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ABSTRACT

This thesis aims to construct a power plant that will provide the lowest cost of electricity on the small islands. The aim is to provide energy to the local consumers with the lower use of fossil fuels, which increases the production cost due to the cost of transporting fuel to the islands. In this direction, we follow the use of electric hybrid systems which are used in several isolated areas. The proposed investments are separated through the investment cost, into a low-cost investment, which provides energy through the tidal energy system and in case of lack is supplied by the existing power systems. The second investment (high cost) is a green hybrid system that produces energy using only renewable energy sources, will store energy whenever possible in green hydrogen and will use this hydrogen to generate electricity when needed.

Table of Contents

1 Introduction

In this thesis, we review the evolution of electricity in the world and Greece. We list all the ways of energy production, and we focus on each one of the RES, mentioning their advantages and disadvantages. We analyze the ways of production and use of green hydrogen, a product that will concern us a lot in the coming decades as the lack of minerals will lead us to other energy sources with lower costs and green hydrogen is one of them. We mention the electricity storage options because the RES produces a low-cost product, and we could not control the time of the production. We make a quick reference to the February events between Russia and Ukraine and the results in energy prices.

We analyze the use of hybrid energy systems to avoid the dependency on fossil fuels and to be most efficient at the use of RES. Then we study the construction of two power plants on the same Greek island, in the first unit the energy production will be as much as possible, and the shortages will be covered by other areas - choices. While at the second investment we construct a whole hybrid unit, to cover all the needs of the island without the use of minerals and the possibility of utilizing energy in other forms (sell it as hydrogen).

Finally, we present the financial data of both investments, provide a financial evaluation of the type of the investment, and perform a SWOT analysis.

2 Electric Energy

Electric Energy is the flow of electric charge, it belongs to the secondary energy sources, which means that we must produce it from other energy sources, such as coal, gas, oil, nuclear energy, and other natural sources, which were called primary sources. The energy sources we use to generate electricity may be renewable or non-renewable, but electricity itself is neither renewable nor non-renewable. The majority of our daily personal needs are covered by the use of electricity, such as lighting, heating - air conditioning, etc. This energy is required even for the operation of telecommunications and public transport (tram, electric railway, etc.).

Electricity is largely generated from non-renewable energy sources (oil, nuclear energy, etc.) which increases the cost and benefits for countries that are rich in mineral wealth. A major disadvantage of electricity is its storage cost; the conservation of this energy to date is mostly done using batteries. A key exception in this area is the country of Ireland[1] which through the peculiarity of its soil uses some natural lakes where through hydroelectric units it stores and generates electricity whenever necessary.

Figure 1 Turlough Hill, Ireland's pumped storage power station Electricity Supply Board (ESB)

The storage of electricity in Ireland, as we see in **Figure 1**, using the local morphology of soil, indicates to us the choice of storage with the combination of natural phenomena (with the use of gravity we produce electricity and with the use of the upper lake we create a technical natural battery) and without the high cost. It is worth mentioning that the damping time of a dam is twenty years in contrast to the batteries which are only five years. We do not require the water that is used to be drinkable or not as it is used only for energy

[1] Turlough Hill, Ireland's pumped *an electricity storage in Ireland using local natural geomorphic place*, [Online]. Retrieved from: https://esbarchives.ie/portfolio/turlough-hill/

production, otherwise, the cost may differ, as well as the sources of income. In the construction of dams in general, we choose locations to build only a part of the dam, which is particularly important, as well as the possibility of releasing water into a river or to the sea.

Due to climate change in recent years, the EU has turned to green energy, these units do not require any special infrastructure for their installation but must meet certain criteria for the correct choice of location. These units produce energy at zero cost since the basic good is zero cost, but the production cannot be based on a design but whenever the weather conditions allow (air, sun, water). The installation of such units was particularly felt in all EU countries and in Greece, which through the construction of photovoltaic and wind farms tried to reduce lignite consumption and CO_2 production. We can also use electricity to produce the green hydrogen of a fuel which can be used to burn it but also to reunite it with oxygen. In the second case, we produce energy without the production of waste.

Also, we must not overlook the transnational connectivity of neighboring countries' electricity grids, whether they belong to the EU or not, which creates another infrastructure for buying and selling electricity on a global scale similar to natural gas. This capability can highlight the power of electricity and its consolidation in the international market, a fact that will increase the strong forces.

In Figure 2 we have the interconnections between the EU countries and ten neighboring ones for electricity exchange and trading. The connections as we can see are **twelve** interconnections of **Belarus** – all to Lithuania, **four** interconnections of **Moldova** – all to Romania **twelve** interconnections of **Russia** connecting Finland, Estonia, Latvia, and Lithuania, and **eight** interconnections of **Ukraine** connecting Poland, Slovakia, Hungary and Romania, **two** interconnections of **Albania** – all to Greece, **twenty-one** interconnections of **Bosnia and Herzegovina** – all to Croatia, **five** interconnections of **North Macedonia** connecting Greece and Bulgaria, twelve interconnections of **Serbia** connecting Bulgaria, Croatia, Hungary and Romania, **three** interconnections of **Turkey** connecting Bulgaria and Greece; as well as **two** interconnectors of **Morocco** – all to Spain.

Figure 2 Interconnections between EU member countries and their neighbours (Source ENTSO-E Retrieved from: https://www.entsoe.eu/)

The physical transmission capacity, the physical electricity flows, and the scheduled commercial flows vary greatly depending on the border, the electricity lines being also characterized by different voltage and capacity. the lines between Croatia and Bosnia and Herzegovina offer in total almost 5.5 GW nominal interconnection capacity, which is the largest capacity between a single EU member state and its neighbor. The two electricity lines with a combined nominal capacity of 1.4 GW between Spain and Morocco remain the only links between Europe and North Africa.

2.1 The value of energy

Energy crises have brought great changes in the 20th century both politically and economically, it is something that will help us realize the value of making the right choice and creating an alternative form of energy. The first energy crisis was the 1973 oil crisis that resulted from the embargo of the OPEC countries (consisting of Arab OPEC members[2], as well as Egypt, Syria, and Tunisia) against the USA, CANADA, JAPAN, NETHERLANDS AND ENGLAND for the decision of US to supply weapons in Israel, which pushed the price of crude oil from $ 3 a barrel to almost $ 12 in less than a year. The results were evident in many basic needs of the world, Nixon exhorted the gas stations not to sell gasoline on Saturday nights and Sundays, the state of Oregon banned special Christmas lighting, and Ted Heath asked the British to heat only one room.

[2] The History of OPEC countries. *[Online]. Available at:* https://www.opec.org/opec_web/en/about_us/24.htm

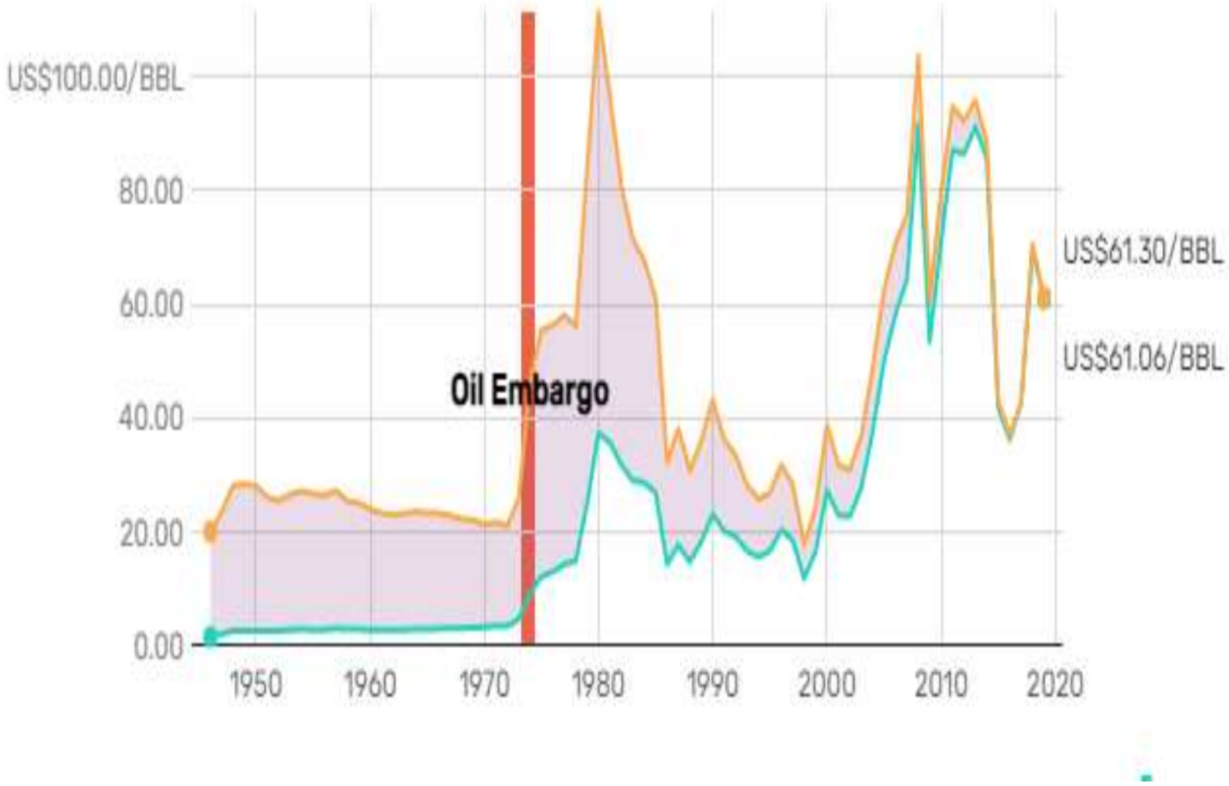

Figure 3 The fluctuation of the Oil price from 1950 [Online]. Retrieved from: https://www.macrotrends.net/

Figure 4 The reaction of the world in the days of the oil crisis 79 [Online]. Retrieved from https://www.thebalance.com/opec-oil-embargo-causes-and-effects-of-the-crisis-3305806

In the 1979 oil crisis[3] in Iran after the change of the political regime of the state the oil sector of the country dissolved, and the price of oil reaches 35 to 40 dollars. Another energy crisis is that of Exxon Valdez[4] in 1989 when the tanker when collided with a reef showed some ecological implications of oil use and informed the world of the consequences. A peculiar crisis was that of the Persian Gulf in 1990 as it was created out of fear of rarity, something that did not happen[5].

In all the above cases we report crises with oil extraction, and we can easily understand that the choice of this material can affect us significantly. The Deepwater Horizon accident[6] is another accident that reminded us that in addition to CO_2 production we also have accidents that can destroy us and the animal kingdom now.

[3]*A digest of the1979 oil crisis* [Online]. Retrieved from: https://www.federalreservehistory.org/essays/oil-shock-of-1978-79

[4]*A summary of the accident of the Exxon Valdez* [Online]. Retrieved from: https://darrp.noaa.gov/oil-spills/exxon-valdez

[5]*A digest of the oil crisis which take place the last thirty years* [Online]. Retrieved from: https://www.kathimerini.gr/economy/local/197193/oi-petrelaikes-kriseis-ton-teleytaion-trianta-eton/

[6] *The Deepwater Horizon accident* [Online]. Retrieved from: https://www.britannica.com/event/Deepwater-Horizon-oil-spill

Figure 5 As the offshore oil rig Deepwater Horizon burns, platform supply vessels attempt to douse the flames. (Image credit: U.S. Coast Guard)

Figure 6 living organisms after the disaster (source WWF)

Finally, an energy crisis that is particularly well known in the EU is that of gas, Russia was connected to the whole EU through gas pipelines, and through 2019 at Russo-Ukrainian crisis, gas prices in the EU increased, and hence the crisis did not produce only from oil but from all energy goods.

The International Economic Crisis is a fact that gives us an understanding of the importance of every good, the fluctuations that are observed in both values and primary goods, and their derivatives. The shift to other energy sources is for many necessary for the release of oil but also for another reason of climate change, with the extensive combustion of petroleum products there is a large production of waste and exhaust gases. The signing of the KYOTO[7] protocol is an important step that demonstrates the desire of many states to become members of a society with principles and respect for the environment as they should significantly reduce waste production and ultimately zero their production by 2050.

A sustainable option for many countries and for those who do not have mineral deposits is RES (Renewable Energy Sources), it is a type of energy that does not produce pollutants and can zero-waste production. The exploitation of RES is done with the use of electricity or green Hydrogen; the mechanisms through natural phenomena produce a constant voltage of electricity which we take advantage of.

2.2 The electricity from RES in the EU

In the European Union (EU), RES has become a key priority for electricity generation, as evidenced by the institutional framework developed in recent years. Until the early 1990s, electricity companies in Europe were state monopolies with the right to supply energy exclusively to consumers. The process of creating competitive electricity and gas markets began in 1992 with the European Commission formally proposing the first set of electricity and gas directives to liberalize free competition in the energy market. The aim is to create a real internal market for electricity throughout Europe, which will be characterized by the gradual liberalization of electricity consumers concerning their choice of supplier and the improvement of the Community electricity markets.

The directives 96/92 and 98/30[8] sets out the rules for the production and operation of electricity transmission and distribution networks with the following important points. Liberalization of energy production and the abolition of exclusive rights and monopolies. the creation of an independent instrument in each country for the issuance of licenses and market surveillance. The creation of an independent management instrument for the whole Union, Transmission System Operator (TSO), for the control, maintenance, and possible development of the electricity transmission network. This instrument must be independent of the production and distribution activities and distributes the electrical load between the power plants impartially with criteria mainly economic, but also safety and reliability. TSO oversights help to prevent abuses of monopoly positions

In June 2003, the EU made some further changes to improve the energy market for both electricity and gas. (Directives 2003/54)[9] . The Market liberalization is extended to all the customers, households or not, by the end of 2007. Separate the energy transmission networks from the production activities, a measure that will establish the differences between the production and the sale of energy, which will begin the end of the monopolies.

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[7]Ministry of Environment & Energy *the terms of the protocol* [Online]. Retrieved from https://ypen.gov.gr/perivallon/klimatiki-allagi/diethneis-diapragmatefseis/protokollo-tou-kyoto/

[8] European Parliament (1996). *DIRECTIVE 96/92/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 December 1 996 concerning common rules for the internal market in electricity*. [Online]. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31996L0092&from=EN

[9] European Parliament (2003). *DIRECTIVE 2003/54/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC.* [Online]. Retrieved from: https://eur-lex.europa.eu/resource.html?uri=cellar:caeb5f68-61fd-4ea8-b3b5-00e692b1013c.0004.02/DOC_1&format=PDF

Finally, it increases the role of Member States' Energy Regulators and requires the publication of network charges.

These efforts at the beginning brought positive results, but there was a delay in removing the oligopolistic situation, while the markets remained largely national. 2007 was a milestone year for the energy markets towards their full liberalization at the European level. The Commission's third package aims to create a competitive energy market that enhances secure energy supply and improves conditions for investment in power plants and transmission networks. The choices for the consumers are expanding and smaller companies are being allowed to access the energy market. In 2008, the Commission proposes additional measures to reduce the environmental impact of energy consumption in Europe.

The third directive, adopted in 2009 (2009/72/EK)[10], focuses on the more efficient separation of transmission system operators from production and supply activities. With the independence of national energy regulators to improve market transparency in the operation of the grid and the supply of electricity. Finally, the solidarity between the national regulatory authorities of the EU Member States and the organization of their cooperation to facilitate cross-border energy trade and promote regional cooperation.

It is worth mentioning that according to the Kyoto Protocol, which was signed in December 1997 by the United Nations for the Climate Change, the goal was to reduce greenhouse gas emissions in the EU by 8% in 2008-12 from levels in 1990. The Report of the National Action Plan for achieving the contribution of Renewable Energy Sources at a rate of 20% to the final energy consumption by 2020, deriving from Directive 2009/28/EK[11] and includes estimates for the development of the energy sector and the penetration of RES technologies by 2020. In 2018, it was agreed that by 2030 a 32% share of EU energy consumption would come from renewable sources[12]. In July 2021[13], given the EU's new climate ambitions, proposed to revise the 40% target by 2030.

2.3 The electricity in Greece

2.3.1 Historically the electricity in Greece

The Power of electricity appeared in Greece in 1889, the first place that was illuminated was the Greek palace and by 1929 more than 250 cities with over 5.000 citizens had electricity.

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[10] European Parliament (2009). *REGULATION (EC) No 714/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003.* [Online]. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0714&from=EN

[11] *Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009 setting emission performance standards for new passenger cars as part of the Community's integrated approach to reduce CO2 emissions from light-duty vehicles.* [Online]. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2009:140:FULL&from=EL

[12] European Parliament (2018). *DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources.* [Online]. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EL

[13] European Commission (2021). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS EMPTY 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality* [Online]. Retrieved from: https://eur-lex.europa.eu/legal-content/EL/TXT/?uri=CELEX:52021DC0550

The Electricity for Greece, a country that has been liberated from the Ottoman Empire and in just a century has been involved in two Balkans and one world war is an event that changes the daily and the quality of life of its citizens. The use of electric lighting and not the oil lamps gives the possibility of recognition by all citizens, regardless of educational level, of the changes it brings to both workplaces and personal homes. Consumers with the use of electric lighting do not inhale the exhaust gases of oil lamps and reduce material damage from daily minor accidents and lamp fires. The electricity market in Greece, although at an early stage, is a fairly profitable market for investment due to its potential. This can be understood from the fact that until 1950 there were 385 companies in Greece, of which 263 were private with a simple license, 54 were private with a privileged license and 58 were common, which makes the final price of electricity different from a city to city, but also from company to company.

All this forced the Greek government in August of 1950 to establish the Public Electricity Company and in 1956 was decided to acquire all the electricity companies, so that there would be only a single entity. Until the beginning of the last century, production processes were evaluated considering only their performance and not their costs and ignoring any problems or the waste created[14].

2.3.2 The Greek Legislation

In 1985, several years before the first package of EU measures through Law 1559/1985[15], the Greek government with the Government Gazette A'135, "Regulation of alternative energy issues and special issues of electricity production from conventional fuels and other provisions" are constructed the first RES in Greece. PPC with this law creates some small wind farms and solar parks that can produce a total of 24MW.

The second point is the law L.2244 / 1994[16], "Regulation of electricity generation issues from renewable energy sources and from conventional fuels and other provisions" (Government Gazette A'168), where we formulate fixed selling prices of electricity produced by RES. In the unconnected islands, the purchase price was 90% of the general tariff in the medium trend with an obligation of PPC to buy it. It is worth noting that for the islands that do not belong to the interconnected system, the price in 2006 corresponded to 0.08458 Euros/kilowatt-hour, as the pricing was based on 90% of the general use tariff (low voltage).

From 1994 onwards, several laws were passed and implemented, we will mention briefly Law 3017/2002[17] which approves the commitment for the Kyoto Protocol to the United Nations Framework Convention on Climate Change "(Government Gazette A '117). With the

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[14] *Historical Review, when did electricity come to Greece-* [Online], Retrieved from https://www.heron.gr/blogs/articles/revma-ellada/

[15] *The law that approved the construction of the first wind farms* [Online]. Retrieved from https://www.e-nomothesia.gr/energeia/nomos-1559-1985-phek-135a-25-7-1985.html

[16] The Government Gazette *The rules for determining the purchase price of electricity* [Online]. Retrieved from https://www.e-nomothesia.gr/energeia/nomos-2244-1994-phek-168-a-7-10-1994.html

[17] The Government Gazette *Ratification of the Kyoto Protocol* [Online]. Retrieved from https://www.e-nomothesia.gr/kat-periballon/nomos-3017-2002-phek-117-a-30-5-2002.html

enactment of the Law 3468/2006[18] "Production of Electricity from Renewable Energy Sources and Cogeneration of High-Efficiency Electricity and Heat and other provisions" (Government Gazette A'129), the licensing process of RES was simplified, and released the sale price from the sale price of PPC.

The law 4001/2011[19] institutes the provisions for the activities of production, supply, purchase, transmission, and distribution of Natural Gas and Electricity, as well as storage and liquefaction of Natural Gas and liquefaction of liquefied Natural Gas within the Greek Territory.

All these laws impose fundamental changes in the electricity market, both in the liberalization of producers and in the sales companies. Finally, the Greek islands were the first to make the changes to reduce costs and adapt to environmental changes.

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[18] The Government Gazette *Generation of Electricity from Renewable Energy Sources and Cogeneration of High Efficiency Electricity and Heat and other provisions* [Online]. Retrieved from https://www.e-nomothesia.gr/energeia/n-3468-2006.html

[19] The Government Gazette *For the operation of Energy Markets for Electricity and Gas, for Research, Production and Hydrocarbon transmission networks and other regulations* [Online]. Retrieved from https://www.e-nomothesia.gr/energeia/n-4001-2011.html

3 Electricity production

As we have mentioned above, electricity is a key tool for the daily life of the average citizen of any civilized society and a strong bargaining chip for countries with self-sufficiency. It should be noted that electricity was discovered in the 7th century BC, but did not develop for quite a long time until 1879 when Edison discovered the first light bulb. The lamp gives value to the discovery in the simple world, which can make use of it in his homes the people can read and work any time day or night.

The most known way of producing is through the combustion of some fossil fuel, which causes the production of steam, the steam then causes the movement of a generator that produces electricity[20]. Fossil fuels can be coal, oil, or some other non-renewable element that through its combustion can heat the liquid element of the generator (usually water, but very often we differentiate water with another element that has a lower boiling point liquid to increase efficiency), this will give us the kinetic energy at the steam turbine and will be converted into electricity. Another option is nuclear power, which also generates electricity through thermal energy and a steam generator. In these ways, the disadvantage is that we have energy production and pollution. Another way of generating electricity is renewable energy sources, these sources can be divided into two categories those that produce steam energy as above but without pollution and those which use only kinetic energy. If we have energy production from geothermal or solar energy, then our system works as follows through the generating station (solar panels, piping system) we heat a liquid element which by moving steam through the generator produces electricity. And finally, the other way of generating energy without pollution, by directly converting the kinetic energy into electricity, concerns hydroelectric or wind farms where we use the flow of air or water.

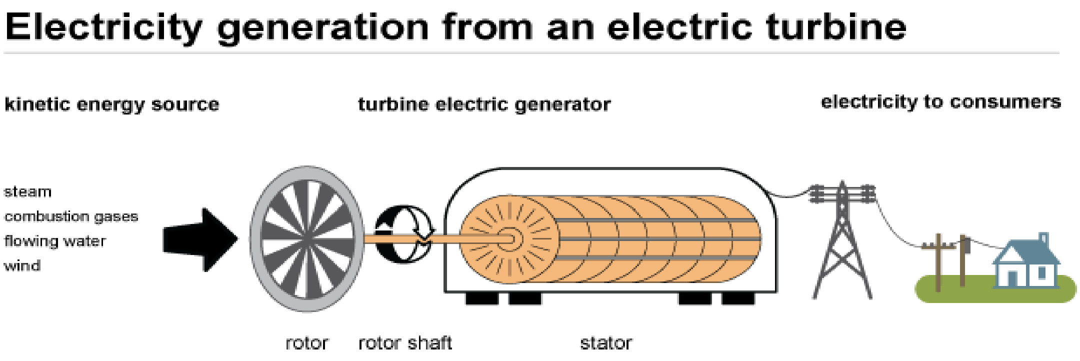

Figure 7 Electricity generation (source EIA)

3.1 Produce energy from non-renewable element

[20] How electricity is generated *a report of production methods* [Online]. Retrieved from: https://www.eia.gov/energyexplained/electricity/how-electricity-is-generated.php

The electric energy from non-renewable sources is produced through thermal power plants. The energy is produced by converting the thermal energy into mechanical and finally into electrical. Thermal energy is produced from conventional sources such as oil. The superheated steam moves the steam turbines and then is produced electricity. Due to its widespread use, all these years the operating costs are very low with a yield of 30-45% but its start is very slow as it requires many hours. The picture below can give us a typical example.

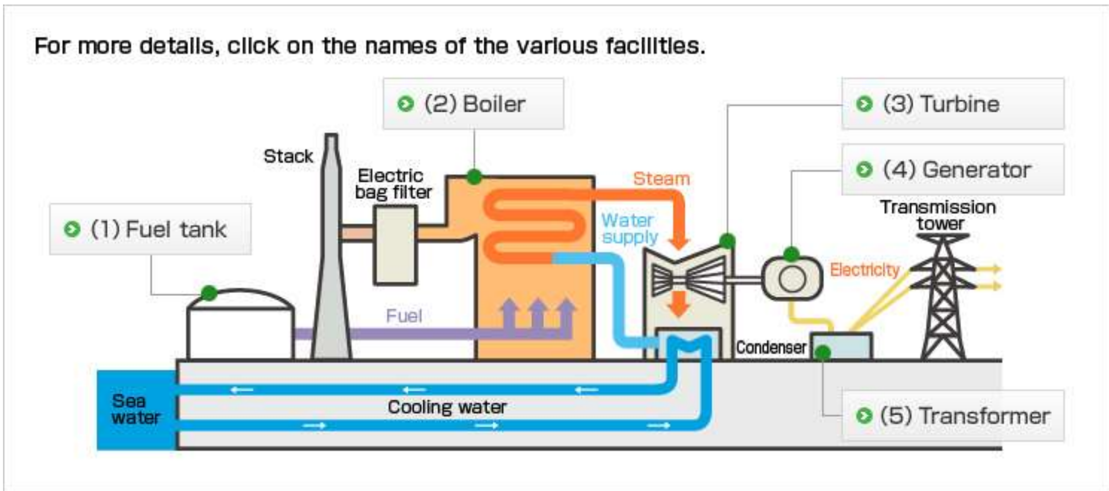

Figure 8 Pressurized water reactor (source KANSAL)

We can also produce energy through combustion with the use of gas turbines the operation is done through the production of pressures. Initially, the air is compressed and sent to the combustion chamber where we add the combustion material (oil or gas) through the combustion the exhaust gases force the piston to rotate the turbine. This process has a very high cost due to both the price of fuel and the low efficiency of 25-30%, its use is mainly done as units in high consumption hours due to the fast start. At this point, we must mention the fact that we can use all the types of fuels and not only the gas.

