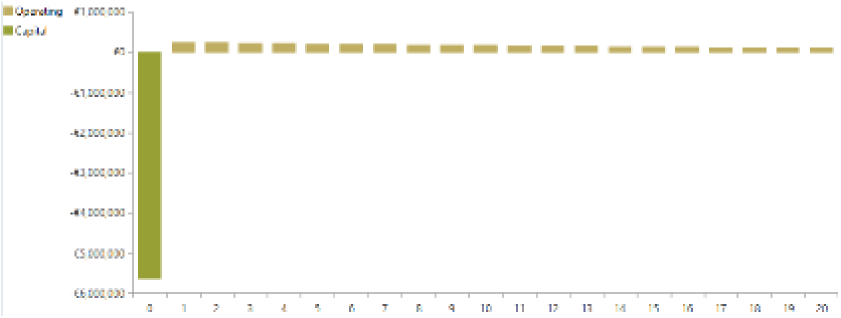


System Architecture: CELLCUBE® FB 200-400 (12.0 strings) HOMER Load Following
PV (2,375 kW) CONVERTER (775 kW)
Norvento nED 24 [100kW]par. (12.0) Grid (1,050 kW)

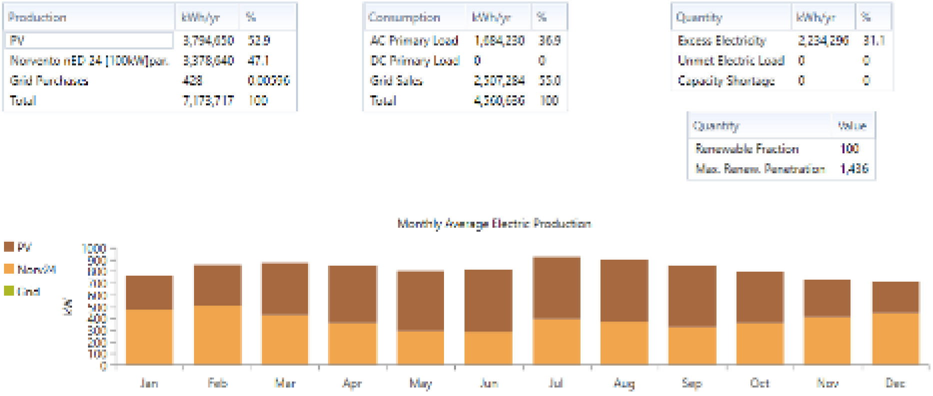
Total NPC: €1,712,146.00
Levelized COE: €0.0274
Operating Cost: -€287,032.90

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€1,536,000.00	€0.00	€328,444.84	€0.00	€0.00	€1,864,444.84
CONVERTER	€181,250.00	€0.00	€248,044.20	€0.00	€0.00	€429,294.20
Grid	€0.00	€0.00	-€5,043,105.60	€0.00	€0.00	-€5,043,105.60
Norvento nED 24 [100kW]par.	€1,548,000.00	€0.00	€213,489.15	€0.00	€0.00	€1,761,489.15
PV	€2,375,000.00	€0.00	€325,023.54	€0.00	€0.00	€2,700,023.54
System	€5,640,250.00	€0.00	-€3,928,103.79	€0.00	€0.00	€1,712,146.21

Cost summary



Cash flow



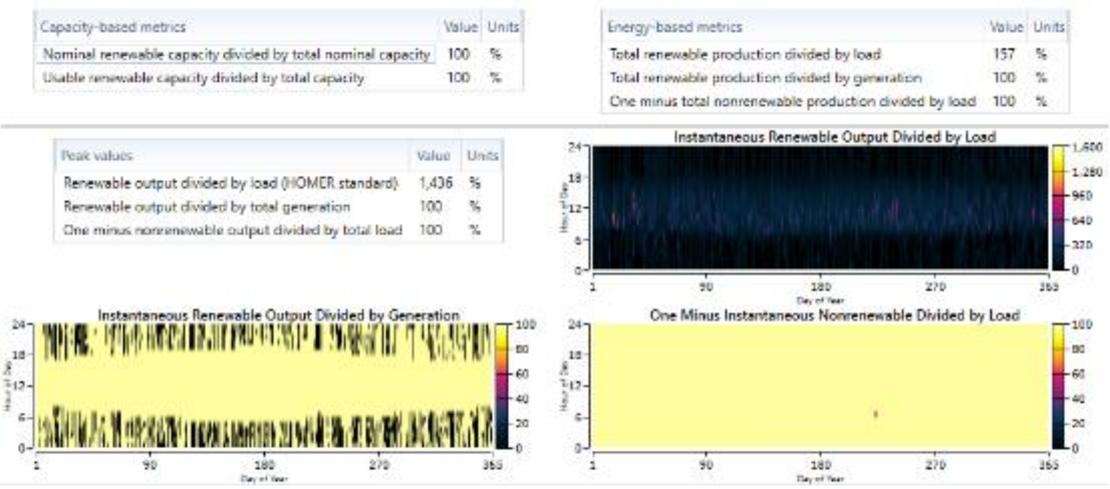
Production	kWh/yr	%
PV	3,794,050	52.9
Norvento nED 24 [100kW]par.	3,378,640	47.1
Grid Purchases	428	0.00596
Total	7,173,717	100

Consumption	kWh/yr	%
AC Primary Load	1,884,230	36.9
DC Primary Load	0	0
Grid Sales	2,307,284	55.0
Total	4,300,636	100

Quantity	kWh/yr	%
Excess Electricity	2,234,296	31.1
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	1,436

Electrical sizes

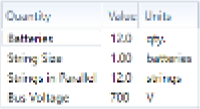


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

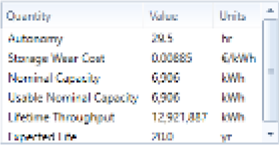
Energy-based metrics	Value	Units
Total renewable production divided by load	157	%
Total renewable production divided by generation	100	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	1,436	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