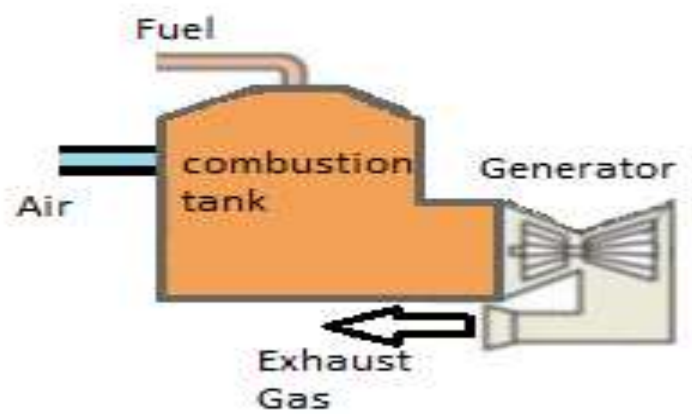

Figure 9 Combustion tank (author picture)

To become more specific in the pictures below we can see the steps of the reaction in a combustion tank. In the first step, we can see the stage of oil spraying. Then we compress the air and the fuel, in the third step there is the explosion that produces the power. And in the last step, the exhaust gases leave the system.

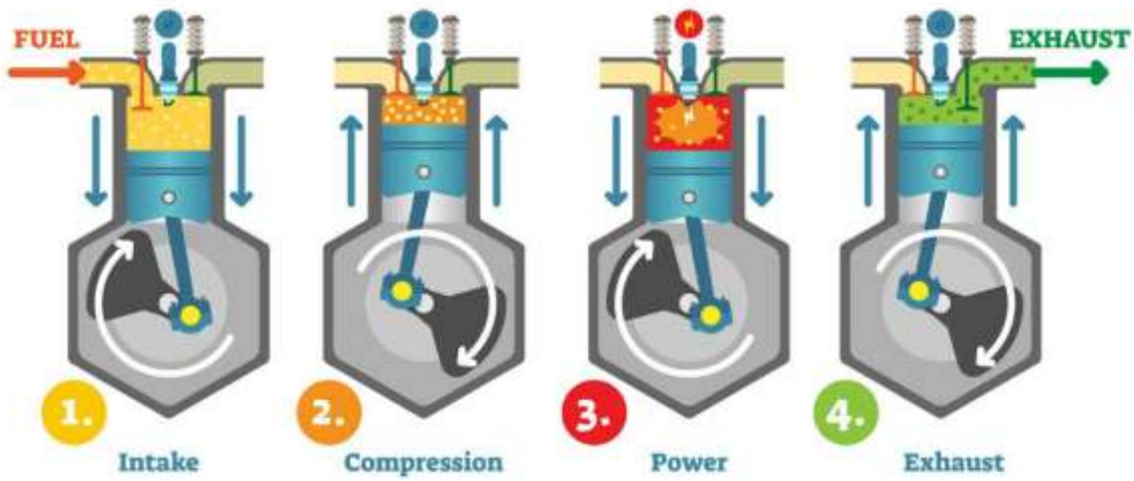

Figure 10 The step of a combustion tank (source Britannica)

Finally, another way of production is the combined cycle burners, the difference between the two previous units is the use of waste-exhaust gases in the production cycle before their exit from the mechanism. The exhaust gases are fed to a different boiler where steam is generated again which moves the steam turbine. An advantage of this technique is that the yield can reach 45-50% of the production yield.

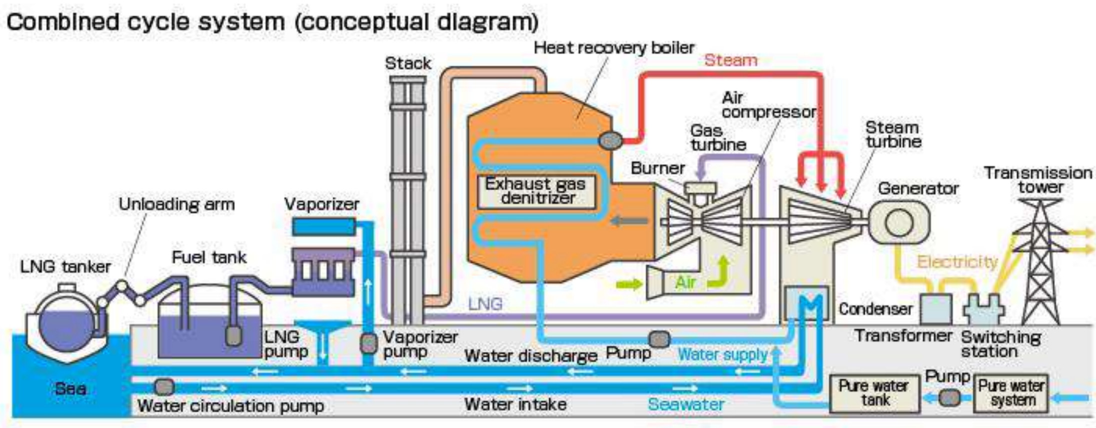

Figure 11 Combined cycle system of an electric generator (source KANSAL)

3.2 Produce green energy from RES

Renewable sources are non-mineral renewable energy sources, wind, solar and geothermal energy, wave energy, tidal energy, hydraulic energy, landfill gases, biological treatment plants, and bio-treatment plants[21]. It is important to mention that we should not include natural gas generally, but only the green hydrogen which we had produced using RES. Because we use zero-cost goods (air, water) production has almost zero cost, but due to our dependence on weather conditions, there are problems with non-continuous production. Let's look at the basic ways of producing energy.

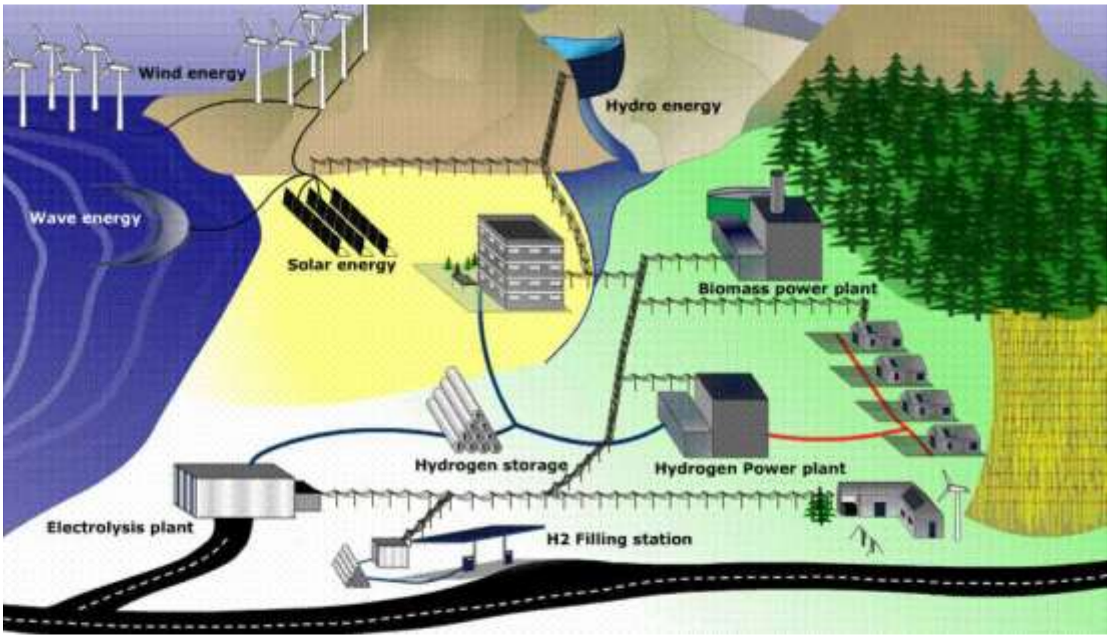

Figure 12 Possible use of RES (source Britannica)

3.2.1 Solar Energy

Solar Park systems have been researched for many years and we have the clearest view of their advantages and disadvantages. The system produces energy from sunrise until sunset, but also stops in extreme weather conditions. The winds create a solar park to lose a lot of power because the panels must be placed in the direction of safety. In addition, on rainy or cloudy days the systems do not produce any power. These facts make us realize that we can generate low-cost energy on summer days when every island needs plenty of electricity and companies must supply customers, but at night or during bad weather we have zero production.

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[21] *European Parliament (2001). Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market concerning common rules on the promotion of electricity produced from renewable energy sources in the internal electricity market* [Online]. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32001L0077&from=EN

The production methods follow two basic techniques, the electromagnetic radiation is converted into electrical energy directly or converted into thermal, then mechanical, and finally electrical.

In the following system, we see the first option, the main advantage is the fact that it can be produced on days with only a few hours of sunshine or cloudy days.

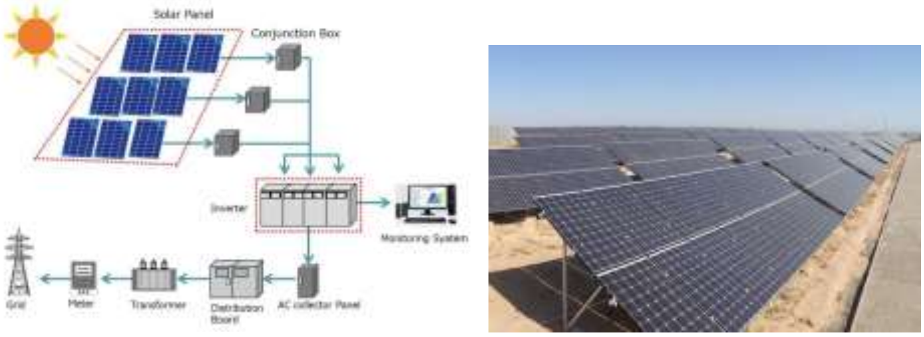

Figure 13 A Solar Park and its part (source HELIOSTAT)

The second option is the production using thermal energy, the main advantage of this option is the fact that extensive research and development has been done for the production through thermal systems.

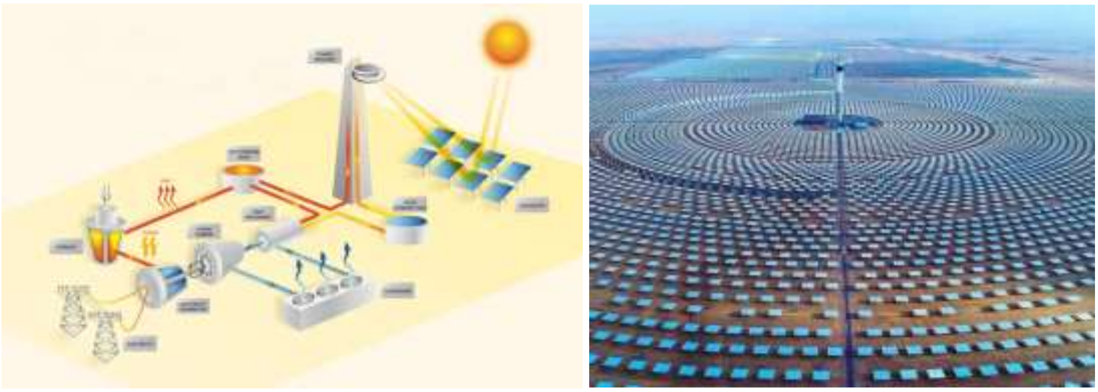

Figure 14 A Solar Park (source HELIOSTAT)

The most important problem in this type of park is the cleanliness and increases the cost (the cleanliness in the mirrors affects the performance as well as the cleanliness of the atmosphere).

3.2.2 Geothermic Energy

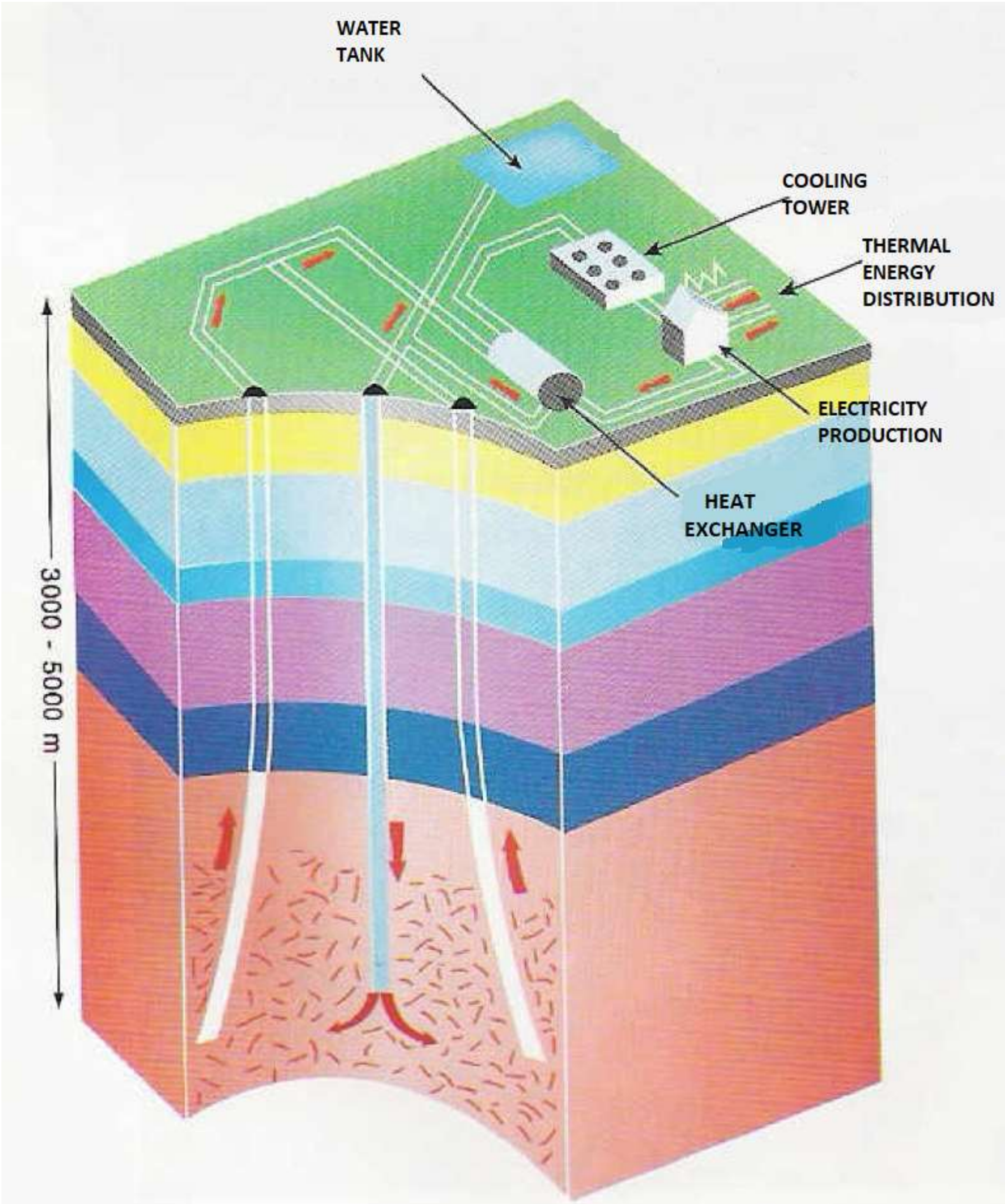

Figure 15 A Geothermic Park (*source Britannica*)

Geothermic energy is produced electricity through the thermal energy generated from the earth[22]. The materials we use are sources of the environment, we use a hot source and through steam systems, we produce kinetic energy and finally electricity. These Parks can be placed near a source and only in a few places this can be, but from there we can produce at any time (day, night summer, or winter). An example can be the island of Santorini, where the production by the volcano of THIRAS can produce electricity 365 days of the year.

[22]BERTANI R (2015) Geothermal Power Generation in the World 2010-2014 a report on the use of geothermal energy [Online]. Retrieved from: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/01001.pdf

There are five types of product lines the first is the Flash Steam Power Plant does not use only the geothermic power but also the physics reaction at different temperatures of a product. Another one is the Dry steam plants are the simplest and oldest design, where we directly use geothermal steam of 150°C or greater to turn turbines. The Dry Steam technology allows for the steam from a geothermal production well to be fed directly to a steam turbine without a secondary heat exchanger. The turbine then covers the change in steam pressure to mechanical rotational energy, which is converted to electrical energy by a generator.

Binary cycle power plants are the most recent development and can accept fluid temperatures as low as 57°C, and is the most common type of geothermal electricity plant being constructed today. The thermal efficiency of this type of plant is typically about 10–13%.

Figure 16 Top image displays the Nesjavellir geothermal power plant in Iceland. Bottom images (from left to right) of the conventional geothermal systems: Dry steam power plant; flash steam power plant; binary cycle power plant; and enhanced geothermal system (source U.S. Department of Energy (DOE))

The hot dry rock geothermal energy takes place in a ground- rock that is hot but dry, or where water pressure is inadequate, injected fluid can stimulate production. the water travels through fractures in the rock, capturing the rock's heat until forced out of a second borehole as very hot gas. The heat of the gas is converted into electricity using a steam turbine. All the hot gas change in cool water is injected back into the ground to heat up again in a closed circle.

Finally, the produced electricity of magma as the first product is the last exploration, we use the magma as we use the rocks at the dry hot rock plant but here, we know that the temperature is the highest of all the others and can produce the steam faster. The system is Binary-Cycle Power because the magma cannot be entered at the turbines

3.2.3 Hydroelectric parks

Hydroelectric parks generate energy from the kinetic energy of a liquid element, usually water, and convert it into electricity. Here we must mention the fact that hydroelectric units are usually built-in artificial dams or not, it could also be classified into units that we can control only the production and storage of electricity. When designing these projects, we can observe that the main advantage is the lifespan of 50 years and this gives us great depreciation of the cost, so there is a profit margin and financial benefit. The disadvantage of this park is the large elevation difference that it requires for the construction and this construction requires the existence of plateaus or rivers, but also the high investment cost.

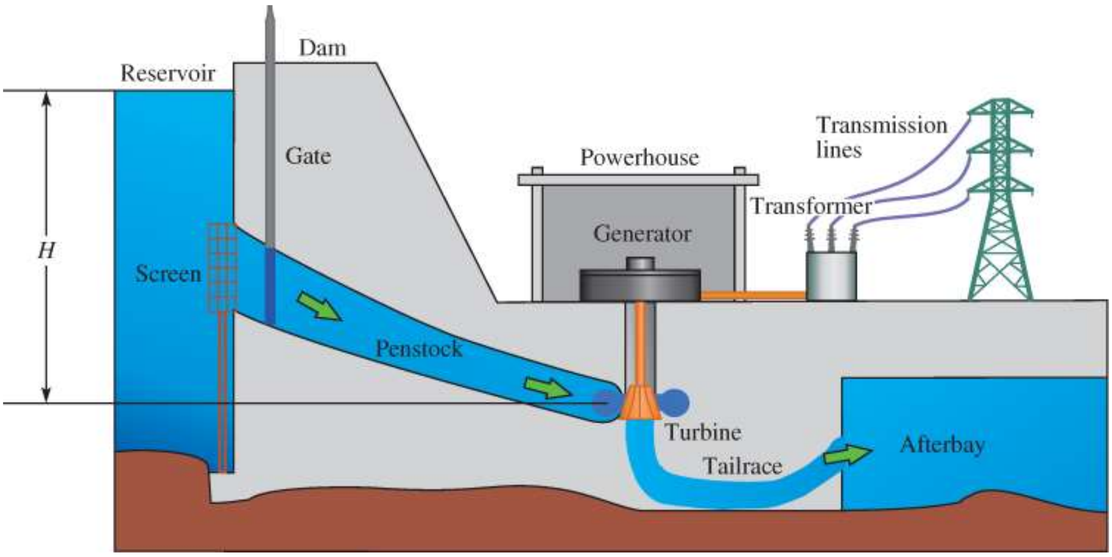

Figure 17 Here we can see a basic construction of a Hydroelectric Park (source Britannica)

Hydroelectric energy is produced by the kinetic energy offered by a liquid element, usually water and we convert it into electricity. Here we must mention whether the hydroelectric units that are built-in artificial dams or not, can be classified into units that we can have in control so that we can control the production to store electricity. In the design of these projects, we can observe the main advantage that the production time is 50 years, and this gives us a long cost amortization so there are margins of profit and economic benefit. The disadvantage of this energy is the large elevation difference that it requires for the construction and for this reason the construction requires the existence of plateaus or rivers, but also the high investment cost.

3.2.4 Tidal Parks

Tidal energy[23] is the movement of the water and is primarily caused by the gravitational pull between the earth, moon, and sun and the rotation of the earth. Wave energy is generated through a turbine of electricity, the main disadvantage being that the units stay obvious and unacceptable to the local population in most places.

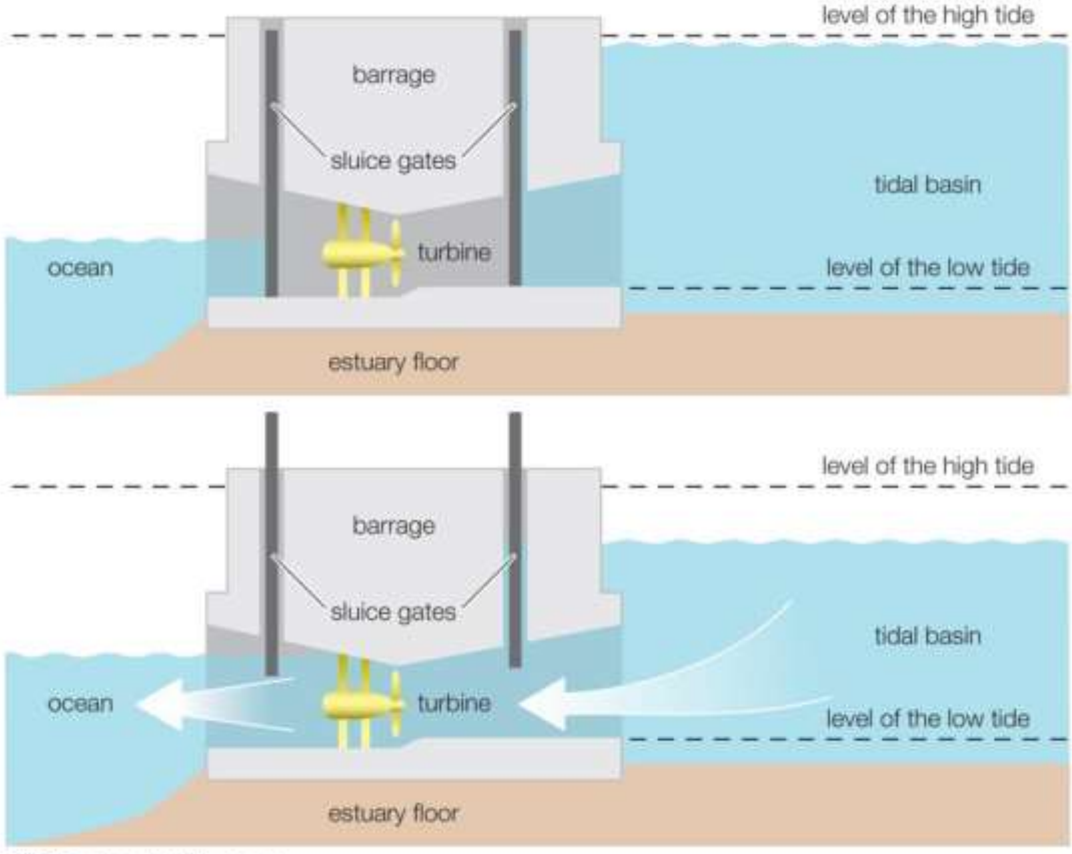

Figure 18 The production process of the Tidal Energy (source Britannica)

Below is the installation La Rance Tidal Power Station located at the mouth of the Rance River in Brittany France and opened on 26 November 1966. The station of La Rance has created some environmental facts (such as the rise of the water level in the lake), but it is worth mentioning that there are no particularly large environmental changes after 60 years of operation.

[23] Tidal Power concerning the properties of this power [Online]. Retrieved from: http://www.bluenergy.com/tidal_power.html

Figure 19 The La Rance Tidal Power Station (Retrieved from https://tethys.pnnl.gov/project-sites/la-rance-tidal-barrage)

3.2.5 Electricity generation by tidal current turbines

In this paragraph, we focus on the underwater wind farm with vertical axis generators, which following the technique of vertical axis wind turbines generate energy using the tidal energy of the waves. These generators have the basic characteristic that they are not visible over the sea, as well as that they do not cause problems to the animal organisms around them. Underwater parks, where all power generation systems are invisible, have been little activity in Europe[24] and experimentally in New York[25]. Although the design and construction of such projects have not been researched as well as other RES, the first project was carried out in Sudan on the Nile in 1982. Another EU-funded study is SEAFLOW[26], a project to study the conversion of a tidal wave into electricity. Tests have shown that at least 48TWH can be generated by installing a single unit; the unit was installed near Lynmouth in North Devon (UK).

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[24] The Clearwater project is research from the University of Edinburgh at the tidal turbine system [Online]. Retrieved from: https://simecatlantis.com/

[25]The project Roosevelt Island Tidal Energy (RITE) in which placed under the river three generators, in the city of New York [Online]. Retrieved from In New York's East River, a tidal power project takes shape (cnbc.com)

[26] The European study on Tidal Energy SAEFLOW [Online]. Retrieved from https://op.europa.eu/en/publication-detail/-/publication/36f20105-3d03-4324-8312-24405bdbd939

Figure 20 The three turbines of the RITE project (source CNBC)

Figure 21 River current turbine on the Nile, Sudan, 1982 (source CNBC)

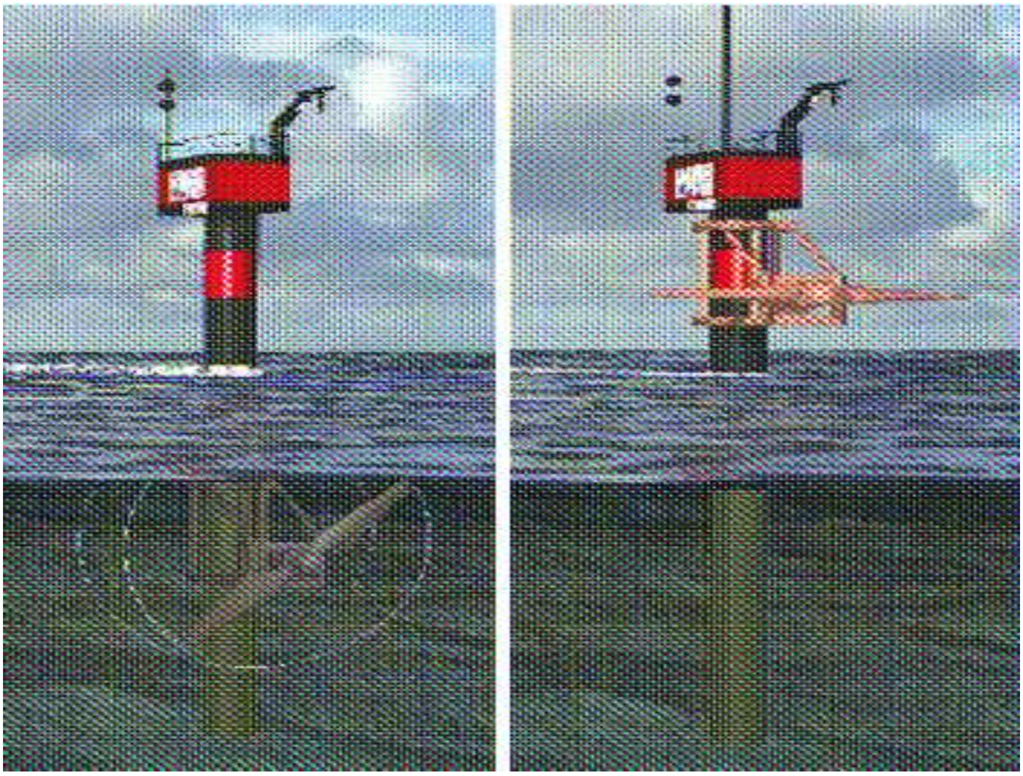

Figure 22 Tidal turbine of SEAFLOW project (source Publication office of EU)

Figure 23 Photomontage of the turbine prepared for the Environmental Statement. (Source Publication office of EU)

3.2.5.1 The advantage of the tidal turbine

Tidal currents offer reliable RES and have many important advantages over wind and solar. The tides as well as the power of the waves are almost one hundred percent predictable, and the endless flows create a very promising choice for the future. Tides are considered to be very long waves that move in the seas and oceans in response to the forces exerted on the earth by the moon and the sun. The tides originate from the oceans and proceed to the shores where they appear as the normal rise and fall of the sea surface. Flooding is the result of an incoming tide with water at the highest level and low tide when the water is at the lowest level of an outgoing tide[27]. Through the underwater turbines, we create conditions for efficient energy conversion; we also, do the minimal use of land without visual effect. Water is more than 800 times denser than moving air, so the speed of the water can be very low but efficient.

3.2.5.2 The results of the SEAFLOW[28]

The results of the project were the construction and operation of an experimental tidal turbine with a power of approximately 300 kW, the acquisition of a cost forecast for capital equipment, installation, operation, maintenance, and decommissioning of commercial seawater turbines. Assessing the impact on the environment and recording real-scale tests of an offshore turbine to determine the parameters that affect its performance. In addition, the total installation cost was just £ 900,000, or £ 3,000 / kW, no divers were used for underwater work, only a 5% reduction in efficiency from the development of underwater organisms, a maximum C_P rotor power factor of 0.4, and we can produce electric power 300 kW in current 2.7 m / s.

A standard way of measuring the performance of a horizontal axis rotor (as used for wind turbines) is to calculate the power coefficient, Cp. This is the ratio of the actual power produced to the kinetic energy of a stream tube the same diameter as the rotor:

$$C_p = \frac{P_{rotor}}{\frac{\pi}{8} p D^2 V_{hub}^3} \quad (1)$$

where p is the density of seawater, D is the rotor diameter, and V is the water velocity at the rotor centra line.

The mechanism was in continuous operation for a whole month, the point of choice should be reached without much cavitation, and finally the development of an accurate mathematical model for the turbine that predicts the output within 2% in steady-state conditions. All the above shows us some key elements to motivate us to take advantage of these energy sources. Also knowing that the rate of production is predictable, we can safely calculate the way of disposal or the most economical way of storage. It is also worth noting that the construction cost is high due to the machinery and for this and we will refer to the changes of other RES (solar panels and wind turbines)

3.2.6 Wind parks

Wind energy is one of cheapest and cleanest renewable energy technologies all other known ones. The potential energy created by wind power is plentiful and reduces greenhouse gas

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[27] The basic features of the tides and water levels [Online]. Retrieved from: https://oceanservice.noaa.gov/education/tutorial_tides/tides01_intro.html

[28] The final publishable report for the world's first pilot project for the exploitation of marine currents at a commercial scale SAEFLOW [Online]. Retrieved from https://op.europa.eu/en/publication-detail/-/publication/36f20105-3d03-4324-8312-24405bdbd939

emissions when it displaces fossil-fuel-derived electricity. Wind turbine technology has steadily improved. Designing a wind turbine system that can generate power with high efficiency requires a thorough understanding of the principles of aerodynamics and structural dynamics of the rotor system. Various wind turbine mechanisms are proposed and built for capturing and converting the kinetic energy of winds. In the area of wind energy, three basic types of wind turbines are commonly used today. There are the horizontal axial propeller and the vertical axial Darrieus and Savonius turbines, and there are many variants of each design as well, like several other similar devices under development. The propeller-type turbine is most used in large-scale applications constituting nearly all the turbines in the global market, while the vertical axis turbines are more commonly implemented in medium and small-scale installations. the simple analysis of these wind turbine designs shows that these designs are not perfect, and the wind force does not use at full scale due to many engineering reasons.[29]

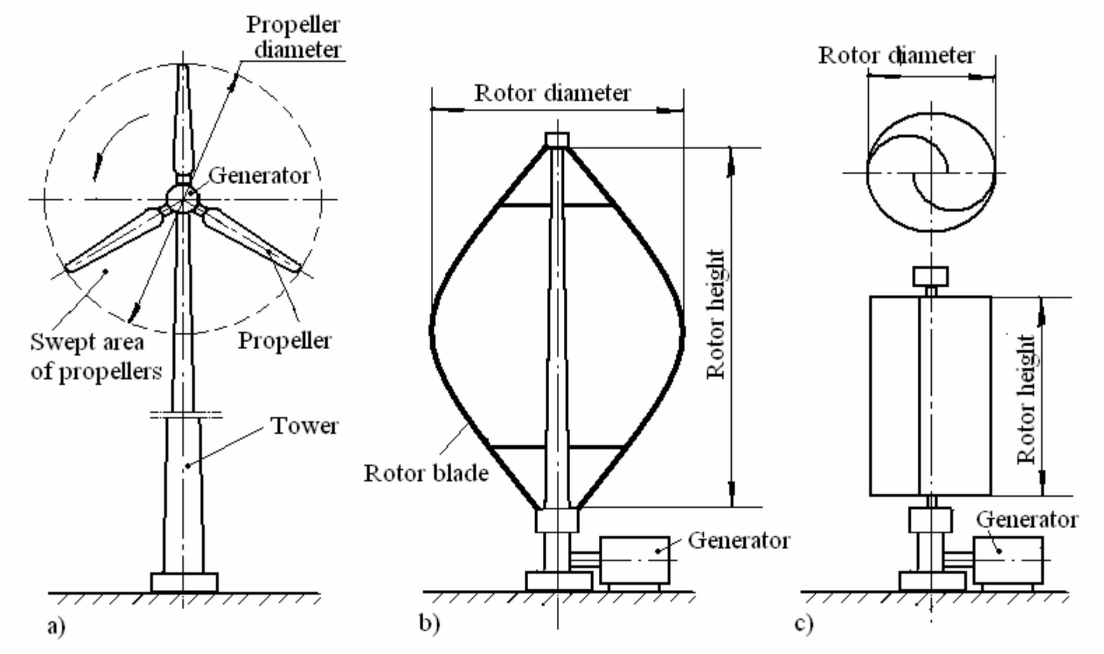

Figure 24 Wind turbine configurations: (a) propeller type; (b) Darrieus; (c) Savonius. (Source Britannica)

It should be noted that wind farms are divided into several categories based on the types of wind turbines, those that have a vertical axis, and those that have a horizontal axis, but in recent years, due to lack of space, have been added the offshore wind farms at seawater[30].

At this point we will refer to the calculation of electricity produced by a wind turbine, we will refer to its power curve, which is given the power ratio of the wind turbine depending on wind speed. The figure below shows two characteristic points: A, which shows the speed at which the generator begins to generate current, and point B, at which the wind speed for

[29] Spera D (1994). Wind Turbine Technology. *analysis in Wind Energy production methods*
[30] The first offshore wind farm conference [Online]. Retrieved from https://www.renewableenergyworld.com/baseload/optimism-in-offshore-wind-a-market-buzzing-with-activity/#gref

this wind turbine is considered prohibitive for the wings to continue rotating, to avoid the risk of its destruction. The power curve of each wind turbine is provided by the manufacturer and the estimate is usually based on empirical field measurements. For this reason, there are uncertainties regarding the measurement of speed and the amount of air entering the impeller. In general, the efficiency of a wind turbine is about 35% of its expected theoretical power.

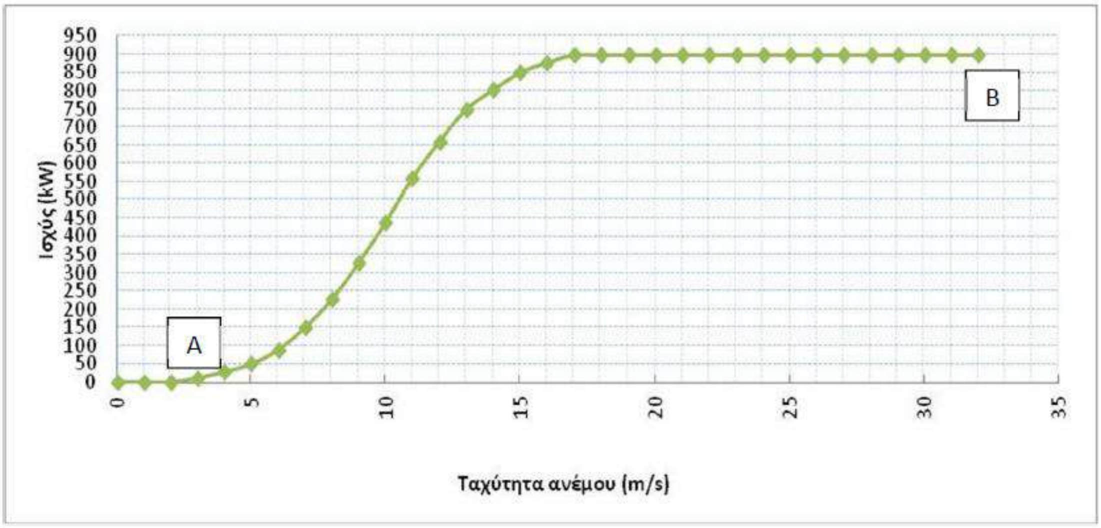

Figure 25 Power - wind speed curve of the wind turbine Enercon E44 - 900 kW (source DEI)

3.2.7 Offshore wind farms

Offshore wind energy is a new way of exploiting RES. Concerning onshore wind farms, the construction of these parks requires significant applicable engineering in terms of infrastructure, installation, electrical connection, and the use of materials resistant to the marine environment. The first experimental offshore units were commissioned at the first offshore wind farm near Vinbedy off the coast of Lolland[31]. This small wind farm consists of eleven wind turbines that are installed at a depth of 3-4 meters, and each has a power of 450KW.

[31] The history of European Wind Parks [Online]. Retrieved from https://windeurope.org/about-wind/history/

Figure 26 The world's first offshore wind farm in Vindeby of Denmark in 1991 (source Windeurope)

The basic parts of an offshore wind farm usually include (1) the meteorological station, (2) wind turbines, (3) collection cables, (4) the offshore power supply substation, (5) the offshore substation for conversion of alternating current (AC) into direct current (DC), (6) submarine power transmission cables and (7) the onshore substation.

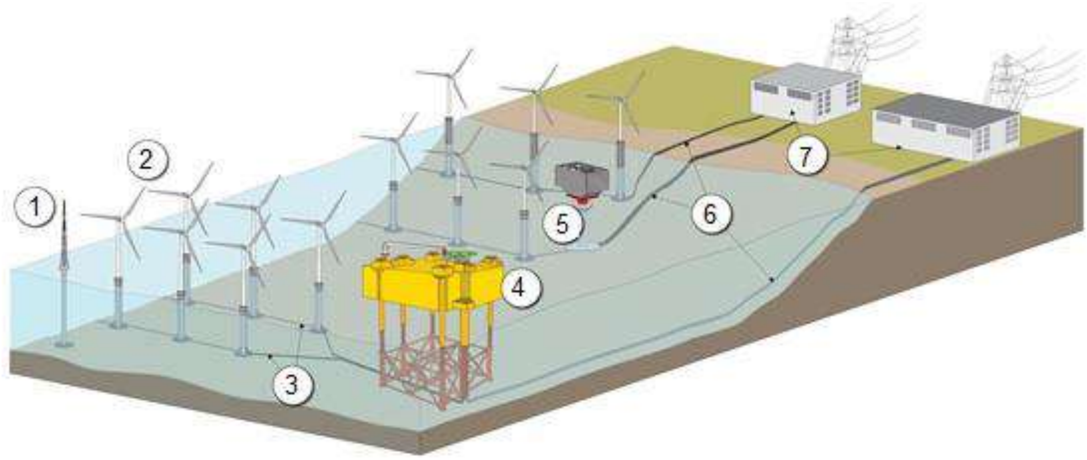

Figure 27 The basic parts of an offshore Wind Park

An important element of offshore wind farms is the support structures of A / G. The support structures are divided into bottom support structures and floating support structures depending on the depth at which the offshore wind farm is constructed. The most important bottom support structures are the monopile, the tripod, the gravity-based bearing, and the four-legged jacket.

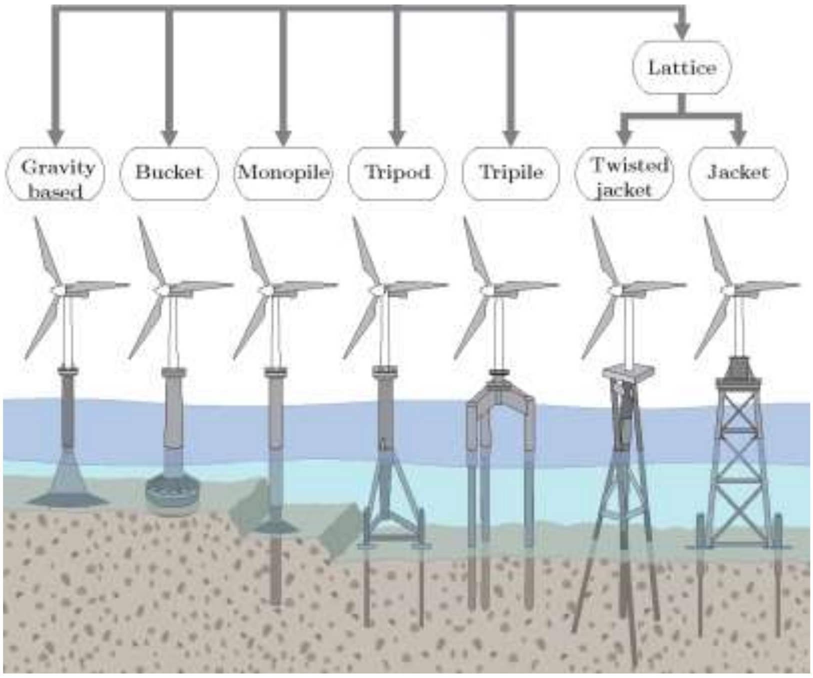

Figure 28 The types of bottom support structures for installation of a Wind Generator

The floating support structures are a solution for the location of offshore wind farms in deep water (> 70m). In essence, floating structures support A / Cs through cables that are connected to the seabed.

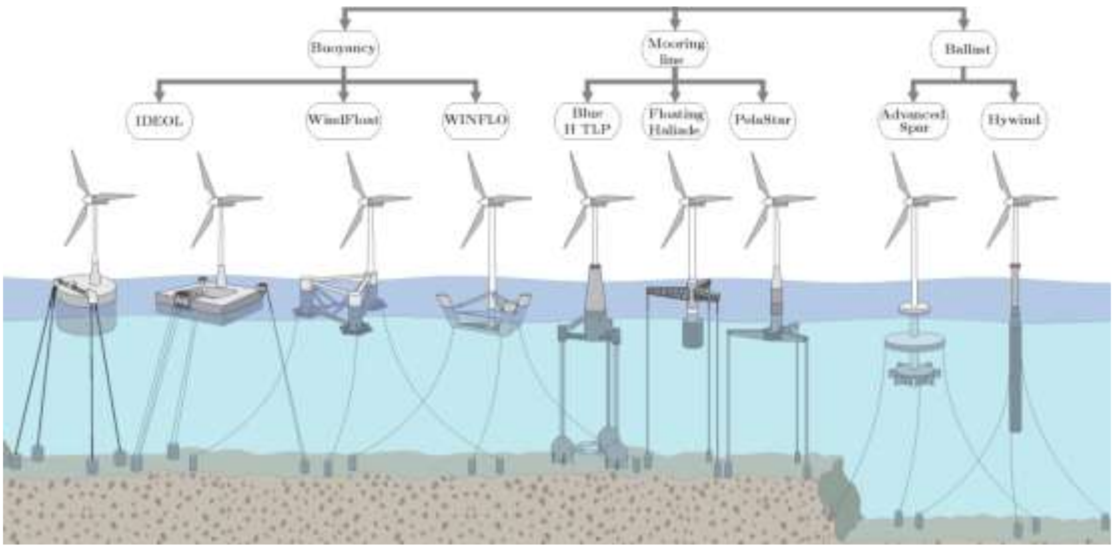

Figure 29 The types of floating support structures for installation of a Wind Generator

Today most manufacturers design wind turbines that can be used in all types of wind farms. One factor that helped was the introduction of new materials such as carbon and fiberglass. These materials allowed engineers to make more resistant and efficient turbine blades under all conditions.

3.2.7.1 Advantages

The advantages of offshore wind farms over land wind farms are the fact that is stronger winds at the sea and since the energy changes with the cube of the wind speed we have a higher efficiency of wind machines up to 30%.

3.2.7.2 Disadvantages

We must include the high cost of construction, the highest of the majority of RES and wind farms (about 50% more), the connection to the network must be made with the submarine cable which increases the cost, the shafts need better sealing, uses a closed system cooling, requires boats with special reinforcements for both severe weather conditions and repairs and finally requires lighting and observance of the rules of the sea.

3.3 The cost of RES

The RES is a mechanism that practically gives value to things we have ignored; wind energy was the first to be used on the islands for one basic need, food through windmills. In the last twenty years, the production from RES has increased more than three and a half times, and the production from 750GW increased to 2.800GW. It should be noted that the sharp drop in costs is due to the steady improvement of technologies, competitive supply chains, economies of scale, and improving the developer experience.

The continuing cost reduction confirms the need for renewable energy sources as a low-cost solution to climate change and carbon offsets, aligning short-term economic needs with medium- and long-term sustainable development goals. From the following tables, we see the change in performance and cost within a few years and how much they have changed because materials (air, sun, water) with no cost can produce.

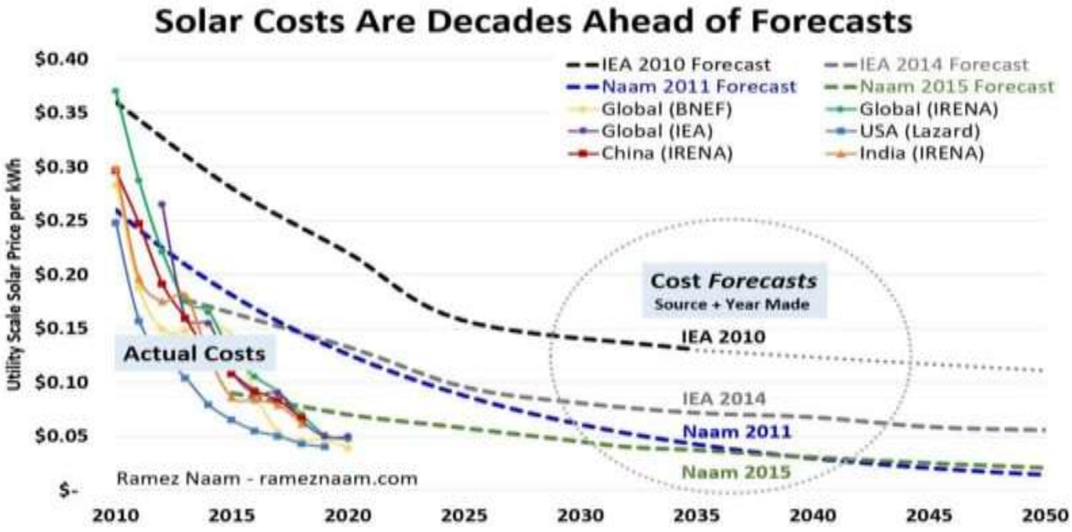

Figure 30 The decrease in the cost of a solar park (source IRENA)

In the diagram, we see how efficient and in-depth research has been done and also how efficient has become. All of this was the impetus for research into solar parks, even though solar energy remained unused due to cost in just ten years.

In 2020 the year of COVID-19, the RES has been improved although the global pandemic, the cost of both solar and wind energy has been continuing reduction. In 2020, the global weighted average flattened cost of electricity (LCOE) from new inland wind capacity additions decreased by 13%, compared to 2019. During the same period, the LCOE of offshore wind energy decreased by 9%, and that of shared use scaling of solar photovoltaics (PV) by 7%.

Figure 31 Global weighted-average LCOE from newly commissioned, utility-scale solar and wind power technologies, 2019-2020 (source IRENA)

The electricity cost from solar and wind energy has fallen to very low levels. Since 2010, a total of 644 GW of renewable energy capacity has been added worldwide at an estimated cost lower than the cheapest choice of fossil fuels each year. In emerging economies, the 500 GW added at a lower cost than fossil fuels will cut electricity production costs by up to $ 30 billion.

For onshore wind projects, the global weighted average cost of electricity between 2010 and 2020 fell by 56%. Compared to solar PV, where electricity cost declines are mainly driven by falling total installed costs, onshore wind cost reductions were driven more evenly by both falls in turbine prices and balance of plant costs, and higher capacity factors from today's state-of-the-art turbines. the cost of electricity from solar photovoltaics between 2010 and 2020 decreased by 85%.

For offshore wind energy, the global weighted average LCOE of new projects fell by 48% in just 10 years. This has increased the outlook for offshore wind energy, which is about one-twentieth of onshore wind energy.