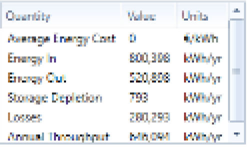
Renewable penetration



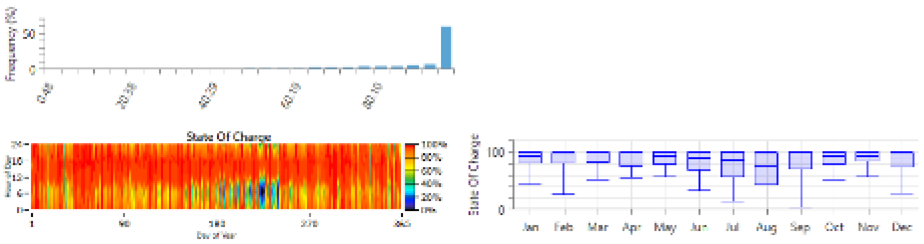
Quantity	Value	Units
Batteries	12.0	qty.
String Size	1.00	batteries
Strings in Parallel	12.0	strings
Bus Voltage	700	V



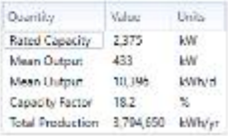
Quantity	Value	Units
Autonomy	29.5	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	6,906	kWh
Usable Nominal Capacity	6,906	kWh
Lifetime Throughput	12,921,887	kWh
Expected Life	20.0	yr



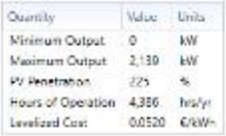
Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	800,308	kWh/yr
Energy Out	520,808	kWh/yr
Storage Depletion	793	kWh/yr
Losses	280,293	kWh/yr
Annual Throughput	648,094	kWh/yr



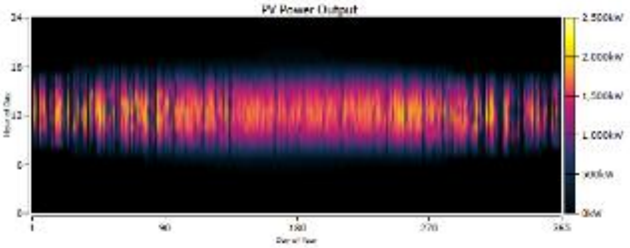
Battery usage



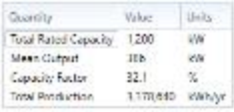
Quantity	Value	Units
Rated Capacity	2,375	kW
Mean Output	433	kW
Mean Output	10,396	kWh/d
Capacity Factor	18.2	%
Total Production	3,794,650	kWh/yr



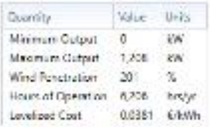
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	2,139	kW
PV Penetration	225	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	€/kWh



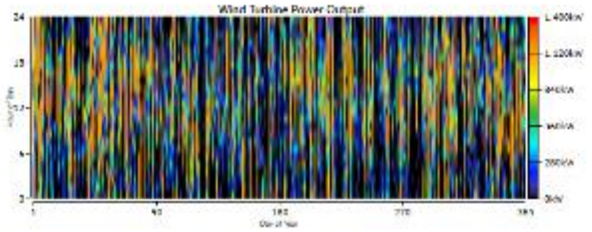
PV output



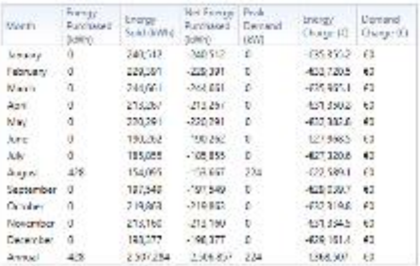
Quantity	Value	Units
Total Rated Capacity	1,200	kW
Mean Output	386	kW
Capacity Factor	32.1	%
Total Production	3,378,840	kWh/yr



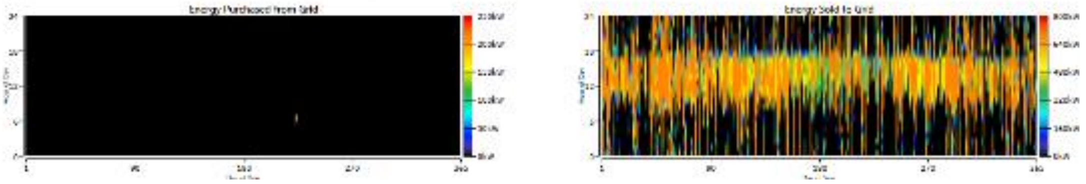
Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,208	kW
Wind Penetration	201	%
Hours of Operation	8,206	hrs/yr
Levelized Cost	0.0381	€/kWh



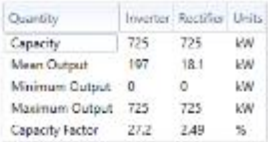
100 kW wind turbines output



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	0	240,512	-240,512	0	[illegible]	€0
February	0	229,391	-229,391	0	[illegible]	€0
March	0	244,651	-244,651	0	[illegible]	€0
April	0	213,257	-213,257	0	[illegible]	€0
May	0	220,291	-220,291	0	[illegible]	€0
June	0	190,262	-190,262	0	[illegible]	€0
July	0	185,855	-185,855	0	[illegible]	€0
August	428	154,095	-153,667	224	[illegible]	€0
September	0	197,549	-197,549	0	[illegible]	€0
October	0	219,863	-219,863	0	[illegible]	€0
November	0	213,160	-213,160	0	[illegible]	€0
December	0	196,377	-196,377	0	[illegible]	€0
Annual	428	[illegible]	[illegible]	224	[illegible]	€0

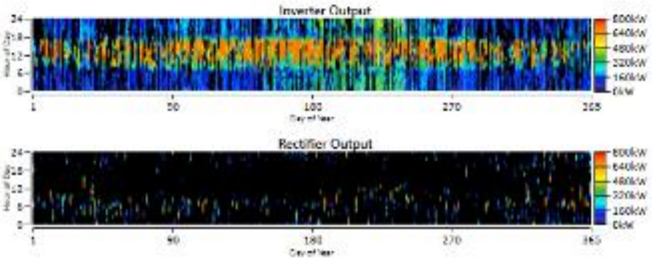


Grid transactions



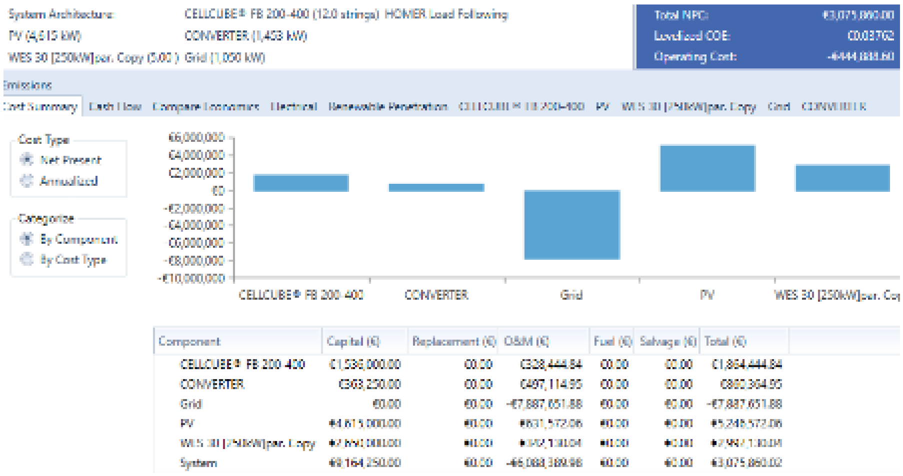
Quantity	Inverter	Rectifier	Units
Capacity	725	725	kW
Mean Output	197	18.1	kW
Minimum Output	0	0	kW
Maximum Output	725	725	kW
Capacity Factor	27.2	2.49	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	5,810	1,729	hrs/yr
Energy Out	1,728,231	158,181	kWh/yr
Energy In	1,819,190	166,507	kWh/yr
Losses	90,960	8,325	kWh/yr



Converter output

<u>4615PV+5*250WT+12BATT:</u>

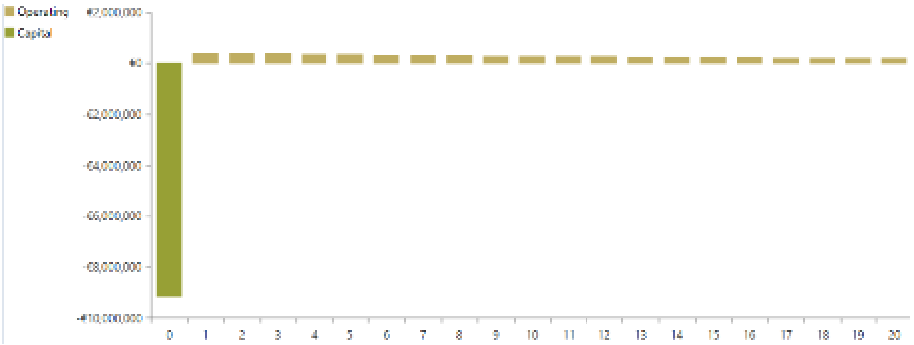


System Architecture: CELLCUBE® FB 200-400 (12.0 strings) HOMER Load Following
PV (4,615 kW) CONVERTER (1,453 kW)
WES 30 [250kW]par. Copy (5.00) Grid (1,050 kW)

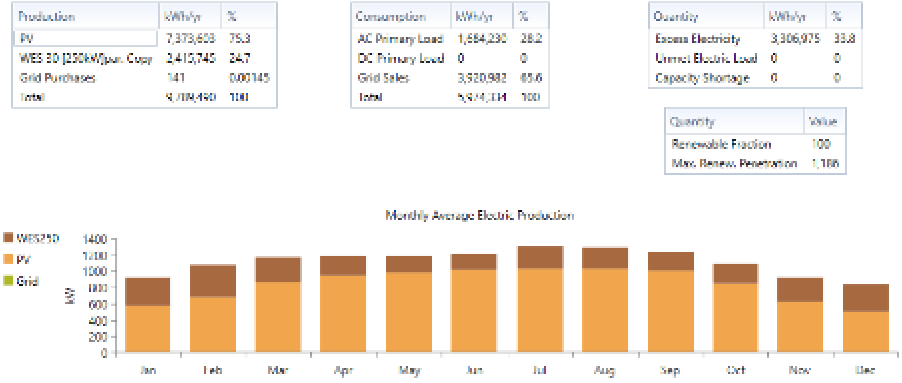
Total NPC:	€3,075,860.00
Levelized COE:	€0.03762
Operating Cost:	-€444,888.60

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€1,536,000.00	€0.00	€328,444.84	€0.00	€0.00	€1,864,444.84
CONVERTER	€363,250.00	€0.00	€497,114.95	€0.00	€0.00	€860,364.95
Grid	€0.00	€0.00	-€7,887,651.88	€0.00	€0.00	-€7,887,651.88
PV	€4,615,000.00	€0.00	€631,572.06	€0.00	€0.00	€5,246,572.06
WES 30 [250kW]par. Copy	€2,650,000.00	€0.00	€342,130.04	€0.00	€0.00	€2,992,130.04
System	€9,164,250.00	€0.00	-€6,088,389.98	€0.00	€0.00	€3,075,860.02

Cost summary



Cash flow



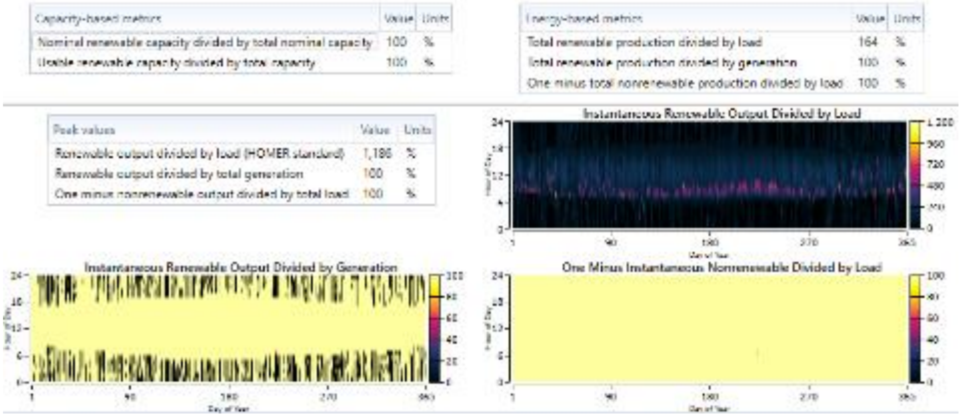
Production	kWh/yr	%
PV	7,373,603	75.3
WES 30 [250kW]par. Copy	2,415,745	24.7
Grid Purchases	141	0.00145
Total	9,789,490	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	28.2
DC Primary Load	0	0
Grid Sales	3,920,982	65.6
Total	5,974,114	100

Quantity	kWh/yr	%
Excess Electricity	3,306,975	33.8
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	1,186