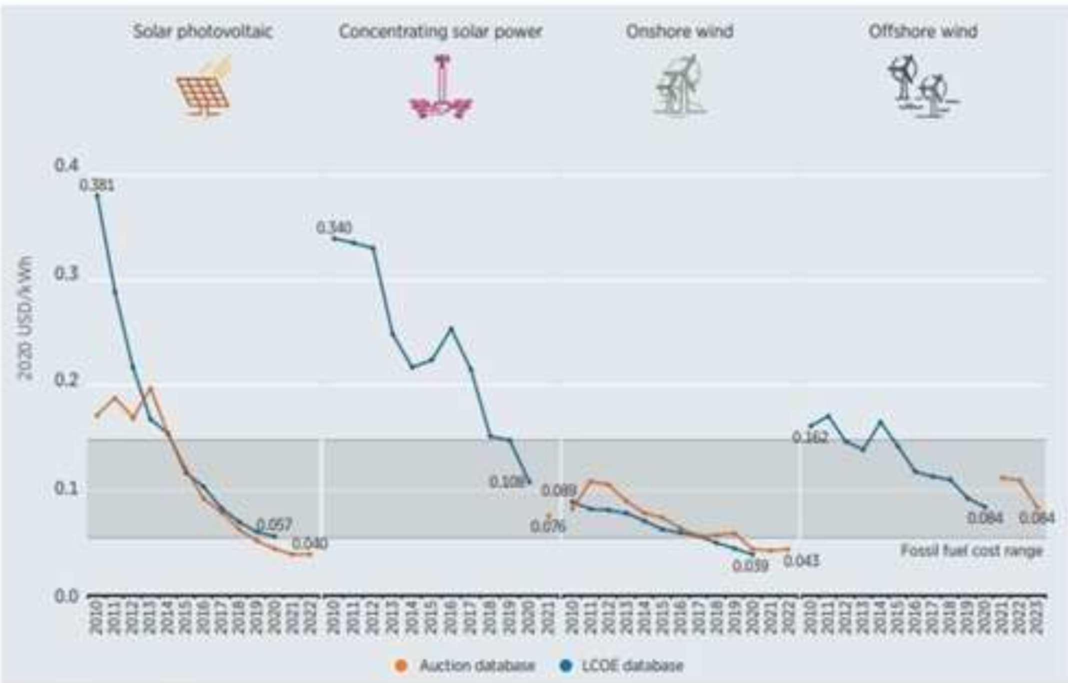

Figure 32 The global weighted-average LCOE and PPA/auction prices for solar PV, onshore wind, offshore wind, and CSP, 2010-2023 (source IRENA)

Finally, between 2010 and 2020, 60 GW of new bioenergy for power capacity was added. The global weighted-average LCOE of bioenergy for power projects experienced a certain degree of volatility during this period but ended the decade at around the same level it began. For the same period, hydropower added 715 GW, while the global weighted-average LCOE rose by 18%. This was still lower than the cheapest new fossil fuel-fired electricity option, even though the cost increased by 16% in 2020, year-on-year.

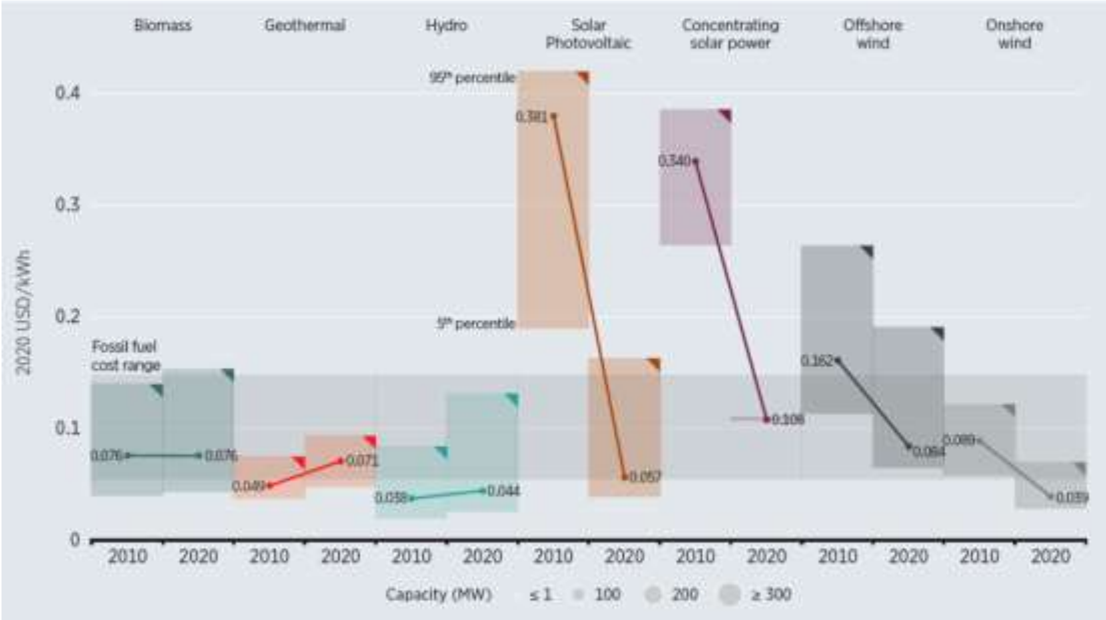

Figure 33 Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020 (source IRENA)

The advantages of using RES are the creation of energy independence and security of energy supply at a national level. The decentralization of the energy system, due to the geographical dispersion of production units, results in the possibility of coverage of energy needs at a local and regional level and the consequent relief of infrastructure systems and the reduction of losses from energy transmission. On the positive side, we must include the low operating costs that are not affected by fluctuations in the international economy and in particular the prices of conventional fuels. Finally, the contribute to the revitalization of economically and socially disadvantaged areas by creating jobs and attracting appropriate investments. All of this makes RES research more efficient and improves performance.

4 Hydrogen

Hydrogen[32] is the first element of the periodic table with special peculiarities and characteristics. It is a chemical element consisting of only one proton and one electron, under normal conditions it is a colorless, odorless, tasteless, flammable gaseous substance. Although hydrogen is one of nature's most abundant elements, it can only be found in combination with other elements. One of the most well-known advantages of this material is the fact that when we combine hydrogen and air (pure oxygen) we produce only pure water and energy without any waste. Hydrogen is also the lightest element in the table, which makes it the easiest to use but also the chemical element with a high percentage of efficiency based on its weight. The disadvantage that will occupy us in our study of hydrogen is also important because in natural conditions it belongs to the gases, and this makes its storage very difficult. The right way of using it can determine a lot of data, the fact that it has been chosen as the main fuel in the spacecraft shows the advantages that it can provide us with its proper utilization. The use of green hydrogen allows us to increase the production of renewable energy sources using it as a storage material.

In the global economy, the aim is to reduce CO2 emissions released by limited fossil fuels. Hydrogen technology and fuel cells are probably the solutions. The advantages of hydrogen as an energy carrier over other environmentally friendly solutions are its versatility in consumption, storage capacity and the ability to be produced from different primary sources. In these options hydrogen will act as an energy carrier, to ensure a continuous supply of energy.

Today, hydrogen is found in a wide range of industrial applications, including its use as a raw material to produce chemicals, the production of electronics, the processing of steel, and the desulphurization and remodeling of gasoline in refineries[33]. In addition, it is used in NASA's space program as fuel for space shuttles and in fuel cells to generate heat and electricity. Fuel cells composed of hydrogen-powered membranes are considered to be the best type of fuel cell that could be used as an energy source in vehicles and has the potential to replace gasoline and diesel in internal combustion engines. According to the United States National Hydrogen Program, the contribution of hydrogen to the overall energy market is expected to be 8-10% by 2025[34].

Hydrogen, in addition to being a very useful reagent for the production of many chemicals, is also the cleanest and most environmentally friendly fuel, which when burned produces water instead of greenhouse gases and has a high energy efficiency of 122 kJ. / g, which is 2.75 times higher than that of hydrocarbon fuels[35]. Hydrogen is a high-quality secondary energy carrier and should not be considered a primary energy source. Hydrogen has the highest energy efficiency per unit weight of all fuels. Specifically, 1 kg of hydrogen contains the same amount of energy as 2.1 kg of natural gas or 2.8 kg of gasoline (120.7 kJ / kg). However, today hydrogen plays an important role in the global energy economy, but to date, this role is limited to the chemical industry (chemical composition, glass industry, food industry, etc.) and is rarely used as a fuel, and this is because there is no infrastructure for its widespread use.

The production of hydrogen is a complex process and requires installations with many components, most of which are at a high level of technique. The basic methods of hydrogen production today are

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[32] The basic data for Hydrogen [Online]. Retrieved from: https://www.ciaaw.org/hydrogen.htm

[33] LUQUE, R., et.al, Handbook of biofuels production, processes and technologies [Online]. Retrieved from https://books.google.gr/books?hl=el&lr=&id=snZwAgAAQBAJ&oi=fnd&pg=PP1&dq=Biofuels+from+chemical+and+biochemical+conversion+processes+and+technologies:+Biological+and+fermentative+production+of+hydrogen&ots=PGHEs0i-GW&sig=QN0suN10wCPxpjXDw-FRXEEItR8&redir_esc=y#v=onepage&q&f=false

[34] THE U.S.A. environmental Protection Agency [Online]. Retrieved from: http://www.epa.gov/agstar/index.html

[35] BOUTETAKHS, S., et al “Existing technologies and end uses of the "fuel of the future” analyzes the possible choices of green Hydrogen

Carbon gasification – biomass, Gas anamorphosis, Electrolysis of water, Thermochemical process, Photo electrolysis, Bio photolysis and photosynthesis, and Cracking of natural gas, heavy oil, or biomass fuels

From the above production methods gasification, anamorphosis and electrolysis are already developed today and may be further improved in the future. Electrolysis can be performed using nuclear and RES electricity as the primary energy source. Research on the other methods must be continued as they are in the very early stages of mass production.

Our research will focus on the produced clean gas of Hydrogen from RES. Electrolysis is the process that splits water into oxygen and hydrogen. When electricity is used in this process produced by RES, then hydrogen belongs to the green gases. The energy sources that can work together to meet all the needs of energy consumers, without the use of coal combustion, are electricity and hydrogen. Hydrogen produced from renewable energy sources (RES) is, according to environmentalists, the ideal fuel, as there is no environmental cost in the production and use of hydrogen, when wind or solar energy is used, as the only release of pollutants is during construction. The transfer and installation of technologies for the conversion of wind (wind turbines) or solar (PV) energy and possibly energy for the transport of hydrogen. The production and use of hydrogen from RES, in a renewable hydrogen economy, would lead to a significant reduction in the cost of carbon dioxide. This is especially important for emerging economies such as China or India, which do not have hydrocarbon reserves. In terms of the sectors in which each of these energy carriers will dominate, it is expected that electricity will retain the fields in which it has already been applied, namely lighting, information technology, and telecommunications, while hydrogen will be used in the areas of liquid fuel applications (transport, heating, etc.).

4.1 Electrolysis

Each chemical compound can be separated into its basic chemical elements by some technique. Clean chemical water has only two elements hydrogen and oxygen, which through electrolysis will be separated into separate atoms. The chemical reaction can be done in any direction when all the conditions let, if the reaction produces energy, then it will be done with the coexistence of the elements in the same space, otherwise must be created under the necessary conditions. The chemical separation of water is required energy to take place, so we will use electricity and the elements will separate.

The chemical reaction is $2\ H_2O_{(liq)} \rightarrow O_{2(g)} + 2H_{2(g)}$ as we can see at the illustration

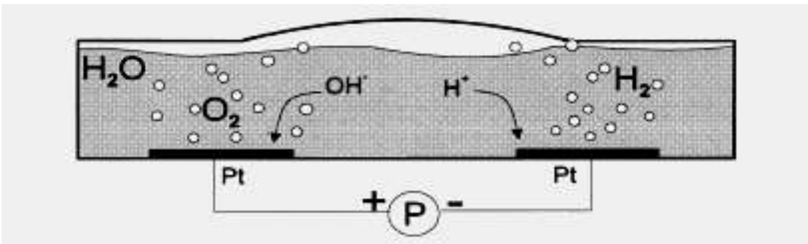

Figure 34 The separation of water through the electrolysis (author picture)

Oxygen and hydrogen generated at the opposite electrodes:

+ Electrode anode: $4OH^- \leftrightarrow 2\ H_2O + \mathbf{O_{2\,(g)}} + 4e^-$

- Electrode cathode: $2H^+_{(aq)} + 2e^- \leftrightarrow \mathbf{H_{2\,(g)}}$

In case of natural water, the reactions are slightly different. In water electrolysis we need for use at the reactions some more of electrons, which will not undesired byproducts, therefore the net balance is $2\ H_2O \rightarrow (4e^-) \rightarrow O_2 + 2H_2$

The minimum necessary cell voltage for the start-up of electrolysis E^0_{cell} is given under standard conditions by the following equation (2):

$$E^0_{cell} = \frac{-\Delta G^0}{nF} \quad (2)$$

Where ΔG^0 is the change in the free energy under standard conditions and n is the number of electrons transferred. In the case of a closed electrochemical cell, the conditions slightly change from standard conditions, open cell (P, T) = constant to closed cell (V, T) = constant because the change in the cell volume is smaller compared to that of pressure. Therefore, instead of ΔG^0, ΔA^0 free energy is used.

The necessary voltage for an electron to overcome the Helmholtz energy barrier is given below:

$$E^0_{cell} = \frac{-\Delta A^0}{nF} \quad (3)$$

$$\Delta A^o = \Delta H^o - TR\Delta n - T\Delta S^o \quad (4)$$

For the electrolysis of water, at the standard reaction, ΔH^o = 285.8 (kJ/mol), Δn =1.5, $\Delta S^o(H_2)$ =130.6, $\Delta S^o(O_2)$ = 205.1, $\Delta S^o(H_2O)$ (l) = 70 J/mol K, ΔS^o_{tot} = 130.6 + ½ 205.1 . 70 = 163.14 J/mol K, and ΔA^o =233.1 (kJ/mol). So, the minimum necessary cell voltage is E^o_{cell} =1.21V. In the case of an open cell, $E^o_{cell} = -\Delta G^o/nF$ = 1.23 V, with $\Delta G^o = \Delta H^o - T\Delta S^o$ = 237.2 kJ/mol (standard conditions, 1 bar, 25 °C).
In order for a reaction to get started, it is necessary to overcome an extra energy barrier, the activation energy E_{act}. The number of molecules able to overcome this barrier is the controlling agent of the reaction rate, r, and it is given by the statistical Maxwell - Boltzman relation which has an exponential behaviour: $r \sim r_o \exp(-E_{act}/RT)$. So, the activation energy expresses the speed with which a reaction takes place.
The maximum possible efficiency of an ideal closed electrochemical cell is defined by the following equation:

$$\varepsilon_{max} = \frac{\Delta H}{\Delta A} = -\frac{\Delta H}{nFE_{cell}} \quad (5)$$

The efficiency of an electrochemical cell in reality is given by:

$$\varepsilon_{real} = -\frac{\Delta H}{nE_{elec}} \quad (6)$$

Where ΔE_{elec} is the voltage to drive the electrochemical cell at I:

$\Delta E_{elec} = \Delta A + IR + \Sigma\eta$ (7)

Where R is the total ohmic series resistance in the cell including external circuit resistance, electrolyte, electrodes, membrane material. $\Sigma\eta$ is the sum of the overpotentials (activation overpotential at the two electrodes, and the concentration overpotential due to the mass transport of the gaseous products away from the anode and cathode surfaces). The balance energy, per mole, during water electrolysis is shown in figure below. The activation overpotential increases by increasing the current density and can be lowered by using electrodes which have a catalytic action, such as platinum.

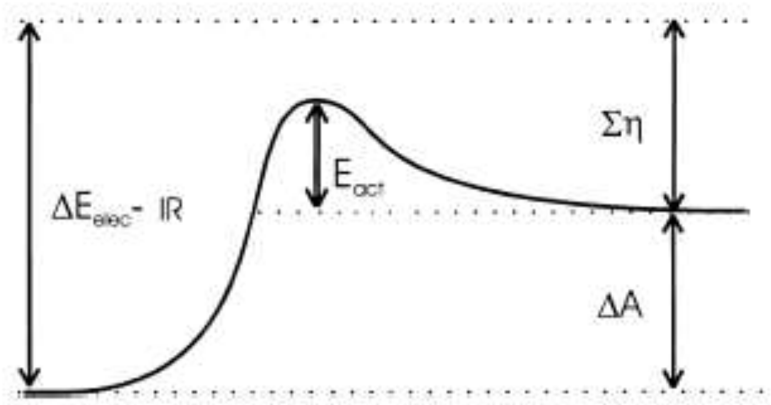

Figure 35 The graphic of the energies which involved in the reaction

Ideally 1.23 Volts of applied voltage are sufficient to carry out the electrolysis. Practically more voltage is required from 1.55 to 1.65 Volts. The electrolysis efficiency is defined as the ratio of 1.23 Volts to the voltage used. The cathode reaction therefore involves four electrons and the oxidation takes place through a series of intermediates. This is due to the need for additional voltage as the whole process is characterized by a slow kinetic mechanism. The use of a catalyst helps to reduce this voltage and speeds up the process. An ideal catalyst for water oxidation should balance the required energy of each intermediate step as well as the transfer rates of each electron. Water electrolytes are usually highly efficient with the best commercially available examples approaching an efficiency of 90%.

4.2 Types of electrolytic units

The three main types of electrolytic units[36] are Alkaline Electrolytic Units, Electrolytic Cells, in which polymeric proton conductivity membrane (PEM) is used as the electrolyte, and Solid Oxide Electrolytic Units, in which solid ceramic is used as the electrolyte.

4.2.1 Alkaline electrolytic

[36] MILLET, P., et al (2010) PEM water electrolyzers: From electrocatalysis to stack development *an analysis of water electrolysis* [Online]. Retrieved from: PEM water electrolyzers: From electrocatalysis to stack development - ScienceDirect

Alkaline electrolysis is the most mature electrolysis technology, as it has been used since the 1920s to produce hydrogen used in the fertilizer industry. Installation costs are relatively low due to the avoidance of using valuable materials. The electrolyte in these systems is usually a liquid solution of caustic natrium (NaOH) or caustic potassium (KOH). The produced hydroxyl anions (OH-) move from the cathode to the anode, while hydrogen is formed at the cathode.

Operates according follow the nature and circulation of an electrolytic solution. A basic key feature is an operation at relatively low current densities, but also the high conversion efficiency ranges from 60-90%. Without auxiliary cleaning equipment, the purity of the gases is usually 99.8% for hydrogen and 99.2% for oxygen respectively. A modern alkaline electrolyze has an efficiency of 90% (consuming 4KWh of electricity per cubic meter of hydrogen produced in NTP) and will give the gas up to 30 bar without auxiliary compression, and we can also use economical catalysts. However, a significant energy consumption exists after electrolysis to compress the gases, for their proper storage and this is something basic for the producers

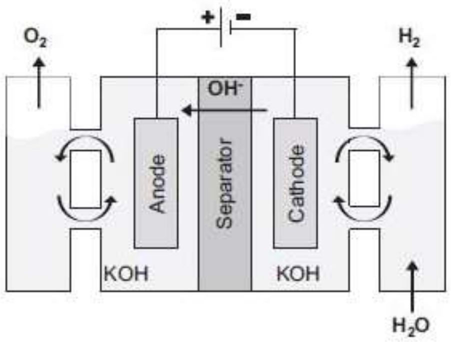

Figure 36 The separation of water with alkaline electrolyte (author picture)

4.2.2 Polymer Electrolyte Membrane

Polymer Electrolyte Membrane (PEM) fuel cells, Figure 6, operate on the principle of an electrochemical reaction between hydrogen and oxygen with the aid of a catalyst (platinum). Hydrogen fuel is channeled through field flow plates to the anode on one side of the fuel cell while oxygen from the air is channeled to the cathode on the other side of the cell. At the anode a platinum catalyst causes the hydrogen to split into positive hydrogen ions (protons) and negatively charged electrons. At the cathode, the electrons and positively charged hydrogen ions combine with oxygen to form water. The PEM fuel cell can produce high current densities, has fast start-up and shut down times and its operating temperature can be between 60°C and 80°C.

Such systems were developed in the 1960s to overcome some of the problems posed by alkaline electrolysis systems. In contrast, PEM systems use pure water instead of electrolyte solution, thus avoiding the need to recover and recycle the sodium or potassium hydroxide necessary in alkaline electrolysis systems. Also, PEM systems are smaller in volume and thus more suitable for installation in densely populated areas. On the other hand, they have a shorter lifespan and are more expensive than alkaline electrolysis systems, mainly due to the expensive catalysts on the electrodes (palladium, iridium) and membranes. The main difference is that the electrolyte in PEM systems is not a liquid solution but a special polymer plastic sheet. Water reacts with the anode to form oxygen, positively charged hydrogen ions (protons) and electrons. Electrons flow through an external circuit, while hydrogen ions selectively penetrate the electrolytic membrane ending in the cathode, where they combine with electrons from the external circuit to form hydrogen in a gas.

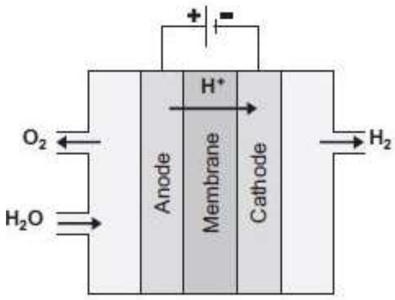

Figure 37 The separation of water with Polymer Electrolyte Membranes (author picture)

4.2.3 Solid Oxide Electrolysis (SOEC)

SOEC is the least mature technology and has not yet been marketed. In these systems the electrolyte is a solid ceramic material, at high temperatures (800-1000 degrees C) selectively transports negatively charged oxygen ions. The water in the cathode combines with electrons from an external circuit to produce hydrogen gas and negatively charged oxygen ions. The latter passes through a solid ceramic membrane and ends up in the anode, where they are converted to oxygen gas and electrons for the outer circuit. The biggest challenge for the evolution of SOEC systems is the high rate of wear of the materials leading to low service life, due to the very high temperatures required for this process.

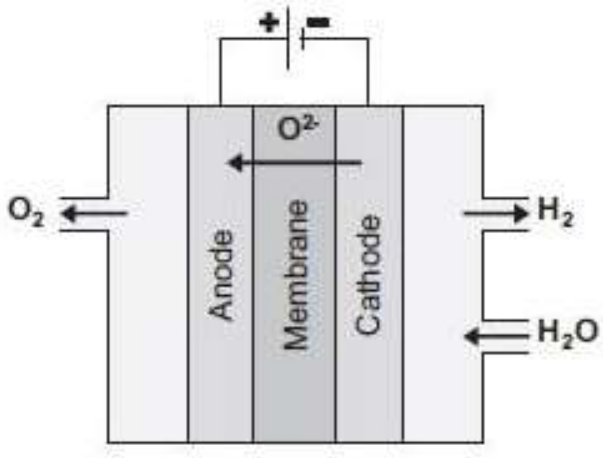

Figure 38 The separation of water with SOEC (author picture)

4.3 The prospects of Hydrogen

For many years we have focused on the production of ecological and friendly energy products. Electricity could be one of them; most countries have built wind or solar parks to generate green electricity. The main problem of these parks is the storage and hydrogen can give a solution. Wind turbines or solar panels generate direct current, this current can then be used in an electrolysis device to produce hydrogen, and eventually, it can be used in a series of fuel cells to generate electricity again. The biggest advantage is that the consumer thus has electricity in all conditions. The second is a system completely free of fossil fuels and pollutants. Third, the losses of AC production, distribution, and conversion no longer exist or are very small. Finally, the waste from the conversion of pure hydrogen to electricity is water, which can also be recycled in many ways. Remote areas that previously did not have access to the electricity distribution network now can be supplied with electricity by applying similar systems. Remote islands, transport antennas, and lighthouses are among the most representative examples of such cases.

Some properties that we should also mention are that the production of hydrogen from renewable energy sources, especially when there is excessive production of energy from renewable sources, gives us the advantage to use all the products whenever and wherever it is produced. Hydrogen can serve as a long-term storage way, capable of storing energy for several months. Long-term storage options can help countries with significant seasonal differences between energy demand and production incorporate more renewable power into the grid. Countries near the poles have many hours of sunshine for six months and about six months no. Hydrogen has a higher energy density per weight than batteries, allowing hydrogen-powered vehicles to travel long distances and is also an effective solution for heavier battery-powered vehicles. This choice is important for many islands, where the cost of fuel transportation is very high. Hydrogen can also be transported through the existing gas network, is needed investment to adapt the gas infrastructure to a hydrogen transmission network, yet it makes more choices to increase the materials we can sell and transfer.

At this point, we will focus on the basic features of using hydrogen as a way of storage. In the transfer of electricity (transporting hydrogen), only 51% can reach the end user, if produced by electrolysis due to efficiency losses and the need for compression. Usual electricity storage technologies allow between 75% and 85% of the original electricity to be delivered[37]. However, Schoenung SM[38] compared energy storage technologies. batteries, compressed air (CAES), pumped hydroelectric, superconducting magnetic (SMES) and supercapacitors with production and storage of hydrogen electricity. Cost, efficiency, quality, UPS, transmission, distribution, spin, load management and load smoothing capabilities were examined. Conclusion Hydrogen compares well with other energy storage technologies in some specialized applications:

- Hydrogen fuel cells or combustion engines are suitable for distributed generation.
- With life cycle cost as the main criterion, for long-term applications, fuel cell technology competes with battery systems.
- Reversible fuel cells make sense for long-lasting discharges (over 4 hours).
- Large hydrogen systems compete with CAES for cost-effective cargo management.

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[37] HAMMERSCHLAG, R., Questioning Hydrogen (2005) an article on hydrogen yield [Online]. Retrieved from: https://www.researchgate.net/publication/222076926_Questioning_hydrogen

[38] HASSENZAHL, W. & SCHOENUNG, S. Long-vs. Short-Term Energy Storage Technologies Analysis A Life-Cycle Cost Study A Study for the DOE Energy Storage Systems Program *this report compare the storage systems* [Online]. Retrieved from: https://www.researchgate.net/publication/268441140_Long-vs_Short-Term_Energy_Storage_Technologies_Analysis_A_Life-Cycle_Cost_Study_A_Study_for_the_DOE_Energy_Storage_Systems_Program

- Hydrogen fuel cells can be used in high quality power applications.