Electrical sizes

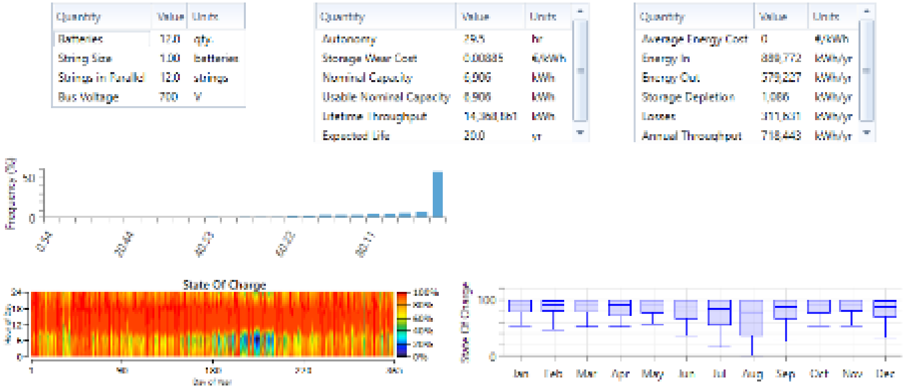


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	164	%
Total renewable production divided by generation	100	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	1,186	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

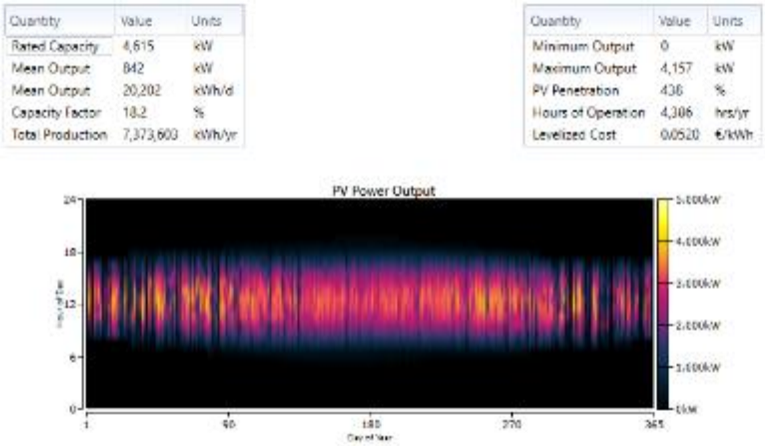


Quantity	Value	Units
Batteries	12.0	qty.
String Size	1.00	batteries
Strings in Parallel	12.0	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	29.5	hr
Storage Wear Cost	0.00885	€/kWh
Nominal Capacity	6,906	kWh
Usable Nominal Capacity	6,906	kWh
Lifetime Throughput	14,368,661	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	€/kWh
Energy In	888,772	kWh/yr
Energy Out	579,227	kWh/yr
Storage Depletion	1,086	kWh/yr
Losses	311,631	kWh/yr
Annual Throughput	718,443	kWh/yr

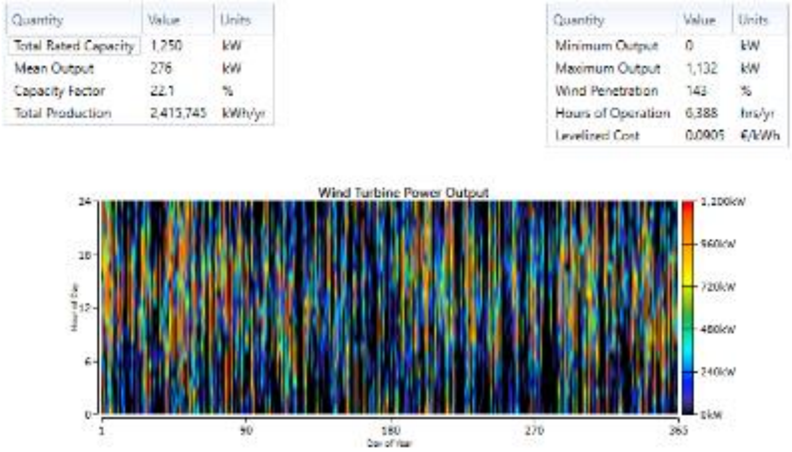
Battery usage



Quantity	Value	Units
Rated Capacity	4,615	kW
Mean Output	842	kW
Mean Output	20,202	kWh/d
Capacity Factor	18.2	%
Total Production	7,373,603	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	4,157	kW
PV Penetration	438	%
Hours of Operation	4,306	hrs/yr
Levelized Cost	0.0520	€/kWh

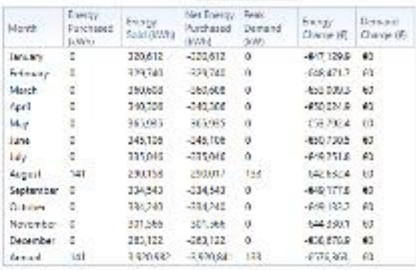
PV output



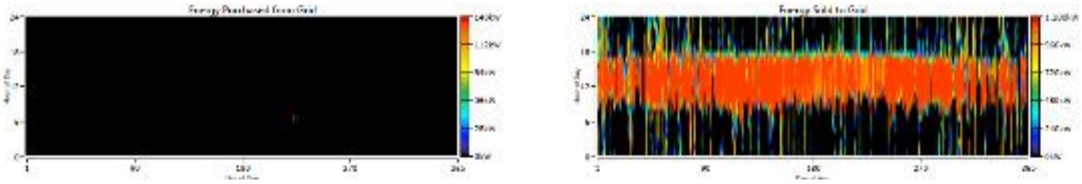
Quantity	Value	Units
Total Rated Capacity	1,250	kW
Mean Output	276	kW
Capacity Factor	22.1	%
Total Production	2,415,745	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,132	kW
Wind Penetration	143	%
Hours of Operation	6,388	hrs/yr
Levelized Cost	0.0905	€/kWh

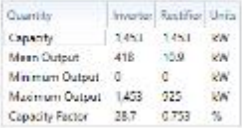
250 kW wind turbines output



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	0	220,612	-220,612	0	-€47,129.6	€0
February	0	229,740	-229,740	0	-€48,471.7	€0
March	0	250,608	-250,608	0	-€52,009.3	€0
April	0	240,308	-240,308	0	-€50,024.8	€0
May	0	365,085	-365,085	0	[illegible]	€0
June	0	245,108	-245,108	0	-€50,730.5	€0
July	0	235,046	-235,046	0	-€49,751.8	€0
August	141	290,158	-290,017	135	-€42,652.4	€0
September	0	234,543	-234,543	0	-€49,177.8	€0
October	0	334,740	-334,740	0	-€49,183.2	€0
November	0	321,566	-321,566	0	-€44,590.1	€0
December	0	283,122	-283,122	0	-€30,670.9	€0
Annual	141	3,920,582	-3,920,441	135	[illegible]	€0