4.4 Electricity from Hydrogen

Fuel cells are electrochemical devices that convert the chemical energy of a fuel directly into electrical energy[39]. Because intermediate heat generation stages and engineering work are avoided, the efficiency of the fuel cells is not limited by the efficiency of the Carnot thermodynamic cycle as well as by higher efficiencies, reduced pollutants and reduced fuel costs.

The basic components of a fuel cell are the electrolyte, which can allow ions to pass through electrodes (anode and cathode) made of porous conductive materials to diffuse fuel (hydrogen), the oxidizing substance and electron conduction.

The electrolyte is to facilitate the electrochemical reaction, to allow ions, either positive or negative, depending on the type of cell to penetrate it, to facilitate the transport of reactants to and from the electrodes and at the same time to be a natural barrier. which prevents the fuel from mixing directly with the oxidizing substance.

The electrodes are to provide the surface on which the electrochemical reaction takes place, provide an electrical connection to the charge, distribute the reacting substances evenly, and direct the reaction products to the output of the fuel cell. For the above reasons, they are made of porous conductive materials[40].

Fuel cells can be compared to a battery, which can be recharged when we consume power from it. As a result, Fuel cells can be used to power different electrical applications. In the image below we see Fuel cells of polymer electrolytic membrane (PEM).

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[39] Electrolytic Cells An article on the possible choices of an electrolytic cell [Online]. Retrieved from: https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Electrolytic_Cells

[40] RAMLI, M., et al (2010) Economic analysis of PV/diesel hybrid system with flywheel energy storage *was analyzed the performance of a hybrid photovoltaic / diesel system with battery storage* [Online]. Available at: http://www.ruralelec.org/PV-Diesel

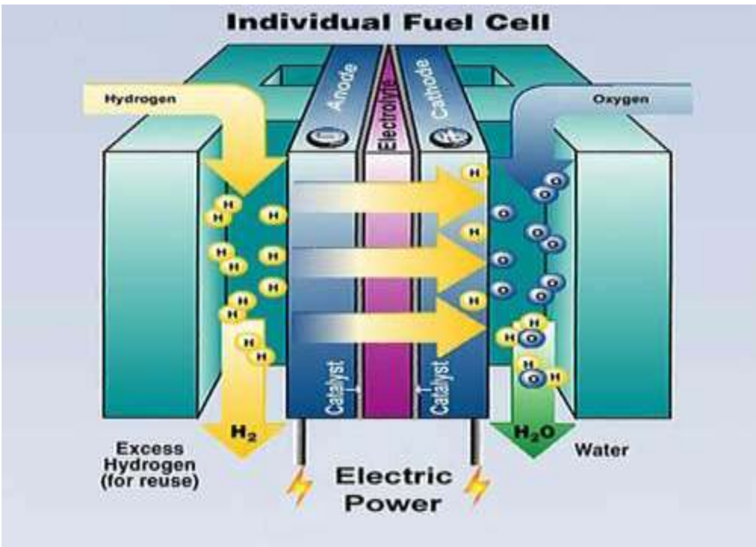


Figure 39 The basic layout of a fuel cell (source Kettering University)

A fuel cell produces only a small amount of voltage, about 0.7 V. To increase the voltage to a more realistic level, several separate fuel cells must be stacked in one, as in the figure below.

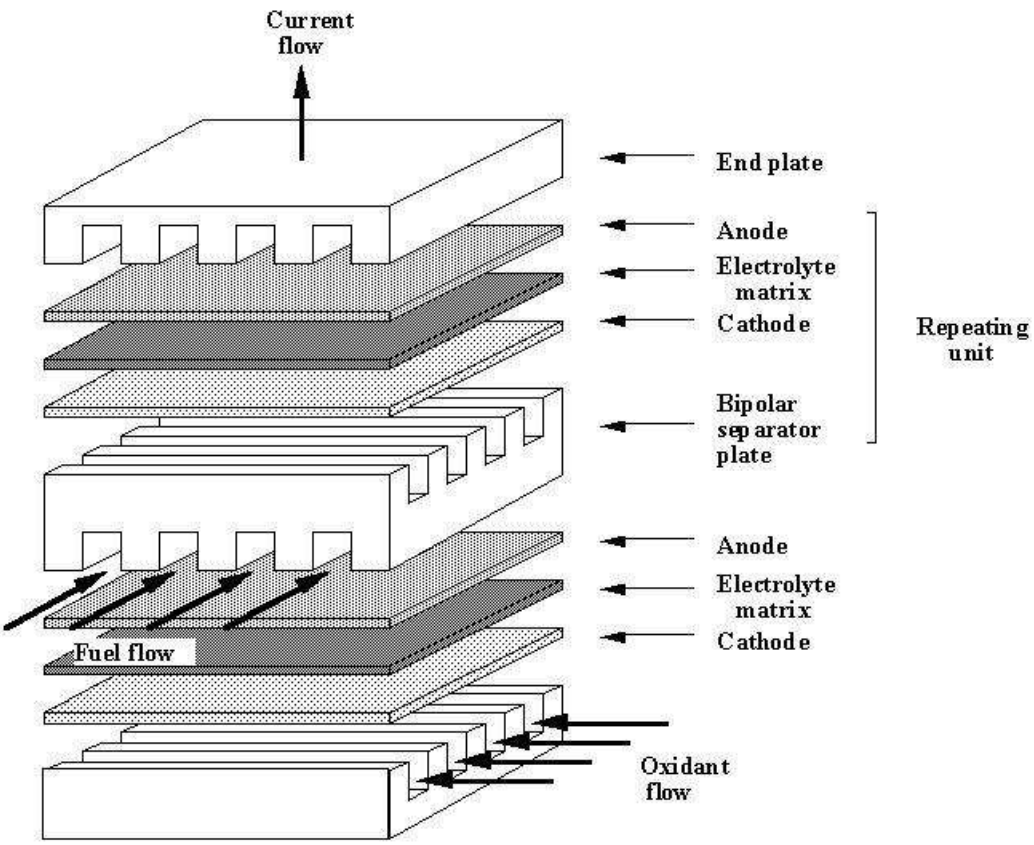


Figure 40 Stack of fuel cell (source http://orgs.kettering.edu/altfuel/fcback.htm)

Generally, when we create a stack of fuel cells, then the output voltage we get is usually in the range of 20-50V and so a DC-DC converter is required to raise the voltage to a level, where then with the help of a converter of DC-AC it will give us alternating voltage 50 Hz, 240V AC.

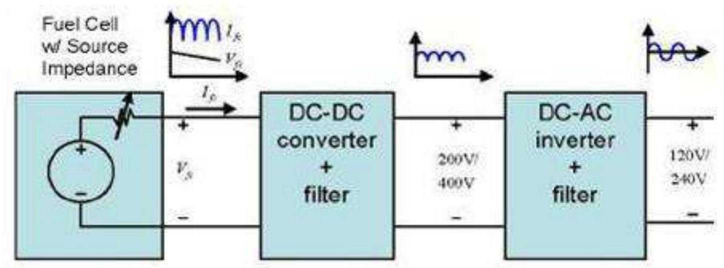
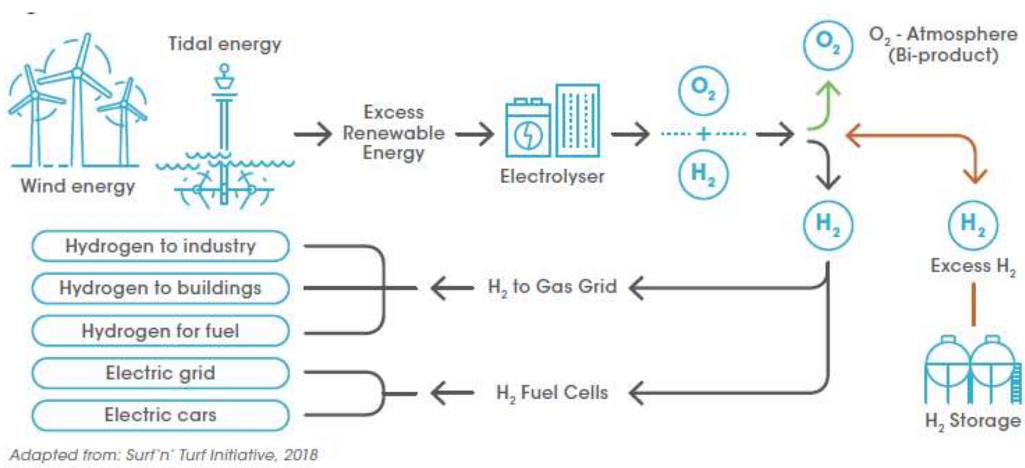


Figure 41 Fuel cell system block (source Wikipedia)

4.5 Green Hydrogen in use

The research has focus on the green Hydrogen with the target of better use of a cheap material. Two examples can show our choices, in the figure below we can see the plan for the use of hydrogen and renewable energy sources on the island of Orkney[41] in the United Kingdom. There we can see all the possible options without CO_2 production.



[41] The ORKNEY Islands use an entire green energy system and are close to being released from oil [Online]. Retrieved from: https://www.orkney.com/news/responsible-island

Finally, we must understand that electrolysis gives as an option not only storage the energy but also to the sale the energy from res with other type of product. The image below makes clear to everyone that we can do it whenever we see fit. The choice of underground hydrogen storage makes the cost of maintaining the temperature much lower and more economical[42].

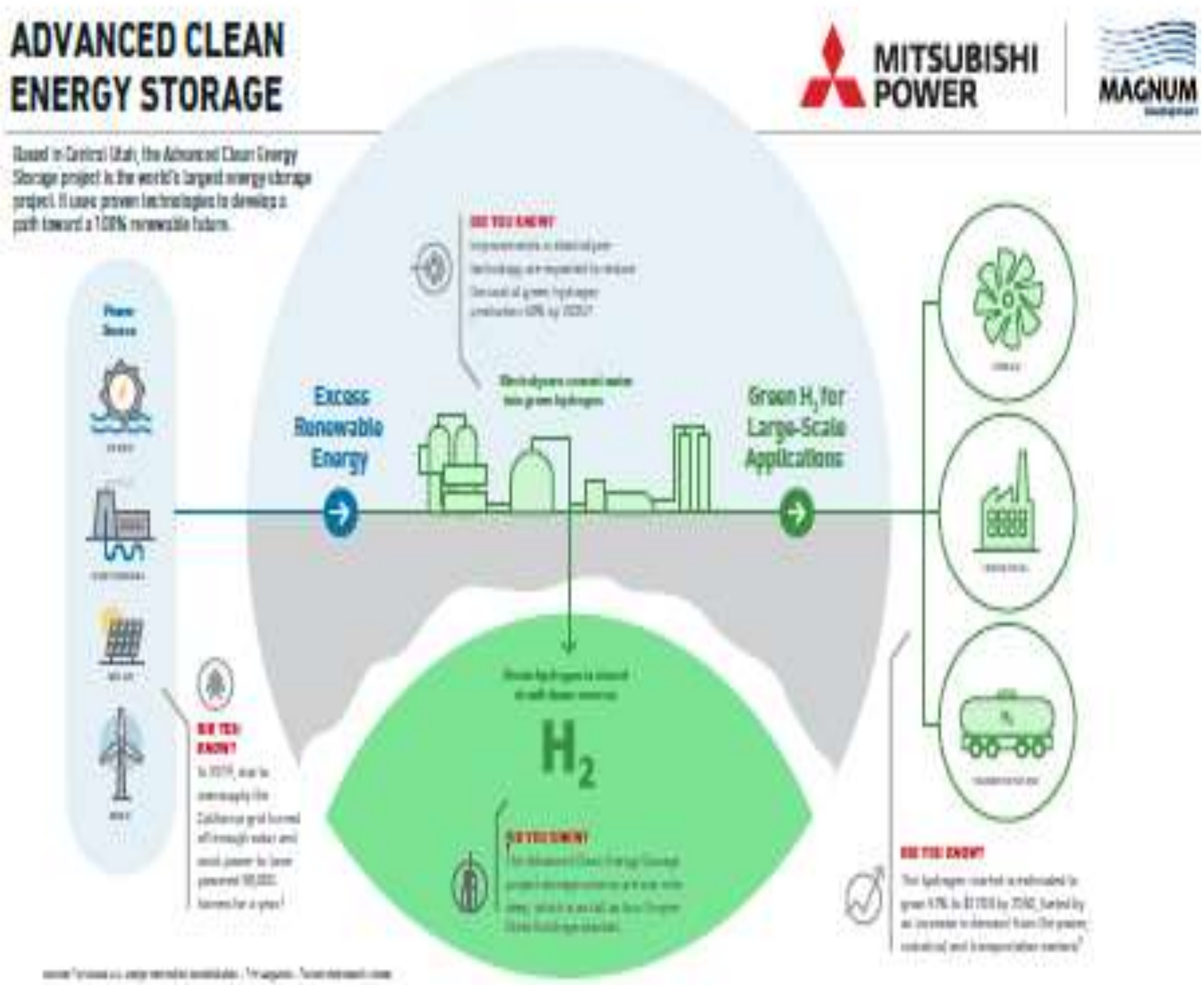


Figure 42 The Advanced Clean Energy Storage program (source IPA)

[42] The Intermountain Power Project in the USA for production and storage of green hydrogen [Online]. Retrieved from: https://www.greentechmedia.com/articles/read/how-to-build-a-green-hydrogen-economy-for-the-u.s-west

5 Energy Storage

The RES has improved their position in the energy production portfolio. As we saw at the beginning, the connection between the neighboring countries has liberalized the international energy market, so to be more competitive in a liberalized market, all the requirements of reliability must be ensured. Energy storage and management of energy production is a daily problem, that is why nowadays have started contracts day by day and hour by hour.

Electricity is necessary under all weather conditions in our daily lives, so production should cover all needs twenty-four hours a day. This is the reason for our dependence on fossil fuels for continuous energy production. The main difference between RES is that we store the energy while in minerals we can store only the fuel which produces the energy, something different.

The use of energy means the conversion of an energy from one form to another. Let's see an example we have coal (primary material) and by combustion it is converted into electricity (secondary energy), through the transmission network it is transferred via electricity to a house (final product) and it is converted through an air condition into heat (useful energy). Through this example we understand that a material that can be found in nature is converted into the final product, but also two basic differences between the final energy and the useful energy. Final energy is the energy that is available in the form used in the end use (the electricity) having deducted the losses, while useful energy is the energy that used at the production.

Primary Energy = Final Energy + Loses in Transformation

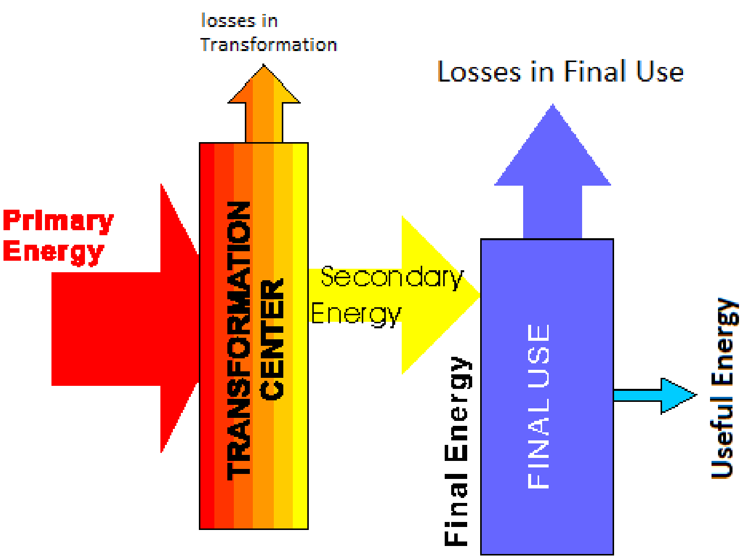


Figure 43 The losses of energy (author picture)

To be able to compare our options we have to compare the efficiency of each inverter on a common reference unit. For safer financial conclusions you should convert the total cost into a common reference unit regardless of the use unit, the converter can use gas, but the cost should be calculated in oil units.

Useful Energy = Efficiency × Final Energy

Below we will give some examples of the efficiency of some converter units, we can focus on the fact that only 30-40 percent has the efficiency of the car engine, but the electric generator has over 80%. Usually, energy losses can be used as energy inputs so that we can increase the final efficiency. (Combined cycle system of an electric generator Figure 11)

Converter	Form of input energy	Form of output energy	Efficiency %
Diesel Engine	Chemical	Mechanical	30-45
Electric Motor	Electrical	Mechanical	80-95
Generator	Mechanical	Electrical	80-95
Hydro turbine	Kinetic	Mechanical	30-70
Battery	Chemical	Electrical	80-90
Solar Cell	Radiation	Electrical	8-15
Solar Collector	Radiation	Thermal	25-62
Water Heater	Electrical	Thermal	90-92
Hydro turbine	Potential	Mechanical	70-99

Figure 44 The efficiency of some inverter's unit (source EIA)

5.1 Battery Storage

Batteries generate electricity thanks to the principle of operation of the potential difference when two different electrode elements are placed in an electrolyte solution. We have three basic types of batteries: lithium, nickel, and lead batteries[43]. The current is generated due to the flow of electrons from the anode to the cathode, while during the charging phase the electrons move in the opposite direction. The voltage generated by a single component is not enough to meet the requirements of most applications; so many components are connected in series to produce the desired output voltage. The main feature of batteries is their fast response in just a few tenths of a second, their time and cost of construction are minimal, as well as the fact that the efficiency is over 90% in lithium batteries[44]. The

[43] KRIVIK, P. & BACA, P. Electrochemical Energy Storage, the types of secondary batteries. [Online]. Retrieved from: https://www.intechopen.com/chapters/42271

[44] SHAHAN, Z. (2015) "Tesla Powerwall & Powerpacks Per-kWh Lifetime Prices vs Aquion Energy, Eos Energy, & Imergy" one comparison of the changes at the batteries the last years [Online]. Retrieved from: https://cleantechnica.com/2015/05/09/tesla-powerwall-powerblocks-per-kwh-lifetime-prices-vs-aquion-energy-eos-energy-imergy/

disadvantages that exist despite their widespread use are their short lifespan but mainly the environmental consequences of the use of their material[45].

5.2 Flywheel storage technologies

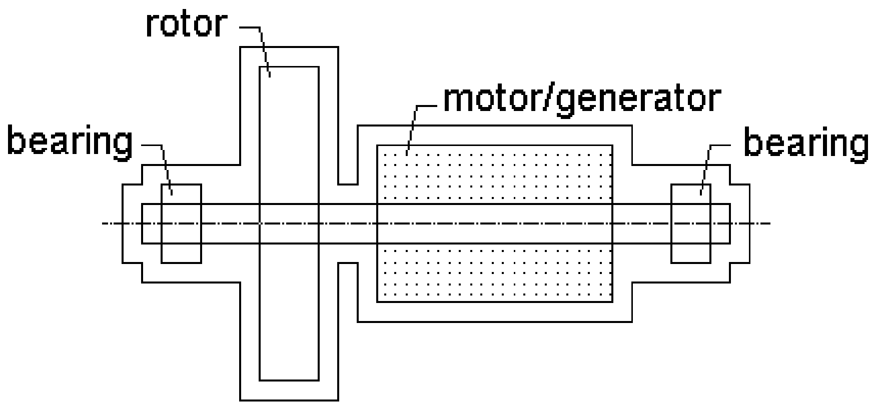


Figure 45 Flywheel energy storage system (author picture)

A flywheel is a mass that rotates in an axis, which can transform the kinetic energy at mechanic energy. When it is rotating, it is in effect a mechanical battery that has a certain amount of energy that can be stored depending on its rotational velocity and its moment of inertia. The flywheel is the mechanism we use in hydroelectric dams. This application can be the integration of a flywheel energy storage system with a renewable energy source power plant system. The main advantages of flywheel storage systems are the high charge and discharge rates for many cycles. The high cycling capability of flywheels is one of their key features and is not dependent on the charge or discharge rate. The flywheel lifetime is quoted as typically 20 years. Their energy efficiency is typically around 90% at rated power. The main disadvantages of flywheels are the high cost of construction facilities.

5.3 Pumped-storage hydroelectricity

Pumped-storage hydroelectricity is a method of storing and producing electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low demand, the excess generation capacity is used to pump water into the higher reservoir and when there is higher demand, water is released back into the lower reservoir through a

[45] JACOBY, M (2019), "It's time to get serious about recycling lithium-ion batteries", *an article on the next day of battery life after use* [Online]. Retrieved from: https://cutt.ly/OhDsqLe

turbine, generating electricity. Reversible turbine/ generator assemblies act as pumps and turbines[46].

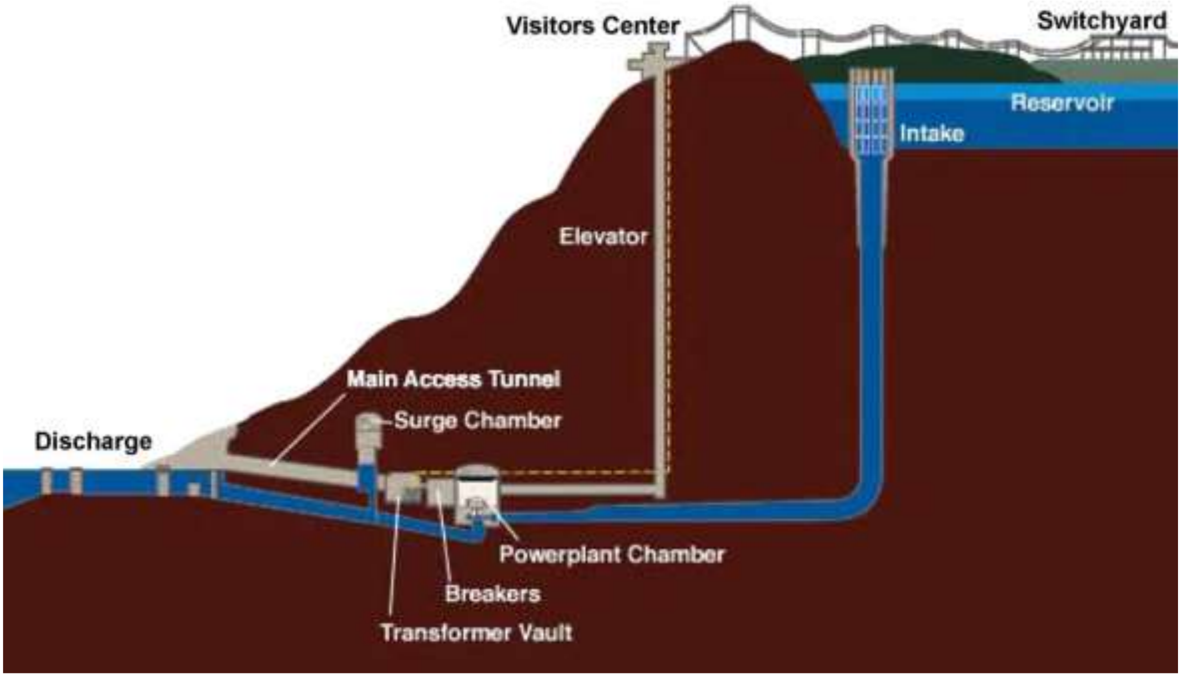


Figure 46 A typical pumped storage plant (source Britannica)

5.4 Compressed air storage

[46] The Amphilochia pumped storage project of TERNA ENERGY [Online]. Retrieved from:https://www.terna-energy.com/restories/to-megalo-ergo-antlisiotamieysis-sti/

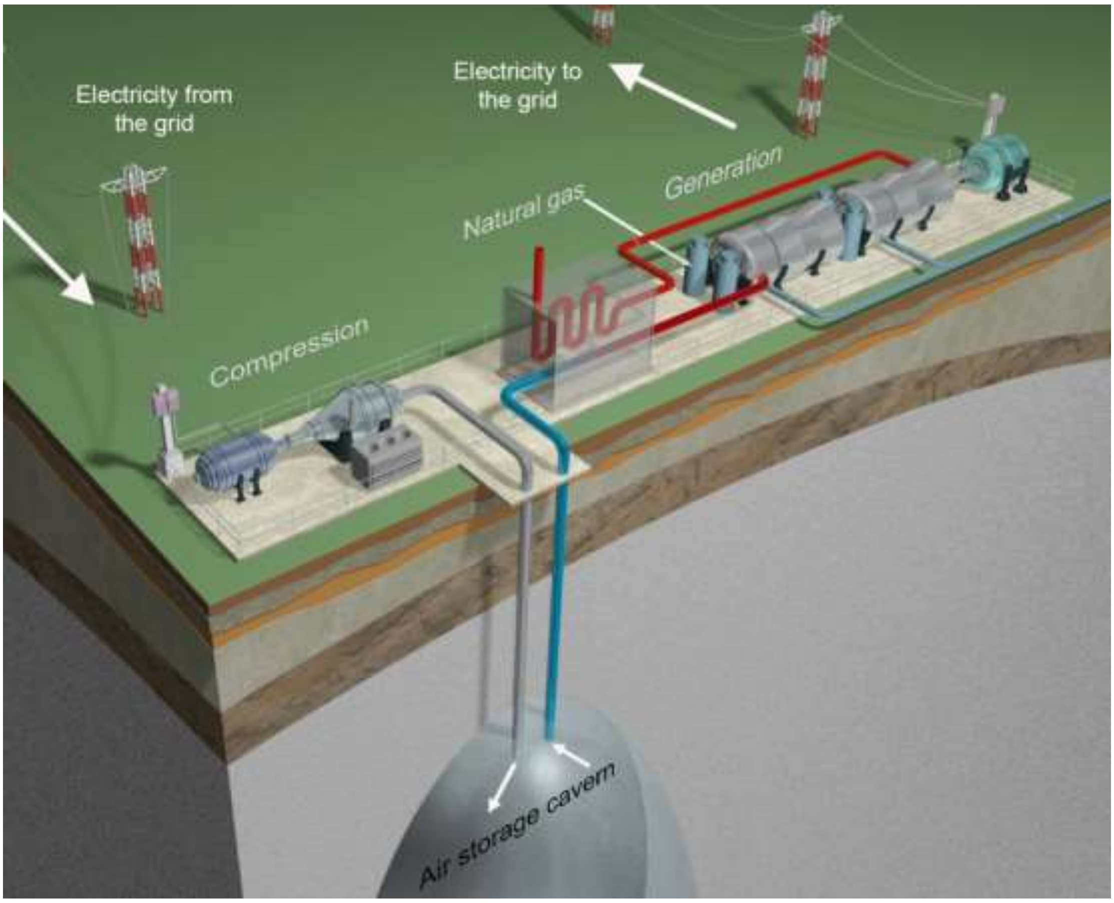


Figure 47 A typical CAES (source Britannica)

The CAES include the conversion of electricity into high-pressure compressed air, which when released will drive a turbine generator to generate electricity[47]. The first CAES plant to be built was in Huntorf, Germany in 1978 and is still operating, but there is also a CAES facility in McIntosh, Alabama, USA, with a total storage capacity of 400 MW. A quick start is the main advantage of CAES. On the other hand, the main disadvantage of CAES is the dependence on the geological structure. However, in the right places, it can offer a viable option for storing large amounts of energy for long periods[48]. There are also two major problems associated with CAES. The first is the temperature of the compressed air and the second problem is that when the compressed air is released, the pressure in the cave decreases slowly and this affects the amount of electricity produced by the turbine.

5.5 Hydrogen storage

[47] The Compressed Air Energy Storage (CAES) and how it works [Online]. Retrieved from: https://www.ctc-n.org/technologies/compressed-air-energy-storage-caes

[48] Compressed air energy storage *an article with the basic characteristics of this system* [Online]. Retrieved from: https://cair.fandom.com/wiki/Compressed_air_energy_storage

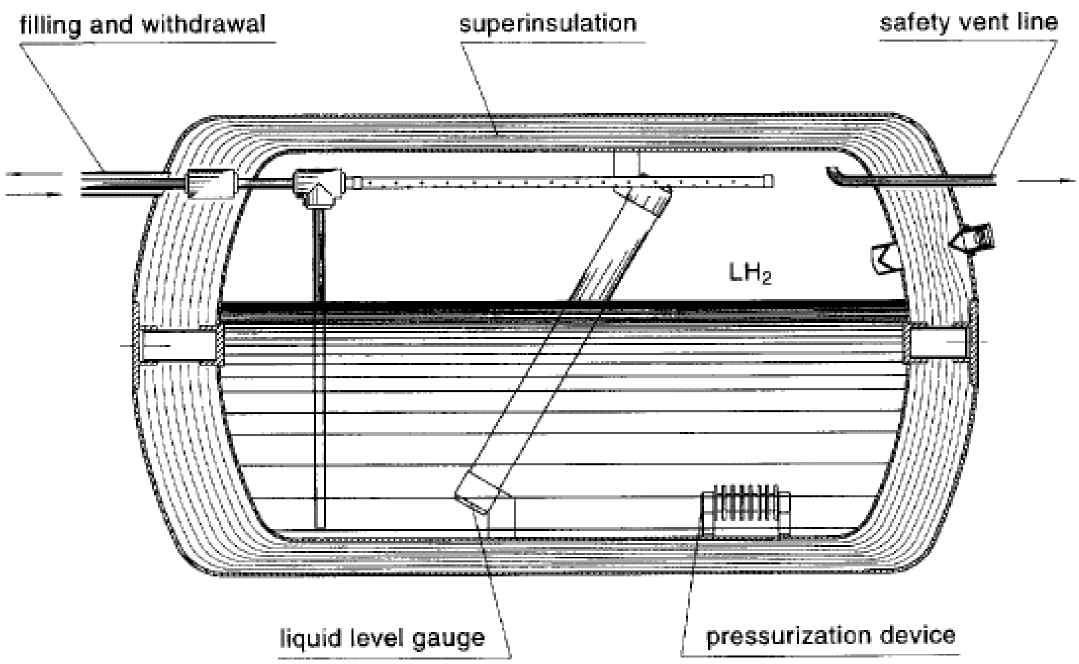


Figure 48 A storage tank and its necessary parts for liquid Hydrogen (source Britannica)

Hydrogen as mentioned above is a chemical element that exists in large quantities in nature but in combination with other chemical elements. However, the safe and economical storage of hydrogen is technically complicated and this is its main drawback. Hydrogen can be stored in the form of compressed gas, in tankers, in liquid form, or finally in solid form by adsorption on various physical or chemical materials. Storage in fixed facilities is possible despite the high cost and you use it in different countries (France, Germany, USA, Japan, Italy) for the supply of various industries. Hydrogen is stored in liquid form in insulated tanks but before it must cool to -253 ° C - not far from absolute zero - and is kept at this low temperature. Caves, salt domes, or old mines often meet the requirements of insulated tanks and are used to store liquefied gas. Another version of hydrogen storage is the use of a tanker, this option can give us many prospects as it can become storage space but also in case of overproduction can be used as a means of transporting and selling hydrogen[49].

5.6 Comparison of specific power and energy storage potential of each storage technology

Below we present a graph in which we can distinguish the performance of the basic storage media; in hybrid systems, they have a special place as they make up for the corresponding shortcomings that exist. The efficiency of hydrogen compared to that of batteries is very high, but we must not forget the cost.

[49] Karagiorgis, G, et al. (2005) A review on Hydrogen storage technologies, *research on the possible uses of green hydrogen* [Online]. Retrieved from: https://www.researchgate.net/figure/Mobile-liquid-hydrogen-storage-tank_fig1_284618929

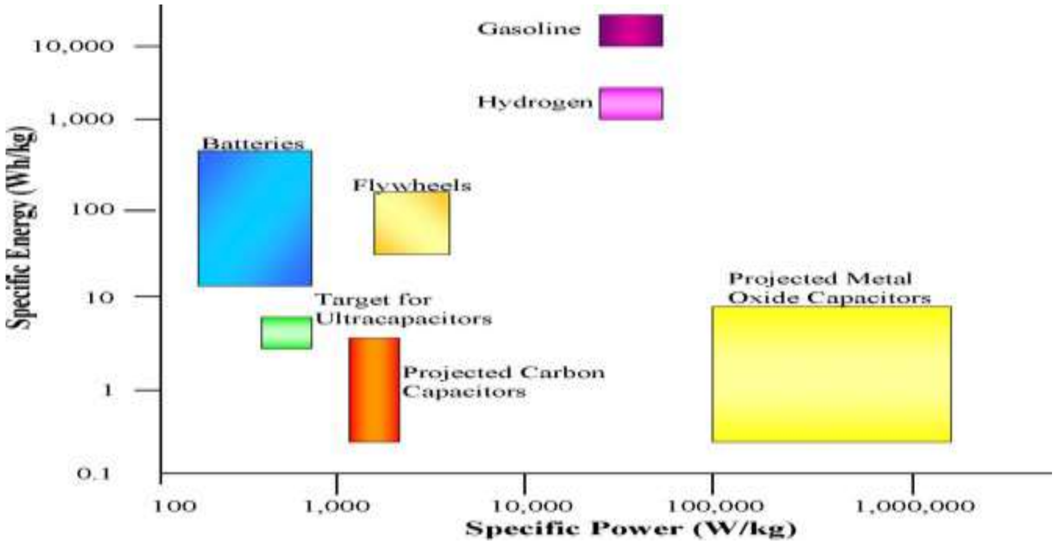


Figure 49 A graph with the performance of the storage media in relation to KWH for each one (source[https://www.nrel.gov/)](https://www.nrel.gov/)

6 The current energy crisis

The crisis we are facing lately is very important, because it concerns our daily lives and affects our standard of living. The price of gas shapes the cost of living of the average EU citizen as the electricity it produces, and its uses belongs to the necessary goods and the vertical increase but also its possible shortage will create daily problems in both industry and personal life level the European citizen.

6.1 Electricity prices in Greece

Russia proceeded with a military operation in Ukraine in February 2022, prompting reactions from both European countries and the United States. The risk of disruption of gas supplies from Russia to Europe, combined with precautionary measures against Russia, has created a volatile global environment resulting in significant increases in the energy market. In the same month, Germany did not complete the inspection and approval for the use of Nord Stream 2, a natural gas that would connect Russia with Germany and the whole of Europe without passing through a third country. These events have increased in the price of gas, an increase in energy costs, the issuance of inflation (costs) and in the end an economic crisis, possibly temporary.

The effects of the current crisis will inevitably lead Greece and all the EU countries to reconsider their energy production strategy in the medium term. If we do not consider that almost all countries have agreed to the gradual reduction of energy production from both fossil fuels and nuclear energy, we should consider the production of renewable energy sources as a one-way street.

Another fact that we must mention is the problem of transportation as in every investment the availability in the final market has a special weight. A product that is produced and sold in the same place the transportation cost is not high, but if the product must be transported to another place, we must calculate both the transportation cost and the storage cost. We have reported a common problem in interconnection systems which is the problem of transport volume within transmission systems. Natural gas can be transported from many places and in many ways to the point of connection of one country to another, but through the pipelines only a certain amount can be channeled from the systems per hour due to the potential of the pipelines. This applies not only to cross-border connections but also to internal connections, which we must always deal with. This problem is especially understandable when it comes to electricity, a product that you only carry with connections.

A high final price can turn a non-profit option at the previous price into a profitable option today. The choice of electricity production only from RES is not accepted by all operators because in the case of overproduction the energy has a higher storage cost and many times, we choose the existence of a fuel unit to cover the needs. However, with the high cost of fuel, building a storage unit can also be profitable.

This fact brought to the surface again several problems which had troubled us in previous difficult economic times. The exclusive supply of a product by only one provider is the one that creates absolute dependence but also the formation of the price by it without the possibility of reaction from the consumers. It is worth mentioning that the free economy has as its main feature the large number of both producers and consumers for the possibility of price formation without the production of excessive profits. A country with the population of Germany cannot be completely dependent on a single provider, after all the EU had set as a key priority in all European countries the abolition of state monopolies in any category (telecommunications, electricity, etc.). The instability in Eastern Europe due to the war and the economic sanctions against Russia, combined with the great dependence of Western Europe on Russian gas caused great instability and an artificial shortage of goods in the market which leads the price of gas to very high flat. In addition, the existence of small security stocks and the limited storage capacity of natural gas, forces the markets to accept any results for some time without the possibility of reaction. The only alternative to deal with the current crisis is to store it on tanker cargo ships, in addition to storage space.

All the above events in Ukraine inform us about an important problem facing Greece and all countries that are not energy self-sufficient. Greece uses both minerals and RES for electricity production, the events of recent months have increased the cost of energy production, due to the cost of raw materials. Below we have the average, the highest and the lowest price recorded on the Greek Energy Exchange for an entire year from April 14, 2021, to April 8, 2022. This price is influenced by various factors and one of them is the price of fossil fuels. Characteristics as we see we have a higher price of 600.07 € / MWh and a lower 0.00 € / MWh.

Figure 50 The average, the highest and the lowest price recorded on the Greek Energy Exchange for an entire year (source ENEX)

The trading on the energy exchange is shaped from the previous day to the next day, as we know the weather conditions that will prevail the next day, we calculate the needs of the market and what we can produce from each type. The transactions concern both the day and the time when the purchase is made. The day with the lowest price of electricity 0 € / MWh is for the time 09:00 at the day May 3,2021 and from the report from the energy exchange we can observe from the following diagram, that the production of energy from renewable energy sources is very high. Another reference is that the price of electricity is not at zero all day but at a relatively low price.

Figure 51 The prices of electricity at May 3,2021 (source ENEX)

The second date we must mention is March 8,2022 with the highest price of 600.07 € / MWh. To make it more understandable we present not only the price of this day but the average, the highest and the lowest for the period from February 24,2022 to March 09, 2022. It is important to note that the previous one we again had a quite low price a little more than 100 € / MWh. However, the events in Ukraine created a strong demand for energy in the North countries and so the purchase price from foreign countries was very high and so this price was set for sale in foreign countries.

Figure 52 The average, the highest and the lowest price recorded on the Greek Energy Exchange the month with the highest price (source ENEX)

6.2 Electricity in islands

All the above can help us understand the specific weight of each good for the final product. Island Greece is usually an area where we can find natural goods in great abundance. In electricity, as we have mentioned so far, energy production can be done in several places, but the consumption is sent to the big urban centers for consumption. The island regions can contribute to the reduction of costs thanks to the production of electricity from RES, a fact that makes necessary the creation and maintenance of the interconnection network of mainland Greece with the island.

A typical example is the electricity consumption in the Greek islands, in winter it is very low and is often covered by RES units, while in the summer months the production does not cover the needs. An investment in an island area with a connection to mainland Greece or not will be able to offer stabilization at the cost. This allows us to calculate only the amount of added value as in the production of energy from RES the cost of raw materials (air, sun, and water) is zero.

Another fact that is particularly important in island areas is the fact that consumption varies depending on the season. An island area may need almost three times more energy during the summer months than during the winter months. Thus, part of the energy produced by RES in the islands will be surplus in winter and will be sent to mainland Greece while in the summer months will be supported by it. For the implementation of the above, the completion of the interconnection network of the islands and the increase of the energy production units from renewable sources in the islands should be accelerated. It is noted that Crete and Skiathos (and other areas) are connected to the rest of the country through underwater connections.

6.3 The possible solution for electricity in the Greek islands

The production and exploitation of energy can shape both the final profit and the decision to implement the project. The main objectives should be:

- Energy adequacy and independence of the country from third parties. However, this does not mean that the country will stop having connections with other countries.
- Adequate production of green energy over time, with negligible production costs.
- The low price of energy supply to consumers due to the insignificant cost of production.
- The economic development of the country is due to the low energy costs used by industrial and tourism units.

One of the systems that will be mentioned below and have been particularly focused on in the last years are the hybrid systems where the basic production is done from green energy sources. The RES can offer us energy with zero production costs. However, their disadvantage is that they do not produce the required grid power whenever we need it but whenever conditions allow. The basic solution for the use of RES is the storage of energy when it is in excess and its use when there is a shortage. Storage can be done in all the above ways (batteries, hydroelectric systems, hydrogen, etc.). On islands connected to other areas, energy can be sold. In the islands that are not interconnected, the installation of small RES and storage spaces is the most appropriate solution, until their interconnection.

7 Hybrid energy systems

Hybrid Energy Systems, or Hybrid Systems, are systems that use multiple energy conversion devices with more than one fuel type, to generate energy. A hybrid system may include a conventional power unit in combination with at least one form of renewable energy, storage devices, monitoring and control systems, and a load management system. In this sense, hybrid systems are an alternative to conventional systems, which are typically based on only one fossil fuel power generation.

The development of hybrid systems aims at the optimal utilization of the various system components used to produce energy from renewable sources. The energy they provide to the grid is smooth and suitable for disposal to meet the needs, as the power supply is fully controlled. They can therefore be developed as autonomous, and independent systems within small energy distribution systems or integrated into existing oil-based thermal units after the necessary interventions in the existing system.

Hybrid fossil fuel power systems (local diesel power plants) operate with the lowest possible fuel consumption. As a result, hybrid systems are more convenient and economical in areas that are not accessible to the network, e.g., mountainous, rural areas or islands (interconnected or not), where connecting areas or communities to the electricity grid, or installing an electricity grid or transporting fuel are considered uneconomical options. In addition, due to their high efficiency and reliability, such systems can contribute to the energy balance especially in cases of power outages.

Below we see a hybrid system in which we have a solar park, a wind farm, an energy storage system, and a polluting power station which exists for an emergency.

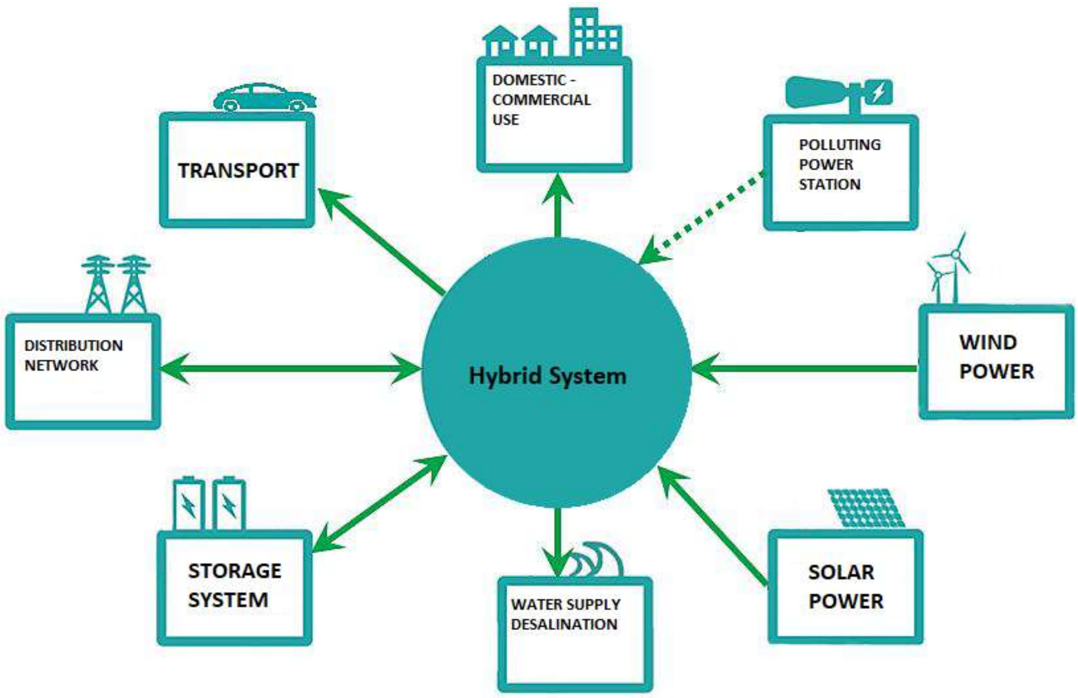


Figure 53 The possible connections of a Hybrid System (author picture)

Many autonomous electrical systems have been installed throughout Europe the last decade. These systems provide power to technical installations and communities in areas that do not have access to the regional or national network. An increasing number of such systems include renewable energy technologies (solar or wind), often in combination with diesel generators with or without batteries as a backup source, but most of the Stand-Alone Power Systems (SAPSs) still rely on fossil fuel power generation. Replacing diesel generators and batteries with plenty of hydrogen-based fuel cells (FCs) would minimize dependence on fossil fuels, thus helping to reduce environmental impact and possibly reduce operating and maintenance costs. The storage of renewable energy (usually solar energy) in the form of electrolytically produced hydrogen in autonomous electrical systems and the production of hydrogen electricity in fuel cells has been investigated in many demonstration systems and is associated with off-grid and isolated communities.

Greece, a country with a shortage of fossil fuels for the supply of electricity at competitive prices, has turned to more efficient use of RES. For many countries, RES is an important domestic energy source with great growth potential locally and nationally, this is because they contribute significantly to their energy balance, thus helping to reduce dependence on oil and enhance the security of the energy supply. Regarding the environmental impact, it has been found that the use of Renewable Energy Sources contributes significantly to the protection of the environment as almost 95% of air pollution is due to the production, transformation, and use of conventional fuels[50].

[50] Greek Association of RES Electricity Producers *the official reference site of Greek producers with reference to official data* [Online]. Retrieved from www.hellasres.gr

The European Parliament has voted in favor of binding targets at the EU level on RES, which is to be reached by 2030. Until then, each Member State should, at its own risk, have an energy efficiency share of 35%, and renewable sources should account for 35% and 12% of energy consumption in the transport sector. All of this can be achieved through the development and operation of hybrid systems which produce electricity from renewable sources. Hybrid power systems are designed to generate and use electricity to be independent of a large, centralized grid and incorporate more than one type of energy source. It can range in size from large multi-megawatt island networks to one-kilowatt individual household power supplies. An important feature of hybrid energy systems is the utilization of existing infrastructure to reduce costs, environmental impacts as well as any problems with the existing system.

7.1 Hybrid system features

The design of hybrid energy systems aims at the right choice in terms of the most appropriate combination of energy sources, the size of the power devices, the energy storage system, as well as the implementation of an effective strategy. The choice of the appropriate combination of renewable technologies to create a hybrid energy system depends on the availability of renewable resources in the area where the hybrid system is to be installed. In addition to the availability of renewable energy sources, other factors can be considered for the proper design of hybrid systems, depending on load requirements such as reliability, greenhouse gas emissions over the expected life cycle of the system, energy conversion efficiency, and economic aspects, and social consequences. The size and optimization of the unit of a hybrid power system play an important role in deciding on the reliability and economy of the system.

To create a hybrid energy system in the initial design stage, the following are identified:

- The type of renewable energy system to be included
- The number and capacity of renewable energy units to be installed
- If the system includes a backup power system such as a diesel generator, a fuel cell, etc.
- Whether energy storage will be integrated into the system

The choice of technology depends on the availability of renewable resources in the specific area where the system is to be installed, where local weather conditions play an important role in decision making.

7.2 Types and combinations of hybrid systems

There are various types and combinations of hybrid renewable energy systems which already used.

- A hybrid system with an oil generator and a wind farm. At this system produces electricity basic from the park and when the conditions of wind do not allow the energy produced from the generator. The Wind turbine can not generate energy when the wind speed is too low but also and when it is too high.

- Another hybrid system is with an oil generator and a Photovoltaic Park. In this system, as in the previous one, we have production from the solar park and whenever there are no suitable conditions, the generator is used. The main problem in this case you consider the low yield up to 20%. However, the installation of photovoltaic systems has increased worldwide. Especially in countries rich in solar radiation such as Greece can be a key pillar in electricity production

- A hybrid system is with an oil generator, a wind farm, and a Solar Park. This system is suitable for areas where there is a balanced potential for wind and solar energy. It has high energy efficiency but is one of the most complex types of systems.

- Wind and photovoltaic energy combination system is one of the most stable and efficient combinations of hybrid systems. This is because it has been shown that when the wind becomes stronger, the solar radiation is usually lower and vice versa. This trend is observed during the annual cycle of the earth. So, if the system is in the right place, properly designed, and capable of storing the extra energy it can work to a very efficient and stable degree.

- Combined with wind and hydroelectric power systems, this system operates with wind turbines in combination with water pumps. This combination has been applied in the ovens of Ikaria with great success. The first experimental system of this kind was created by the company Nova Scotia Power in the late 1970s. According to scientists, this system still has great potential for development and many prospects in the future.

- A photovoltaic system in combination with biomass is a system that is still under research on how it could be implemented and become efficient but has not yet been implemented.

7.3 Types and combinations of hybrid systems - Hybrid system selection methodology

There is a well-defined and standard framework for choosing the right system, the steps of which are described below[51]:

- Demand assessment. (Assessing the amount of electricity required can be done through local factors, calculating street lighting needs, calculating the number of homes, schools, health centers, industries, and energy demand they have, and finally calculating the various other activities that require electricity).
- Evaluation of available resources (Evaluation of resources can be done by calculating the potential of renewable energy sources available in the area and using meteorological data).
- Identify obstacles and constraints (The next step is to identify the obstacles and constraints that the selected installation area may present, such problems may be the demand for electricity, reliability, financial costs, protection environment, and the workforce in the area).
- Selection of the appropriate type of hybrid system of renewable energy sources.
- Once the appropriate hybrid system is selected, the system is optimized using the appropriate optimization technique.

7.4 Hybrid systems in operation

In 2004 a demonstration project by a Norwegian company, Norsk Hydro (now Statoil Hydro[52]), started on a small island, Utsira, 20 km off the Norwegian coast in the North Sea. The main electricity supply for ten houses on the island is a 600 kW wind turbine, with energy storage in the form of compressed hydrogen and flywheels. The high wind speeds on the island provide excessive wind power to an electrolyte (10 Nm^3 / h) and a compressor, which supply hydrogen to the storage cylinders (2400 Nm^3, 200 Bar). A fuel cell (10 kW) and a hydrogen-powered ICE generator provide back-up power to homes and excess and off-peak electricity is used to generate hydrogen as transport fuel to the island. Success of this project continues, and a lot of information has been gathered from the project. About 90% availability was achieved with good power quality and satisfied customers. In addition, no accidents were reported during the project and recommendations have been made on the size of storage tanks and the need for a remote access control system[53].

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[51] Swati, N and Mathew, L (2014) Hybrid Renewable Energy System: A Review, *the standard frame* [Online]. Retrieved from https://www.ripublication.com/irph/ijeee_spl/ijeeev7n5_15.pdf
[52] The wind/hydrogen demonstration system at Utsira in Norway, *an existing system in Norway* [Online]. Retrieved from: https://www.equinor.com/en/what-we-do/utsira-nord.html
[53] NAKKEN T, et al. (2010) The Utsira wind-hydrogen system - Operational Experience, *the results of the UTSIRA hybrid system* [Online]. Retrieved from http://www.ewec2006proceedings.info/allfiles2/135_Ewec2006fullpaper.pdf. .