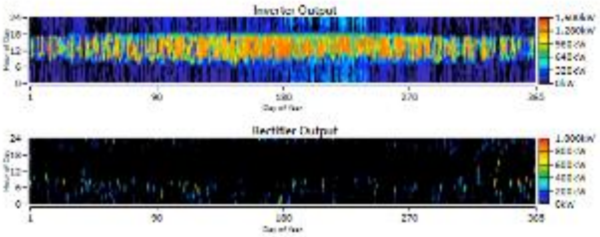


Grid transactions



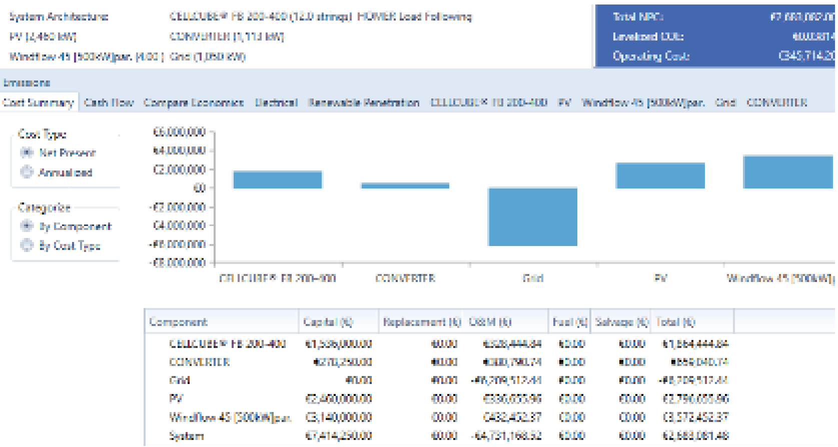
Quantity	Inverter	Rectifier	Units
Capacity	1,451	1,451	kW
Mean Output	418	10.9	kW
Minimum Output	0	0	kW
Maximum Output	1,453	925	kW
Capacity Factor	28.7	0.753	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	7,756	1,107	hrs/yr
Energy Out	3,659,297	95,808	kWh/yr
Energy In	3,851,892	100,850	kWh/yr
Losses	192,595	5,043	kWh/yr



Converter output

<u>2460PV+4*500WT+12BATT:</u>

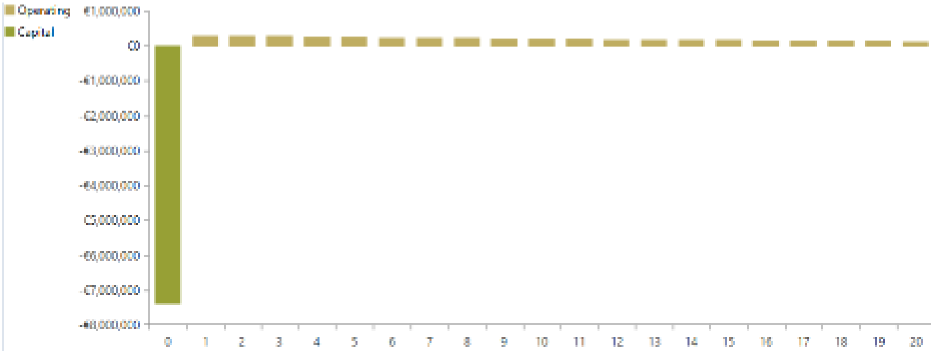


System Architecture: CELLCUBE® FB 200-400 (12.0 strings) HOMER Load Following
PV (2,460 kW) CONVERTER (1,113 kW)
Windflow 45 [500kW]par. (4.00) Grid (1,050 kW)

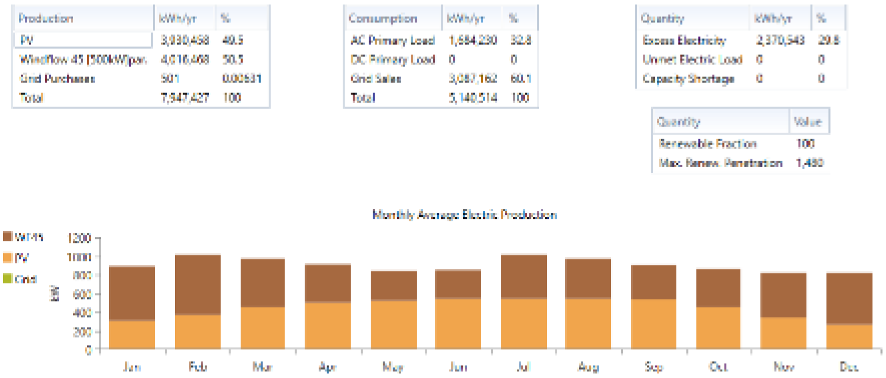
Total NPC: €2,683,082.0
Levelized COE: €0.03814
Operating Cost: €345,714.2

Component	Capital (€)	Replacement (€)	O&M (€)	Fuel (€)	Salvage (€)	Total (€)
CELLCUBE® FB 200-400	€1,536,000.00	€0.00	€328,444.84	€0.00	€0.00	€1,864,444.84
CONVERTER	€270,250.00	€0.00	€388,790.74	€0.00	€0.00	€659,040.74
Grid	€0.00	€0.00	-€8,209,517.44	€0.00	€0.00	-€8,209,517.44
PV	€2,460,000.00	€0.00	€336,055.96	€0.00	€0.00	€2,796,055.96
Windflow 45 [500kW]par.	€3,140,000.00	€0.00	€432,452.37	€0.00	€0.00	€3,572,452.37
System	€7,414,250.00	€0.00	-€4,731,168.52	€0.00	€0.00	€2,683,081.48