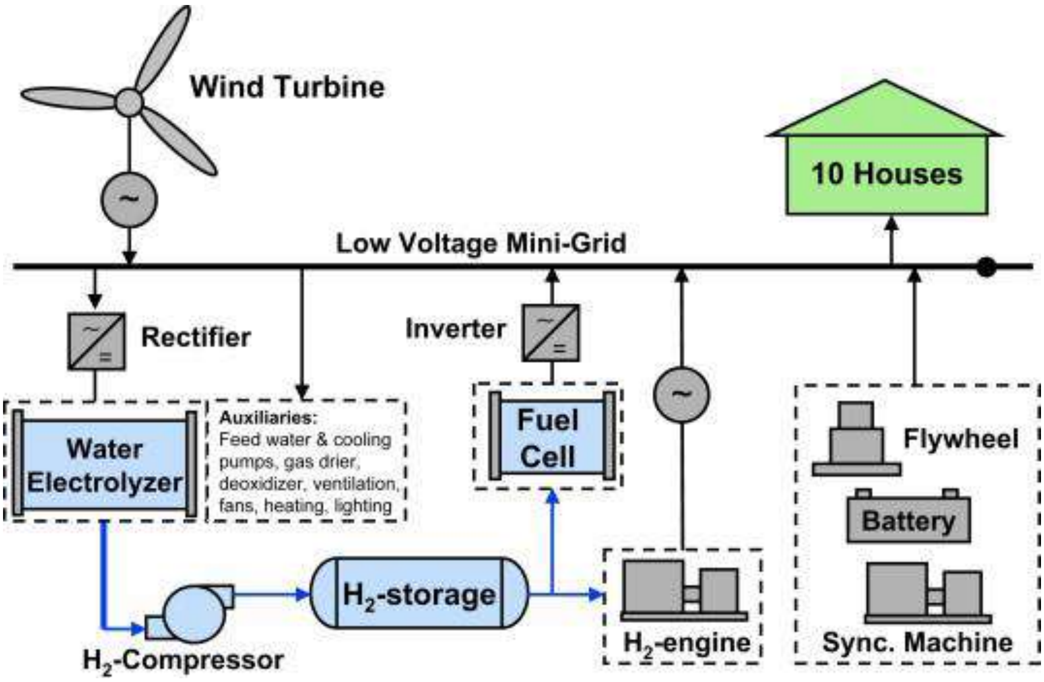

Figure 54 System schematic of the wind/hydrogen demonstration plant installed at Utsira

Kassem's study[54] applied methods of risk analysis to evaluate the simultaneous effect of multiple input uncertainties of wind energy and provide an assessment of the techno economic viability of offshore wind farms for electrolytic hydrogen production. It was concluded that the capacity factor of wind turbine has a dominant effect on the wind power economy. Excess electricity, in times of low demand, could be converted to hydrogen and stored. This hydrogen could later be used to power fuel cells and offset the production during peak demand hours. Hydrogen storage can be applied in both isolated and grid-connected systems and utilized for stationary energy supply and/or as a fuel for transportation. The results also indicated that there are large benefits of using the grid as backup for hydrogen production in periods with low wind speed.

[54] Kassem, N. (2003). Offshore wind farms for hydrogen production subject to Uncertainties. *the risks and the estimated cost of the capital investment* [Online]. Retrieved from: https://www.researchgate.net/figure/Mobile-liquid-hydrogen-storage-tank_fig1_284618929 .

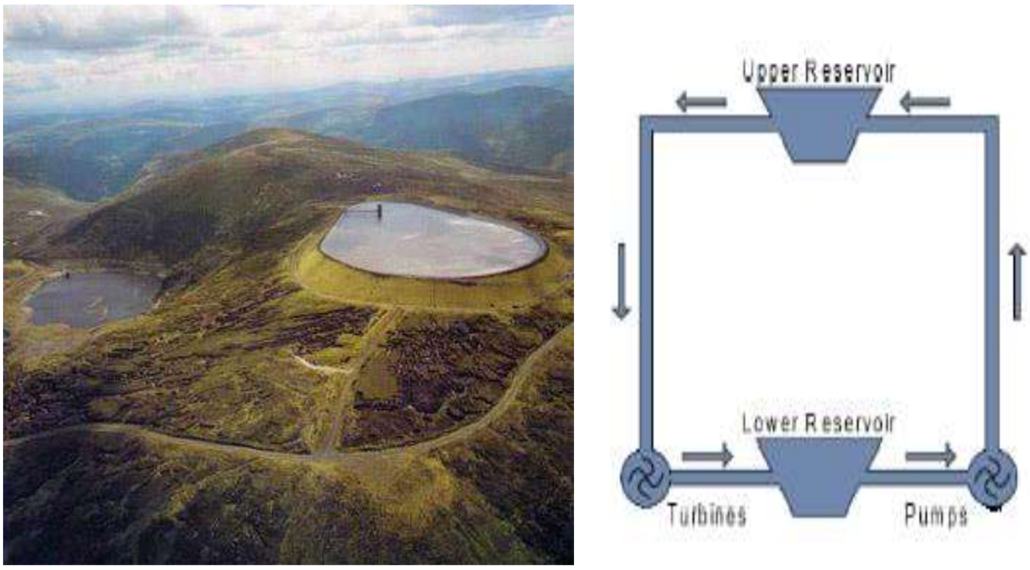

Figure 55 The Turlough Hill pumped hydro power station in Ireland and its generation system

The Turlough Hill[55] is the only one of its kind in Ireland, it is a hydroelectric pumping station consisting of an upper tank and a lower lake. It was built in 1968 and achieves greater operating economy because capacity from other facilities can be used during periods of low demand to pump water from the lower lake to the upper tank where it is ready for use when demand increases. Greater flexibility is achieved because generators in a pumped storage system can be synchronized in seconds, providing power quickly to meet maximum or sudden power demand.

In Greece, a similar construction has been done in Fourni Ikaria for the self-sufficiency of the island as we see below. The wind farm generates energy and is used either directly on the grid or in the storage system.

[55] Turlough Hill, Ireland's only storage pump power station, *with 40 years of operation* [Online]. Retrieved from: https://www.esb.ie/docs/default-source/education-hub/turlough-hill-power-station

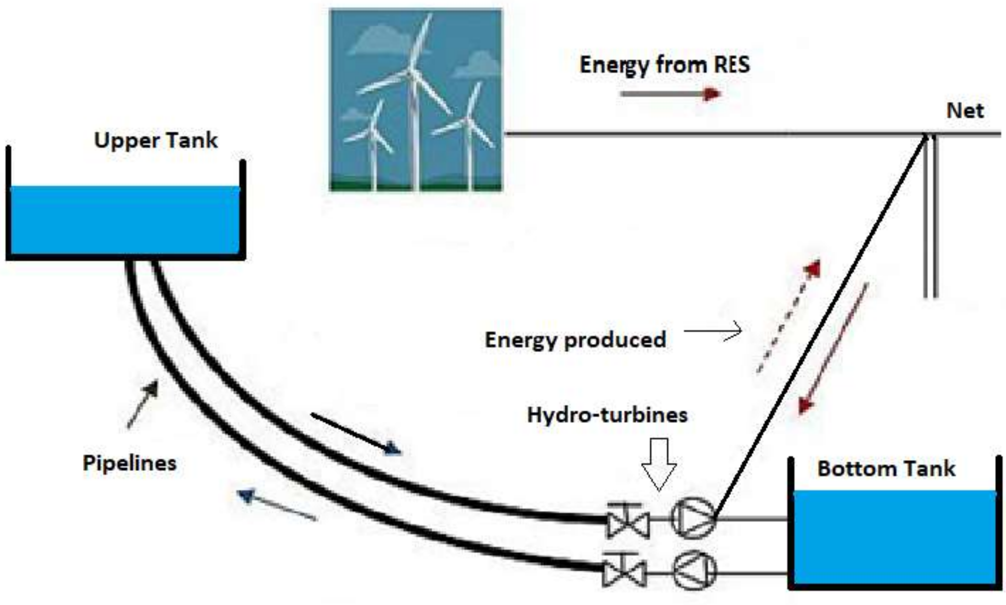

Figure 56 The operation of the Hybrid system of Fourni

7.5 Disadvantages and Advantages of Hybrid Renewable Energy Systems

Hybrid systems take the advantage of each technology and provide power of the same quality as that of the grid, with a range from 1 kW to several hundred kW. Thus, they can be developed as autonomous new and independent systems within small energy distribution systems and integrated into existing oil-based thermal units after the necessary interventions in the existing system.

At the same time, hybrid systems find application in areas where the connection to the electricity grid and the transportation of fuel are considered uneconomical options (rural areas, unconnected islands). They also provide the possibility of a future connection to the network in the areas where they are installed. In addition, due to their high efficiency and reliability, such systems can be useful as an effective power supply solution in case of power outages or even to specialized consumers, such as telecommunication stations and hospitals.

Hybrid systems that contain fuel technology (diesel generators, fuel cells, biomass power plants) operate with the lowest possible consumption, because it is expected to produce energy only during periods of high load demand or low renewable potential. This indicates reduced fuel consumption compared to a stand-alone conventional technology unit.

If the previous characteristics are added to the classic advantages of RES, such as the absence of risk of energy supply from fossil fuels, the predictability of the cost of electricity generation, the rapid installation of technologies, the safe operation of facilities and their competitiveness in economic, socially, and politically, concerning to conventional forms of energy (mainly nuclear and oil), hybrid power systems can be the best decentralized solution.

The area in which such power systems are significantly superior is the protection of the environment, as they reduce energy dependence on fossil fuels and increase the ecological efficiency of energy production and energy security. They also contribute to the decentralization of the energy system, thus enabling the coverage of energy needs at local and regional level, decrease both energy transmission losses and the use of energy transmission networks. The RES is practically inexhaustible resources and friendly to humans and the environment, so their utilization is widely accepted by the public. In addition, we can consider RES as domestic energy sources that contribute to increasing energy independence and energy security at the national level. They offer the state the possibility of rational utilization of their energy resources, covering a wide range of energy needs while having low operating costs that are not affected by fluctuations in the international economy and in particular the prices of conventional fuels.

Finally, at the local level, RES investments create a significant number of new employees, both in their construction phase and in their operation, of course, depending on the size of the project, the corresponding number of jobs is created. Also, like any major project, the construction of an energy park can help financially the area in which it is built as it will bring young people who will stimulate the local economy in many areas (hotels, rentals, restaurants, etc.). Therefore, in many cases, they are the core for the economic and social revitalization of the regions and a pole of local development by promoting such investments[56].

The main disadvantage of hybrid systems is the energy storage system, as it is easy to understand that energy production only from renewable sources is highly dependent on weather conditions (sun, wind, and wave), so it is difficult to achieve optimal energy production. For long periods and without interruption. This role is taken by the batteries or diesel generators that participate in the system, to maintain the desired power in the network in dead periods. Most the hybrid systems require storage devices, which usually use batteries that increase their installation and operation costs as they require constant monitoring and maintenance, and their lifespan is limited to a few years[57].

[56] Ing, J., and Bukeridg, JS. Design considerations for a sustainable hybrid energy system, *a paper that informs us about the necessities of a sustainable energy system for the lighting of night paths* [Online]. Retrieved from: https://www.researchgate.net/publication/266408087_Design_considerations_for_a_sustainable_hybrid_energy_system

[57] Hussein, I. et al (2015) Investigation of Usage of Compressed Air Energy Storage for Power Generation System Improving - Application in a Microgrid Integrating Wind Energy, *this paper examines technological developments in CAES* [Online]. Retrieved from: https://www.sciencedirect.com/science/article/pii/S1876610215014629

7.6 Hybrid systems on small communities - islands

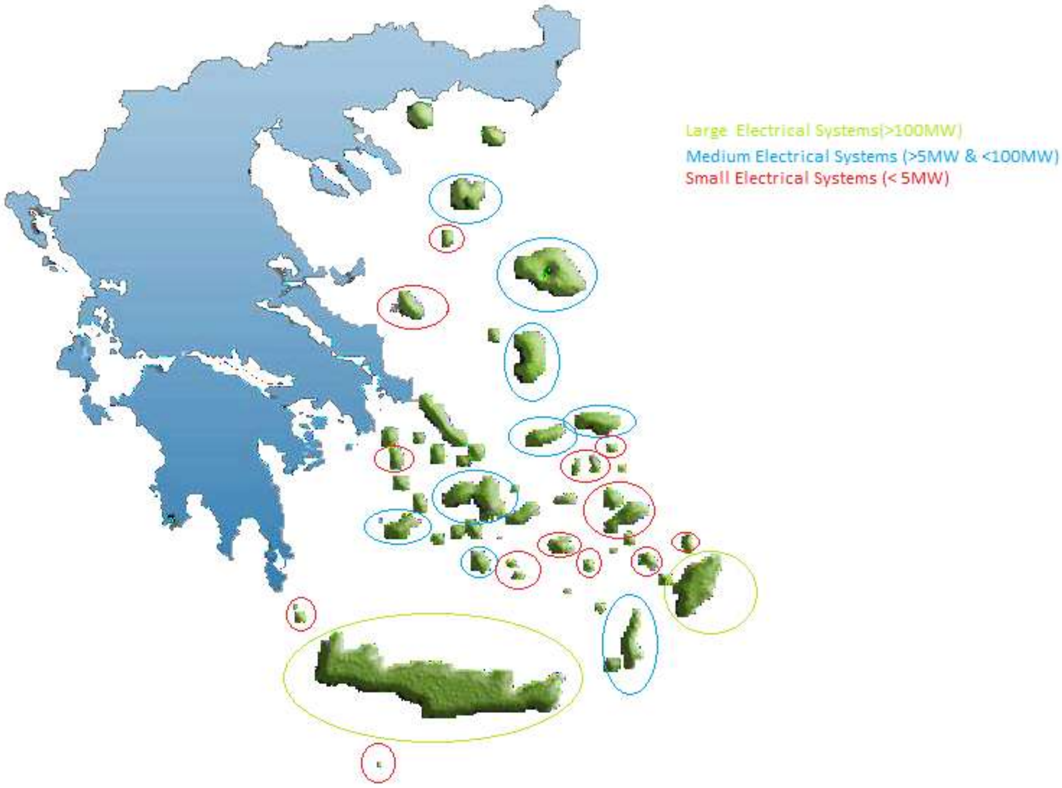

Figure 57 Unconnected islands of Greece (source IPTO- ADMIE)

In 2018 in Greece there were 29 island power generation systems, including Crete and Rhodes, which are the largest, Non-Interconnected Islands (NNI), whose electricity is based on oil and the increased cost of electricity is borne by all consumers as SGI - Public Utility. The demand for electricity in island systems, which represents 10% of total domestic demand, has production costs from 3 to 30 times higher than on the mainland, which helped to create models with innovative hybrid technologies. This is a different form of development based on the energy self-sufficiency of the island regions, which is at an early stage and is expected to be in line with the clean energy policy for the EU islands, which was signed in May 2017 in Malta. The gradual reduction of RES costs as well as the rapid development of technology in smart grids and electricity demand forecasting systems, which significantly contribute to the increase of RES penetration in electricity production combined with storage systems, make the new systems attractive both economically and with green energy.

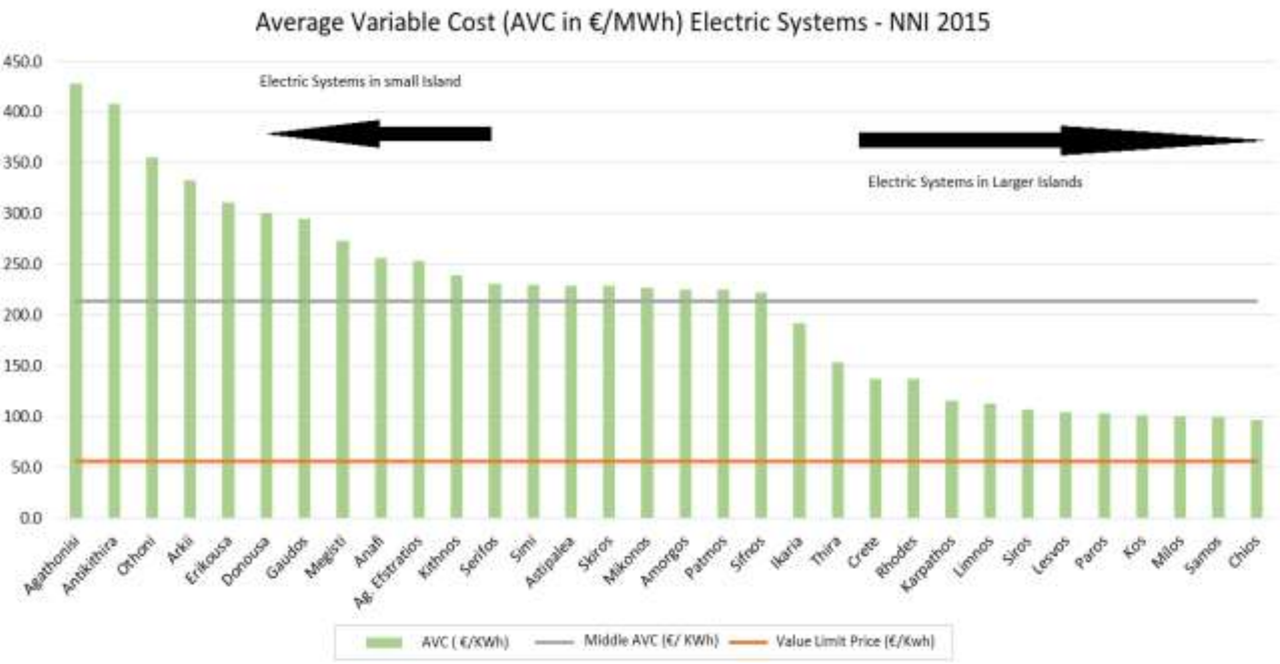

Figure 58 The cost for each NNI Island (source IPTO- ADMIE)

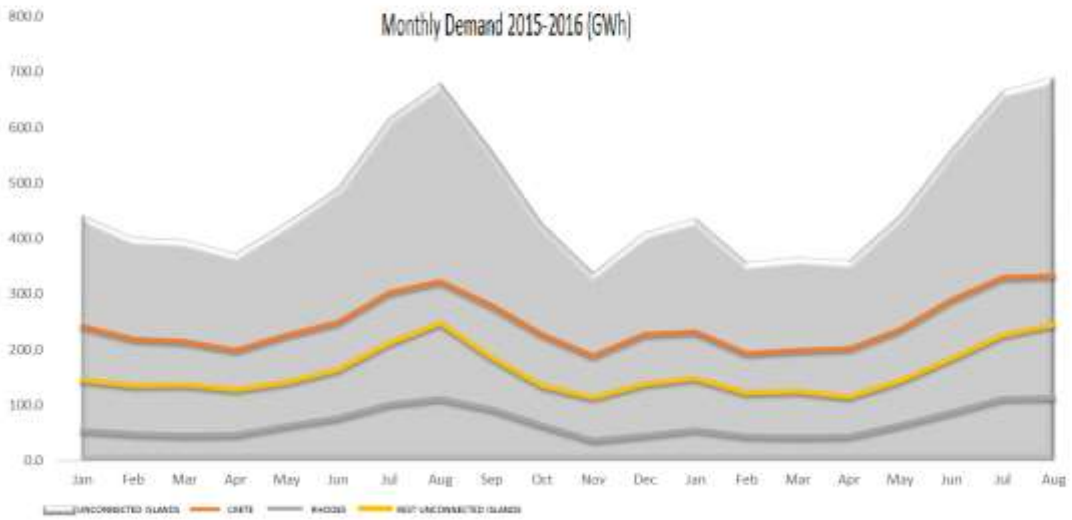

Figure 59 Monthly Demand 2015-2016 (GWh) (source IPTO- ADMIE)

In the two diagrams above we see the fluctuation in the cost price depending on the island for which it must be produced and the energy demand per month for more than a year. Demand in the summer months increases very high compared to the winter months. The limited price of electricity is 41,40€ for 2015 according to the data of HEDNO.

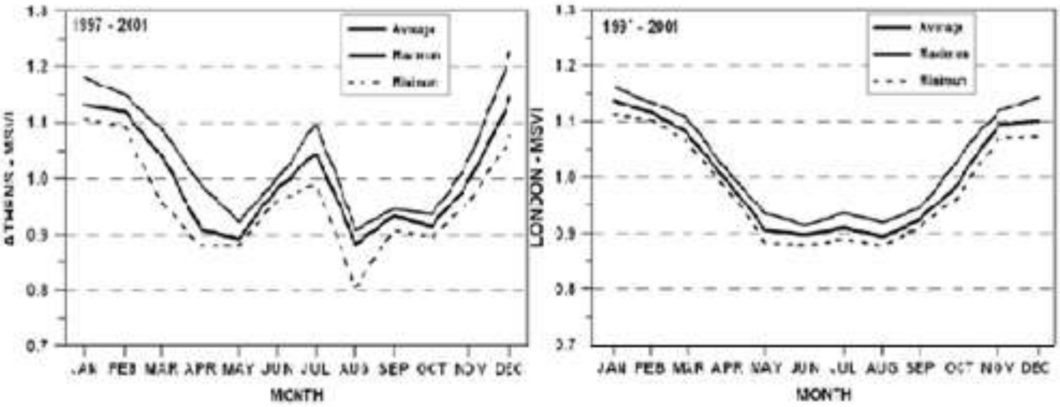

Figure 60 The consumption in London and Athens

In the two diagrams above we see the electricity consumption in the city of London and the city of Athens on average per month from 1997 to 2001. In both cities, the winter has high consumption, but Athens has another long period of high consumption in the summer months due to the high temperature. If we become more careful, Athens has high consumption in July and not in August and this is because the population of the city is out of it due to holidays. the Demand exists but is not in the capital but the island country for this and there is a great demand in the islands in August as we have seen in the diagram before[58].

In the table below we can see the cost of producing electric energy in a Non-Interconnected Island. It is worth noting that the average annual full production cost for NNIsfor 2018 amounted to 1,387.5 € / MWh on the island with the lowest demand (Antikythera) and to 483.4 € / MWh on the island with the highest demand (Megisti), with the average annual electricity generation costs of the five years 2014 - 2018 ranging from 1,283.9 € / MWh (Antikythera) to 451.15 € / MWh (Megisti) respectively. The variable cost of electricity generation in the specific island systems is also very high, with the Average Monthly Variable cost of production ranging from 239 to 443 € / MWh for 2018 and from 188 to 686 € / MWh for the period 2014 - 2018.

Electric system	Total production 2018 (MWh)	Means Yearly production (MWh / year) (2014 -2018)	Yearly cost of electricity 2018 (€/MWh)	Means Yearly cost of electricity (€ / MWh) (2014-2018)	Total cost of produce electricity 2018 (€)	Means of total cost of produce electricity (€) (2014-2018)	Means Monthly Variable Cost Produce (€ / MWh) (2018)	Means Monthly Variable Cost Produce (€ / MWh) (2014-2018)
AG EFSTRATIOS	1.124,01	1.109,26	490,59	525,93	551.428	583.389	from 252 to 297	from 209 to 322
AGATHONISI	717,56	708,42	1.093,51	1.011,12	784.655	716.293	from 241 to 350	from 200 to 423

[58] Karakatsanis, et al (2015) Analysis of the electricity demand of Greece for optimal planning of a large-scale hybrid renewable energy system, *we compare the differences of the Greek capital in relation to London*.

ANAFI	1.370,58	1288,42	476,89	549,88	653.613	708.481	from 244 to 322	from 188 to 322
ANTIKYTHIRA	274,30	261,63	1.387,51	1.283,90	380.593	335.906	from 336 to 443	from 277 to 508
ARKI	397,05	361,42	765,29	779,22	303.860	281.622	from 267 to 436	from 259 to 686
GAYDOS	491,02	485,38	767,17	673,42	376.697	326.862	from 269 to 367	from 205 to 377
DONOYSA	1.118,38	900,66	707,20	865,49	790.914	779.515	from 239 έως 349	from 204 to 366
EREIKOYSA	894,94	819,23	708,20	700,14	633.792	573.580	from 240 to 424	from 191 to 467
MEGISTI	3.761,56	3.401,69	483,44	451,15	1.818.507	1.534.686	from 247 to 325	from 189 to 325
OTHONI	639,65	630,42	980,37	761,07	627.095	479.793	from 246 to 396	from 237 to 531

Table 1 Data of production and cost in 10 NNIs with Zero production of RES (2014 - 2018) (source IPTO- ADMIE)

From the above data we see the value of creating a self-sufficiency system in the small islands to control costs, the first step is to avoid the use of minerals.

7.7 The purpose of Hybrid systems

The purpose of the construction of these projects is the production of green energy in order we sell it on the grid or to use it in other forms, mainly the production of green hydrogen. This project is directly applicable in remote islands or heavy industries and the chemical industries. The projects can be divided into three main types

- Individual islands or groups of islands that have a common electricity network, in these islands we offer the production of the final product at a price that covers the cost of production.
- Near industrial units that require electricity which can be nearby to our production unit, as well as units that require a high amount of Hydrogen. In the second case we have little need for gas storage, and it is an important parameter in both units.
- Another option is to install it in rivers. It is important that we avoid the construction of a dam so the installation costs will reduce to a very high degree.

8 An investment in a small island

Construction of submarine turbines on a Greek island to produce the electricity needed without the use of fossil fuels. The surplus production will be used either by sending it to the national network or using it in the production of other products to have a viable and economically viable unit. Our goal is to produce at least as much electricity as will adequately cover the island throughout the year, which will be supplied with electricity at a lower price. The main criterion that we will follow is the production of energy without affecting both the local population of the island and the environment.

The project will take place on remote islands with electricity problems or in places where electricity companies want to invest. It should be mentioned here that in case of choosing the investment plan with the production of liquefied gases (H2, O2), they can be included in the operators and companies of paramedical materials (for the sale of oxygen), in the chemical industries, steel industry, cement industry, as well as companies that consume large amounts of electricity (e.g., for battery charging). Finally the project can also take part in the Region and Municipality where belong the maritime areas.

In our thesis we will focus on electricity generation using only renewable systems. The main energy producers will be underwater turbines and batteries, or green hydrogen will be used for energy storage.

8.1 Island of Skiathos

In the present thesis we chose the island of Skiathos for the implementation of the investment. In particular, the unit will be installed in a secluded and barren area that will not affect the environment, which will be indicated by the island's authorities.

The island of Skiathos to the 2011 census consists of a population of 6,610 people, this population during the summer months increased and so did the need for energy. Below we see a table with the change in population.

Figure 61 The Island of Skiathos

Month	Population
January	6.610
February	6.610
March	6.610
April	6.610
May	7.000
June	11.500
July	22.000
August	28.000
September	17.000
November	6.610
December	6.610

Table 2 Population of Skiathos (source Hellenic Statistical Authority)

Through the data we have, the energy consumption is

Month	Population	Average Daily consumption per person	Average Daily consumption per day	Average Monthly consumption
January	6.610	7,00	46.270	1.388.100
February	6.610	6,00	39.660	1.189.800
March	6.610	5,00	33.050	991.500
April	6.610	4,00	26.440	793.200
May	7.000	5,10	35.700	1.071.000
June	11.500	7,40	85.100	2.553.000
July	22.000	8,00	176.000	5.280.000
August	28.000	14,00	392.000	11.760.000
September	17.000	4,00	68.000	2.040.000
November	6.610	3,50	23.135	694.050

December	6.610	7,00	46.270	1.388.100
			Yearly	29.148.750

Table 3 Demand Energy per month (Author's calculations)

Within the sea area will be placed five submarine turbines with a capacity of 1MW SABELLA D10. These units in total with absolute efficiency can produce a total of over 43, 5 million KWH with an efficiency of 100%, we will set a minimum efficiency of 80%, with the result that the production they will offer us will amount to a minimum of 52.5 million KWh. It is worth mentioning that capacity factor of wind farms is between 25 and 30% in a year, therefore our calculations have been made with very low efficiency criteria.

8.2 The underwater turbines

The installation of water turbines must be done in a coastal area in which it meets some specifications. Technical standards are very important for both performance and failure prevention

- The top of the installation must be at least 10 meters (for safety reasons) from the sea surface.
- The installation place should not belong to a residential, tourist, or protected place, both in terms of safety and for the installation of the electricity management unit.
- It will be necessary to build a small construction site (200sqm) on the coast that will be a warehouse of machinery and mechanical equipment, an engine room, offices, and electronic systems, as well as a power substation to convert the generated direct current into alternating current.

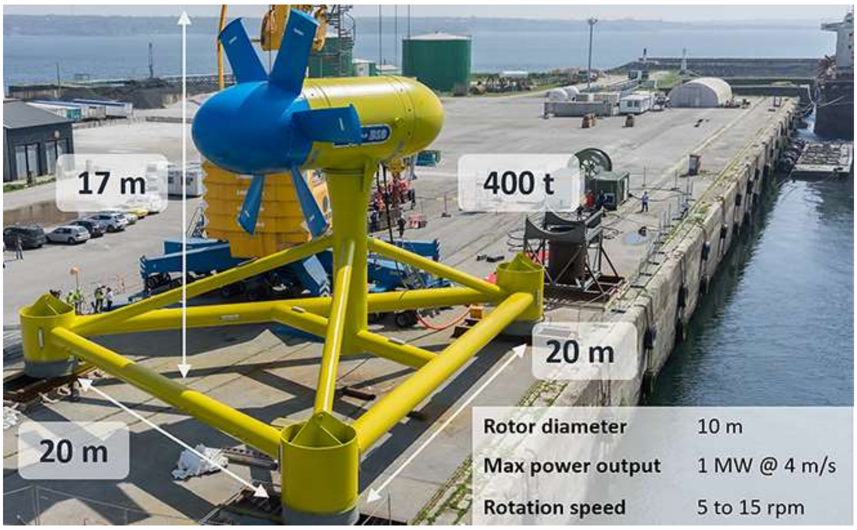

Figure 62 The SABELLA D10 tidal turbine (source sabella)

- In the picture above we see the SABELLA D10[59] submarine generator which we will use in our project. According to the measurements that have been made in previous models of the company in previous projects, it has been found that it does not destroy the local microclimate but also does not injury any animal organism. Five submarine mechanisms will be installed in the project in order to reduce the cost of investment. Their installation in the sea is very simple and safe.
- The production and storage of hydrogen through the electrolysis process must take place in a seaside area, possibly next to the facilities of the management center. The cost of electrolytic machines amounts at the three hundred and fifty thousand of euro.

Underwater energy production is particularly high as well as predictable due to high and low tides. From the installation of Atlantis,[60] we know that the efficiency exceeded 90%, a percentage that is not compared to any other RES, the wind farms have a fairly high efficiency of only 30%.

8.3 Conditions to create a power unit

The basic condition is the correct position and the approval it of all the authorities because that point should have a continuous movement of the water. The investment also should not affect both the sea movements and the tourist enterprises (the islands have a main source of income in tourism). For the success of the construction of the submarine park, must also get some basic approvals. The Ministry of Shipping and the ministry of Environmental have to approve the installation site after a check of the changes it may cause; it can affect any movement of ships or problems at the fishers. The placement should take place in Greek territorial waters. There must be an agreement with a power provider to purchase a guaranteed quantity at a specific price and connection to the transmission network. Finally, to approve the Operating License and its acceptance by all partners (State, local government, and local population).

8.4 The stages of a hybrid system with the use of underwater turbines

The project can be divided into three main stages, the first is the stage where the kinetic energy production, at this point we have the energy produced by submarine generators. The second stage is the conversion of kinetic energy into electricity; at this stage, we have to produce electricity at the substation from the submarine generators. Here at this point, we

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[59] Progressive Hybrid Architecture for Renewable Energy Solutions in islands the installation of Sabella D10 tidal turbine at Ushant Island [Online]. Retrieved from: https://www.sabella.bzh/en/projects/phares

[60] The specifications of the tidal turbine of Atlantis Resources AR1500 specifications with a rated efficiency of over 90% [Online]. Retrieved from: https://simecatlantis.com/wp-content/uploads/2016/08/AR1500-Brochure-Final-1.pdf

have the production of a quantity of electricity which we choose if will be promoted or stored.

The third step (the elaboration) is the production of green hydrogen through the process of electrolysis, at this point with the electricity we produce and the water that we have in abundance we will produce green and pure hydrogen but also oxygen. Then through the options of selling the product that is produced not only in the form of electricity but also through hydrogen and oxygen, and we will choose the best.

8.5 Financial analysis of an investment

We will design two units that will have their main difference in the final stage of production.

In this unit, the construction stops in the second stage with the production of electricity and its distribution in the network. This option is the production only when the necessary conditions exist and its disposal without any infrastructure for its storage. This plan gives a lower risk investment cost as construction is reduced but also a more economical investment. This scenario will cover the needs of consumers when RES does not produce energy through the submarine connection with the rest of Greece or will transfer the excess energy when it exists.

In the second scenario the investment we will proceed at the construction of all stages of production, the cost increases considerably thanks to the cost of storage units. We must also focus on points of secondary products, such as the production of hydrogen gas and its storage in tanks for sale, or re-liquefaction in the form of water to produce the required energy when the system needs it. We have also the opportunity to evaluate the selection of drinking water production for local communities and the sale of gaseous oxygen to medical companies and industry. We must remind that we cannot release clean water at the sea because is too dangerous for the environment.

We will analyze below with financial data the cost of analysis of the investment as well as a typical plan for each of the two options.

8.5.1 Production unit and distribution only in the network

This unit includes the cost of installation and basic connection to the grid with only a small storage unit so that electricity can be distributed day and night without being supplied from another area. Therefore, the energy produced should be sold without much time to differentiate the price from that of the daily market.

Table of Estimated Procurement and Installation Costs		
A/A	Job description	amount
1	Costs of a license supervision study	40.000 €
2	construction of buildings on land	80.000 €
3	Infrastructure (Roads, Pier etc)	100.000 €
4	Complete hydrogen generator equipment (5*960.000)	4.800.000 €
5	Transport / installation costs	100.000 €
6	Machinery	15.000 €
7	Supply of Crane at land	10.000 €
8	Supply of boats with crane	25.000 €
9	Diving & other equipment	10.000 €
10	Electronic equipment	15.000 €
11	staff education	500.000 €
12	Transmission Pipes / Network Connection - Meters	40.000 €
	Total	5.735.000 €

Table 4 Estimated procurement and installation cost (Author's calculations)

The total cost of the investment is quite high, but the production unit belongs to the green energy units and the subsidy is 70%. Below we list two investment schemes with which we can finance the investment.

The following table lists the amounts that each investor must deposit to complete the project. It is important to mention that the investment is made exclusively by investors without the participation of the state.

Private Investment

Private Investment	%	amount
Own Participation	25%	1.433.750 €
Bank Participation Grant	5%	286.750 €
Subsidy	70%	4.014.500 €
Total	100%	5.735.000 €

Table 5 Cost of a Private Investment (Author's calculations)

Borrowing with a feasible interest rate of 3.45% for ten years will bring a subsidy of 33,887€ and so fixed and variable cost tables are configured.

Stable cost	amount
Taxes	5.000 €
Permanent Staff Expenses (3 Employees)	65.000 €
Maintenance / Repair Expenses	20.000 €
Consumables	10.000 €
Sinking fund	33.887 €
Total	133.887 €

VARIABLE COST	amount
PAYMENTS	40.000 €
CONSUMABLES	30.000 €
FUEL	30.000 €
maintenance team	50.000 €
Total	150.000 €

Considering that is necessary the different selling prices of electricity to the habitants of the island, this price will amount to 2 cents of euro and the selling price of the other units in the network to 6.3-euro cents as it stands today.

The quantity of the dead point amounts to 2.226.028 KWh and the details of the investment as shown below.

total incomes	954.124 €
production cost	143.648 €
GROSS PROFIT	810.476 €
project life	20 years

PPP investment

The second option is the investment in the form of PPP, and then the amounts are made very competitive with the construction of a large photovoltaic park. An investment in which, as we have already mentioned, the weather conditions affect the production process without being able to predict it.

PPP Investment	%	Amount
Own Participation	15%	860.250 €
Bank Participation Grant	15%	860.250 €
Subsidy	70%	4.014.500 €
Total	100%	5.735.000 €

Table 6 Cost of a PPP Investment (Author's calculations)

By borrowing them at a feasible interest rate of 3.45% for ten years, he will have an annual interest arrears of 101,660€ and fixed and variable cost tables are configured.

Stable cost	Amount
Taxes	5.000 €
Permanent Staff Expenses (3 Employee)	65.000 €
Maintenance / repair Expenses	20.000 €
Consumables	10.000 €
Sinking Fund	101.660 €
Total	201.660 €

Variable cost	Amount
Payments	40.000 €
Consumables	30.000 €
Fuel	30.000 €
Maintenance Team	50.000 €
Total	150.000 €

The price for the inhabitants of the island will again amount to 2-euro cents and the selling price of the other units in the network to 6.3-euro cents as it stands today.

The quantity of the dead point amounts to 3.352.835 KWh and the details of the investment as shown below.

Total Incomes	2.057.884 €
Production cost	211.229 €
Gross Profit	1.846.655 €
Project Life	20 years

In both investment schemes, the payback time is minimal as well as the life of the project quite high. It is worth noting that the investment form of PPP is particularly advantageous due to the low participation.

8.5.2 Unit with the ability to store and produce other products

This unit can be divided into two phases, the first of production and the second of production of products other than electricity. We will check if the increase in costs is covered by the investment given that the output from the generators remains the same. We will note here that in our analysis we will assume that the entire output will be available for sale so that we can evaluate any differences. This allows the investor to assume that any unit converted to another product at a higher price will be additional revenue.

In the table below we see the total cost of the investment, including the amounts of the previous investment.

	Electrolysis	
13	Construction and configuration of the environmental area, safety measures	50.000 €
14	Electrolysis Unit (Mechanical Equipment)	250.000 €
15	Pumping Station Tanks – Filters	100.000 €
16	Transport Pipeline H_2	80.000 €
17	Creating liquid storage areas of H_2	320.000 €
18	Equipment for sale of H_2	80.000 €
	Total	6.605.000 €

Table 7 Estimated procurement and installation cost for Electrolysis (Author's calculations)

The following table lists the amounts that each investor must deposit to complete the project. It is important to mention that the investment is made exclusively by investors without the participation of the state.

Private Investment

Private Investment	%	Amount
Own Participation	25%	1.651.250 €
Bank Participation Grant	5%	330.250 €
Subsidy	70%	4.623.500 €
Total	100%	6.605.000 €

Table 8 Cost of a Private Investment (Author's calculations)

By borrowing them at a feasible interest rate of 3.45% for ten years, he will have annual interest arrears of 39.096€ and fixed and variable cost tables are configured.

Stable cost	Amount
Taxes	5.000 €
Permanent Staff Expenses (3 Employee)	65.000 €
Maintenance / repair Expenses	20.000 €
Consumables	10.000 €

Sinking Fund	39.096 €
Total	139.096 €

Variable cost	Amount
Payments	40.000 €
Consumables	30.000 €
Fuel	30.000 €
Maintenance Team	50.000 €
Total	150.000 €

The price for the inhabitants of the island will again amount to 2-euro cents and the selling price of the other units in the network to 6.3-euro cents as it stands today.

The quantity of the dead point amounts to 2.312.635 KWh and with the details of the investment as shown below.

Total Incomes	2.057.884 €
Production cost	145.696 €
Gross Profit	1.912.188 €
Project Life	20 years

PPP investment

The second option is to invest in the form of PPPs then the amounts are.

PPP Investment	%	Amount
Own Participation	15%	990.750 €
Bank Participation Grant	15%	990.750 €
Subsidy	70%	4.623.500 €
Total	100%	6.605.000 €

Table 9 Cost of a PPP Investment (Author's calculations)

By borrowing them at a feasible interest rate of 3.45% for ten years, he will have an annual interest arrears of 117.288 € and fixed and variable cost tables are configured.

Stable cost	Amount
Taxes	5.000 €
Permanent Staff Expenses (3 Employee)	65.000 €
Maintenance / repair Expenses	20.000 €
Consumables	10.000 €
Sinking Fund	117.288 €
Total	217.288 €

Variable cost	Amount
Payments	40.000 €
Consumables	30.000 €
Fuel	30.000 €
Maintenance Team	50.000 €
Total	150.000 €

The price for the inhabitants of the island will again amount to 2-euro cents and the selling price of the other units in the network to 6,30-euro cents as it stands today.

The quantity of the dead point amounts to 3.612.699 KWh and with the details of the investment as shown below.

Total Incomes	2.057.884 €
Production cost	227.598 €
Gross Profit	1.830.286 €
Project Life	20 years

In both investment schemes the amortization time increases due to the increase of investments, but thanks to the life of the project and the production of new products which we cost low, the investment is profitable.

9 SWOT analysis

9.1 Strengths

- Using only RES in our project, which are inexhaustible and clean, we have zero carbon dioxide production and we product energy with zero raw material costs, we exploit only natural resources. These features make our investment plan safer and more reliable than the variable price of all other materials used to generate electricity.

- The whole installation has low visual impact, causes minimal interference in the environment and is silent. In the proposed installation the generators will be located at a depth of 25 meters and a relatively short distance from the shore without being visible. In contrast of a Wind Farm where the wind turbines reach 40-60 meters height from the support base, or a Solar Park that covers very large areas.

- The investment can also be used for research work in academic research, which will give additional development to the local community. The scientific research is conducted throughout the year and may extend the tourist season of the island

- In contrast of the wind and solar energy, tidal energy is produced 24 hours a day, and not only some hours of each day. Also, Tidal energy contains about 1000 times the kinetic energy of the wind, so the same amount of electricity can be produced in a much smaller space

- The green hydrogen is produced with the use of electricity from RES and the electrolysis of water. In the area we are investing, the water is abundant as it concerns an island, the seawater may not offer the same efficiency as the clean water but through the zero cost of it, can be ignored. The whole using of the producing energy or producing other finished products without shortage problems can offer us significant prospects for expanding production and increasing profits. In RES systems many times the produced energy is not consumed due to network saturation.

- This investment will zero the environmental costs by covering all the needs by RES resulting in a high reduction in utility fees, which will reduce the final cost to the entire consumer public. In the final bills, consumers are charged by companies an amount related to the fine for fuel used to generate electricity from non-RES.

- The island will be energy self-sufficient, Skiathos today is supplied with energy through an underwater connection from the region of Pelion and this connection continues to supply the island of Skopelos and Alonissos. Improving the reliability and quality of energy supply, it is worth noting that these islands were left without electricity for several days in 2016 after problems in the network of Pelion that supplies them.

- Acquisition of know-how of smart micro-networks to reduce the energy costs of the islands but also to reduce losses. There are many losses in energy transmission due to the age of the networks and the islands need to be turned green.

9.2 Weaknesses

- The security of the place (which will be selected after a relevant study) and its approval by the competent authorities is a key issue, in addition to the involvement of many organizations it can also affect the relationship with neighboring states for the national borders.

- The purchase of the product by a limited number of providers - electricity distribution companies influence the formation of the final price. In the Greek market, only a few companies can distribute electricity as a final product, which limits the options in selling the final product.

- The high cost of purchasing advanced mechanical equipment, as there are not enough suppliers - manufacturers of these machines, is increases vertically the final amount of investment and cannot be done in small-scale investment projects. Also, the specialization of employees requires the selection of employees with specialized knowledge that is difficult to find.

- The high cost of training our workforce leads to the conclusion of leasing contract's and not to hiring staff. The peculiarities of the machines but also of the conditions that will exist do not allow the hiring of employees without the necessary knowledge and the corresponding physical condition. This leads us not to hire staff but to find another solution.

- The investment is made with investment plans that lead to joint ventures and the search for a high percentage of subsidies. As we have mentioned in the project plans, the use of investment programs and the joint venture with social actors can turn the investment into a very profitable option for several investment houses to cover the required funds.

- Finally, it is necessary to have a cable connection of the island with the mainland, to channel the excess cargo. The production can in these ways be sent for consumption in the network of mainland Greece without any processing. This eliminates the need to discharge energy due to storage capacity saturation or lack of demand.

9.3 Opportunities

- Electricity is a basic tool in today's world, costs in island markets are being reduced through government subsidies so that it can be sold at competitive prices. the state's participation in such an investment will reduce state subsidies.

- The use of electricity at the transport vehicles on the islands has become very popular thanks to the rather high cost of fuel, so the production and sale of cheaper electricity will turn many islanders into electric vehicles. Also, many state vehicles of the island can be converted into electric vehicles and will reduce the expenses of the municipality, it has already started experimentally on some islands.

- The high rate of reduction of RES costs in all types is an omen that shows the declining trend of construction costs, the solar parks have already reduced their construction costs to what they had set for 2050. With a corresponding reduction in costs in these units It will be possible to expand the investment to many islands due to the special taxes which provided on all the islands.

- The EU and all international organizations aim to reduce waste resulting in favorable investment financing policies (Kyoto Protocol). With decrease to zero the fossil fuels for energy production can reduce the fines imposed in Greece and further reduce the final cost per KWh

- Several young scientists have turned to substantial and effective research into the most cost-effective RES, providing adequate and competent staffing resources. Enabling researchers from all over the world to conduct research and experiment in a safe and special area.

- Our country has a coastline of about 16,000km, this construction produces high electricity potential in coastal areas. The potential of the Aegean is large resulting in the relatively strong wave activity - tidal energy. According to measurements, the average values of the annual wave power range from 4 to 11 kw / h per meter of wave, without the construction being far from the land.

- By installing small potential units, we can ensure self-sufficiency in small population groups on any island. The construction of such units can reduce the cost of current production and increase the operation of many mechanisms that use electricity, reducing both their dependence on minerals and their costs. For example, heating using electric units and not from fossil fuel units in island areas significantly changes the cost in local communities.

- Finally, one of the most economical possibilities of electricity production is the possible production of drinking water by desalination of abundant seawater, thus solving the big problem of water scarcity of the Greek islands. This production has proven its effectiveness when all the necessary measures are installed and used correctly. Water can greatly affect not only the daily lives of citizens but also lay the foundations to produce agricultural products that due to transportation costs will be particularly economical in local communities.

9.4 Threats

- Reactions from NGOs or locals seeking to remain in the current system, either out of self-interest or lack of information, are an unpredictable problem. Local communities have repeatedly refused to use natural resources because of the changes being caused. The installation of mechanisms in the marine environment can for many citizens cause a change in the natural environment. Something we always hear is that natural beauty is the reason why many tourists visit Greece, and we should not change anything

- The difficulties of preparing the strategic development plan due to the demanding controls by uninformed - untrained employees. The checks for approval by the state committees should be done by civil servants who in their majority do not have the necessary knowledge on the technology and this can significantly affect the completion of the construction dates.

- Problems of scientific documentation for the competent authorities, incorrect information may approve or reject a correct plan due to lack of understanding of the size of the problem or the data used to prove what is presented. Stay at the same is something that may not even allow the completion of the investment plan.

- The lack of initiative by the competent authorities is still an important factor that will affect the correct construction. An example is the island of HERAKLION NAXOS, due to lack of information, they did not install the desalination mechanism in the best place so as not to alter the local beauty of some coastal areas, they did not do the proper maintenance and because less resources from the wrong place, did not produce a lot of water. These events forced the devaluation and eventual destruction of an investment that would offer many advantages to a remote island.

- Finally, the high return on investment in a short period of time directs the investing public to other areas. It is worth noting that the investment does not require seaside and does not need an island, the investment can be made in an area next to a large urban center in which the buying public is much larger and therefore profits.

10 Conclusion

The main goal was to study the results that the combination of RES will offer us through the hybrid systems and to lead us more directly to the independence from fossil fuels. The cost of storage and the high waste of energy produced whenever it cannot be stored, due to the uneven rhythm of production, is the main factor in the use of minerals as an alternative or as a safety option. The combination of RES, batteries and green hydrogen can give us a solution using materials that are in abundances such as hydrogen, oxygen, and the kinetic energy of sea waves. In addition, the use of natural phenomena allows the production of electricity at zero cost from inexhaustible sources, the movement of sea currents will provide us with kinetic energy and with proper planning and study we will not cause ecological and environmental change.

The acceptance of the investment by the local community can be done with the appropriate information, as the production of energy from RES is something that is always improved. The construction of an underwater park is not obvious (the construction is placed underwater) and with proper construction does not affect the local flora and fauna. The construction of such a park will also motivate many scientific research teams to visit this project to understand and evaluate its operation, thus creating a new tourism team from the existing ones. Informing locals about the most efficient and economical choice of electric vehicles will also reduce the cost of living, electric vehicles already exist on many islands and will invest more easily accepted. Saving energy for a long time increases the cost and this is especially important for the winter months, so direct selling is more desirable and will focus the population on increasing the consumption of cheap electricity (electric heating).

An alternative that allows us to produce products that will also offer incentives and income is electrolysis. Through the Electrolysis we can produce materials that are in short supply on the market, such as hydrogen and oxygen. Oxygen can be packaged for medical and professional use with a small production unit, and hydrogen can be used as fuel, for sale, or as alternative storage. The sale of hydrogen is more feasible as it can be sold in tankers, which due to their easy access to the island, can store it in liquid form and transport it. The sale of these two materials will allow us to sell the products at prices higher than those recorded in our study. Finally, the hydrogen production of a product from one EU country and its disposal in all the others can lay the groundwork for the independence of the whole EU from countries outside it.

The main purpose of the above study was to provide a green energy source for a Greek island to cover its needs, which depend on various factors that do not exist on the island, such as the production of fossil fuel units. The construction of a hybrid park that, in addition to generating electricity, can also produce pure hydrogen, enables the production units to benefit from the full range of final products that they could produce. With the realization of the proposed investment and the implementation of the plan in other islands or coastal parts of the country, Greece will have ensured self-sufficiency in electricity from RES. At the same time, the production of hydrogen will help in the gradual modernization of the Greek

Industry and the attraction of new investors, due to cheap and green energy. These programs can be implemented with the simultaneous construction - expansion - maintenance of ports on our major islands (via PPP). Finally, with the proposed investment, with the LNG storage unit (Revithoussa) and the connection to Egypt via the Eastmed pipeline, Greece can become the most important energy hub for energy or gas transmission in the EU, improving its geostrategic position.

From the results and conclusions of the above work, in future research, we can focus on more efficient hybrid systems to cover both the local electricity networks in the Greek islands and for the complete coverage and detachment from the now hard to find fossil fuels with hybrid systems. With the use of all possible green options for more efficient production. Even a study for hydrogen production in several parts of the country and not in specific areas will offer a significant field of research for safer hydrogen transport.

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