Cost summary



Cash flow



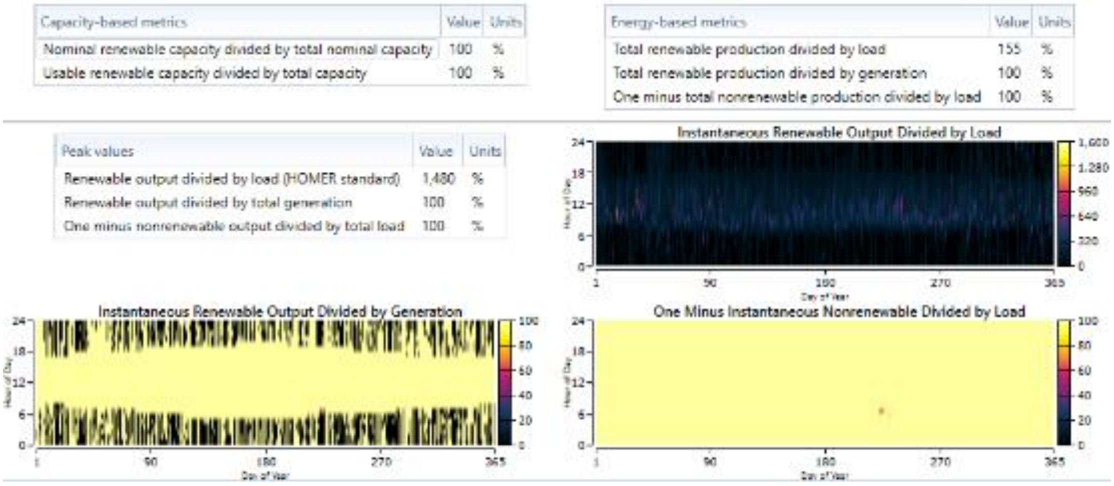
Production	kWh/yr	%
PV	3,930,458	49.5
Windflow 45 [500kW]par.	4,016,468	50.5
Grid Purchases	501	0.00631
Total	7,947,427	100

Consumption	kWh/yr	%
AC Primary Load	1,684,230	32.8
DC Primary Load	0	0
Grid Sales	3,087,162	60.1
Total	5,140,514	100

Quantity	kWh/yr	%
Excess Electricity	2,370,543	29.8
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	1,480

Electrical sizes

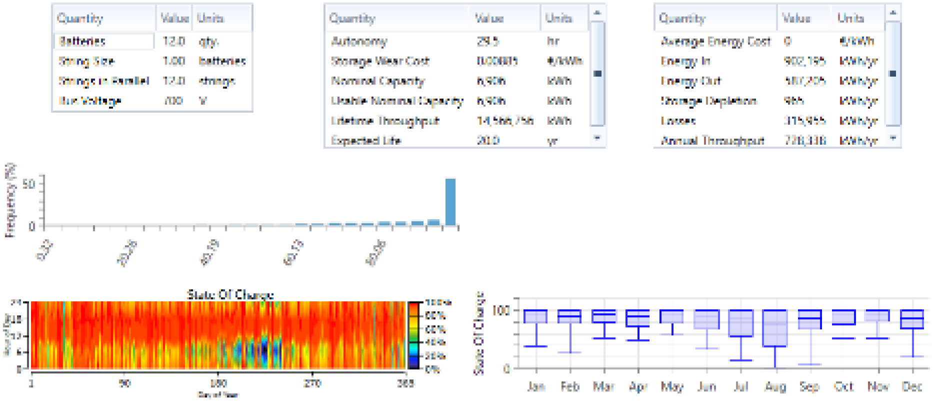


Capacity-based metrics	Value	Units
Nominal renewable capacity divided by total nominal capacity	100	%
Usable renewable capacity divided by total capacity	100	%

Energy-based metrics	Value	Units
Total renewable production divided by load	155	%
Total renewable production divided by generation	100	%
One minus total nonrenewable production divided by load	100	%

Peak values	Value	Units
Renewable output divided by load (HOMER standard)	1,480	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Renewable penetration

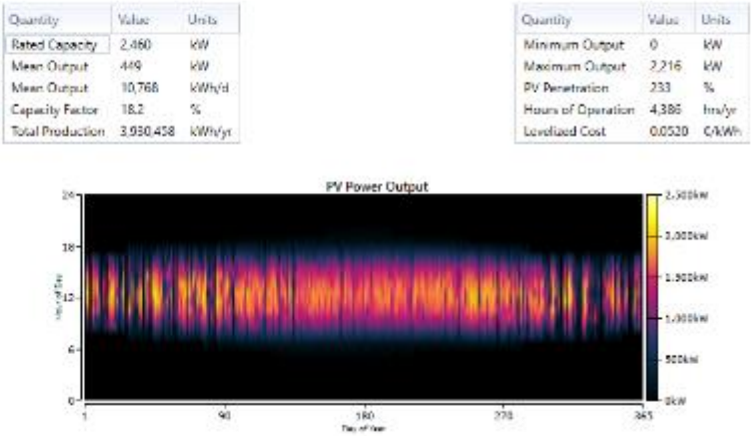


Quantity	Value	Units
Batteries	12.0	qty.
String Size	1.00	batteries
Strings in Parallel	12.0	strings
Bus Voltage	700	V

Quantity	Value	Units
Autonomy	29.5	hr
Storage Wear Cost	0.00005	$/kWh
Nominal Capacity	6,906	kWh
Usable Nominal Capacity	6,906	kWh
Lifetime Throughput	14,566,756	kWh
Expected Life	20.0	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	902,195	kWh/yr
Energy Out	587,205	kWh/yr
Storage Depletion	965	kWh/yr
Losses	315,955	kWh/yr
Annual Throughput	728,338	kWh/yr

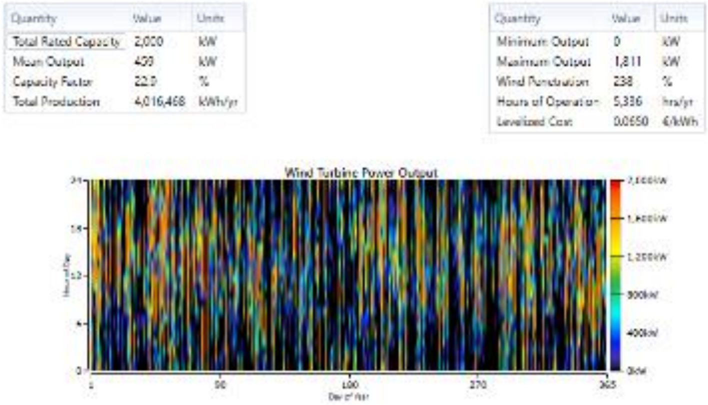
Battery usage



Quantity	Value	Units
Rated Capacity	2,460	kW
Mean Output	449	kW
Mean Output	10,768	kWh/d
Capacity Factor	18.2	%
Total Production	3,930,458	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	2,216	kW
PV Penetration	233	%
Hours of Operation	4,386	hrs/yr
Levelized Cost	0.0520	$/kWh

PV output

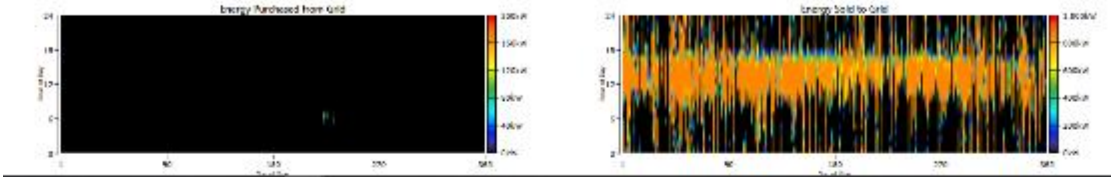


Quantity	Value	Units
Total Rated Capacity	2,000	kW
Mean Output	459	kW
Capacity Factor	22.9	%
Total Production	4,016,468	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1,811	kW
Wind Penetration	238	%
Hours of Operation	5,336	hrs/yr
Levelized Cost	0.0650	$/kWh

500 kW wind turbines output

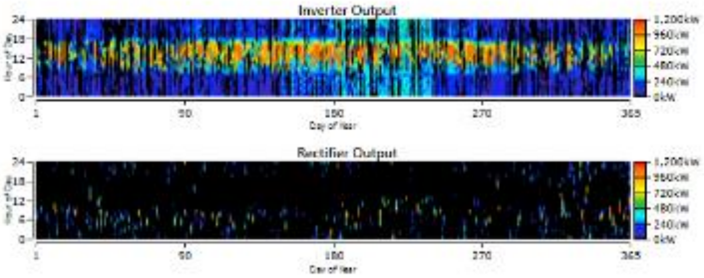
Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (€)	Demand Charge (€)
January	0	291,500	-291,500	0	[illegible]	€0
February	0	[illegible]	[illegible]	0	[illegible]	€0
March	0	[illegible]	[illegible]	0	[illegible]	€0
April	0	281,276	-281,276	0	-428,407.5	€0
May	0	287,901	-287,901	0	[illegible]	€0
June	0	[illegible]	[illegible]	0	[illegible]	€0
July	0	[illegible]	[illegible]	0	[illegible]	€0
August	501	[illegible]	[illegible]	174	[illegible]	€0
September	0	[illegible]	[illegible]	0	-435,077.9	€0
October	0	[illegible]	[illegible]	0	[illegible]	€0
November	0	[illegible]	[illegible]	0	[illegible]	€0
December	0	[illegible]	[illegible]	0	[illegible]	€0
Annual	501	3,007,162	[illegible]	174	[illegible]	€0



Grid transactions

Quantity	Inverter	Rectifier	Units
Capacity	1,113	1,113	kW
Mean Output	241	21.8	kW
Minimum Output	0	0	kW
Maximum Output	1,113	1,113	kW
Capacity Factor	21.7	1.96	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	5,958	1,634	hrs/yr
Energy Out	2,114,834	191,383	kWh/yr
Energy In	2,226,141	201,455	kWh/yr
Losses	111,307	10,073	kWh/yr



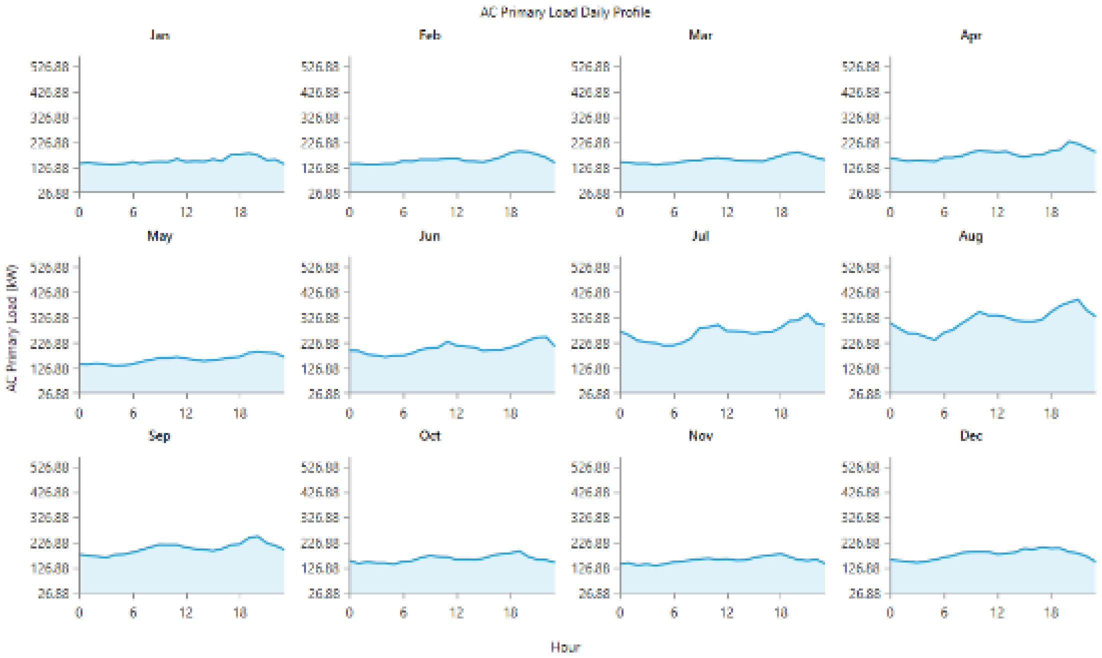
Converter output

Appendix 2:

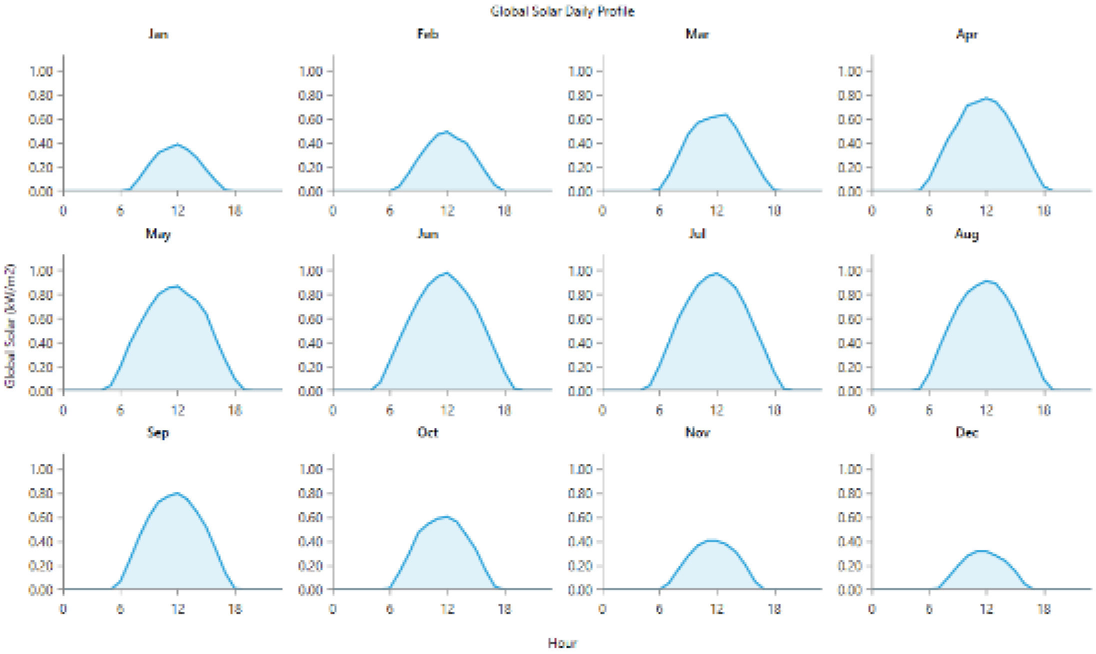
Adoption Rate	Combination	NPC (€)	COE (€/kWh)	CC (€)	EE (kWh/yr)	GI (kWh)	GS (kWh)	WC (€/m3)
25%	**340PV**	2,997,035	0.1066	425,000	230	1,538,933	1,871	3.91
	12PV+2*100WT	2,719,161	0.0968	270,553	11,228	1,539,618	1,068	3.75
	40PV+250WT	3,060,619	0.1085	587,150	8,938	1,532,168	7,402	4.07
50%	**746PV+1BATT**	3,126,522	0.1111	1,218,250	367	1,025,199	2,744	4.04
	5*100WT	2,208,768	0.0716	645,000	269,508	1,116,674	201,920	3.20
	577PV+1*100WT+1BATT	2,601,022	0.0869	925,750	51,991	1,081,350	133,564	3.57
	435PV+250WT+1BATT	2,972,061	0.1002	1,181,250	33,697	1,080,560	113,816	3.88
75%	**1609PV+3BATT**	2,968,314	0.0871	2,135,750	305,893	621,680	437,305	3.67
	12*100WT+2BATT	2,321,573	0.0627	1,874,750	1,210,806	675,902	653,122	3.08
	1060PV+3*100WT+1BATT	2,581,729	0.0743	2,144,250	396,790	626,764	486,503	3.60
	765PV+2*250WT+2BATT	3,005,025	0.0941	2,156,000	247,275	576,653	280,842	3.91
	865PV+500WT+1BATT	2,372,765	0.0668	1,875,500	305,893	647,583	541,012	3.24
100%	**4375PV+23BATT**	2,593,041	0.0538	3,254,000	2,747,270	47	1,467,847	2.14
	2375PV+12*100WT+12BATT	1,712,146	0.0274	5,640,250	2,234,296	428	2,507,284	2.81
	4615PV+5*250WT+12BATT	3,075,860	0.0376	9,164,250	3,306,975	141	3,920,982	4.03
	2460PV+4*500WT+12BATT	2,683,081	0.0381	7,414,250	2,370,543	501	3,087,162	3.66

Comparative table of results

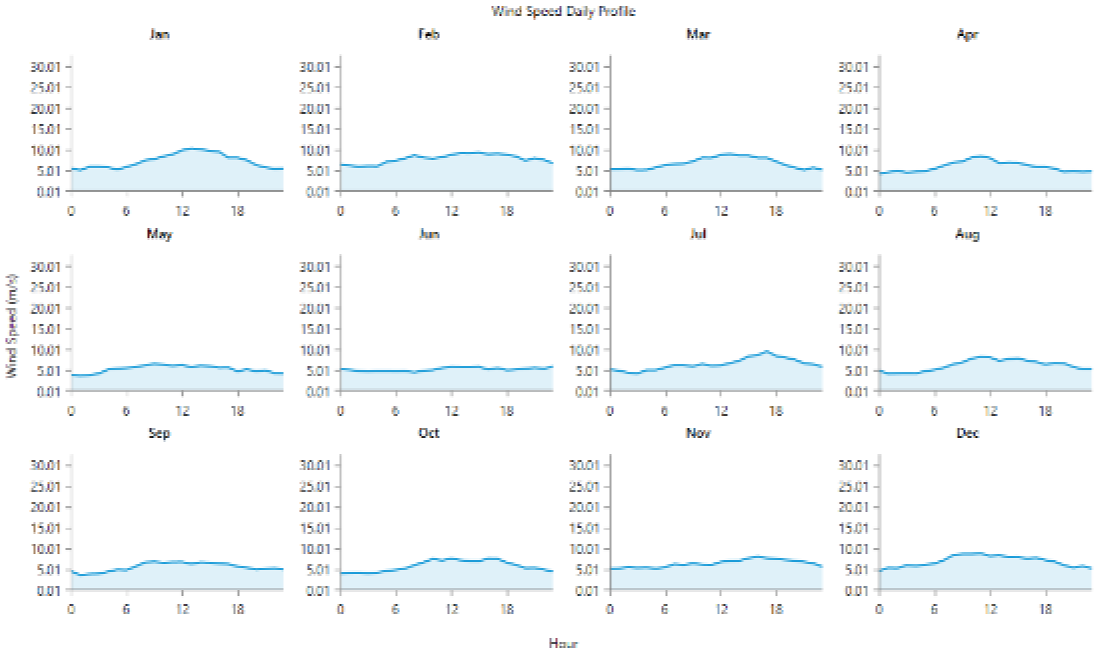
Appendix 3:



Average monthly AC Primary load for Ano Koufonisi



Average monthly Global Solar radiation values for Ano Koufonisi



Monthly average wind speed profile for Ano Koufonisi