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50% GREEN ELECTRICITY FOR LEBANON TOWARDS 2050

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Abstract

In the recent years, the Lebanese economy has been heavily crippled by energy and electricity demand. In fact, since the early 2010s, around a quarter of the national budget deficit is used up by fuel oil imports, with the energy demand rising steadily due to population and economic growth all the while electricity generation is not made any better, resulting in it falling short when compared to the total demand. Most households are only provided with around 12 hours of electricity from the public sector. To close this gap, private producers provide energy and electricity that the state is not able to. However, this is neither beneficial for consumers nor the state, nor is it sustainable since all these energies come from fossil fuels.

Lebanon needs new, cleaner, and completely local energy sources, which is why this study revolves around the diverse ways of generating electricity and how these can be applied within the Lebanese territory, aiming for those to make up for 50% of the demand in 2050.

The aim of this project is to achieve the 50% renewable energy goal. For this reason, four different energy sources have been reviewed, not considering combustible fuels and the already present hydroelectric power.

Using this information, while also looking at multiple completed studies which cover the relevant subjects, we were able to determine the production capacity and possible locations for the chosen energies, considering a demand growth scenario which was set using population and economic expectations in the coming years, up until 2050.

The energies turned out to be biomass, offshore wind, photovoltaic farms and concentrated solar power, which were compared in terms of cost to the current thermal and hydroelectric production. Using an algorithm, we developed, this cost analysis was made possible by estimating the cost of installation of the production which would require little to no further investments unlike current plants which require a constant stream of combustible that expensive and cause huge environmental risks. This was only possible after defining the maximum production capacity of each source as well as defining the locations and justifying the choices.

Finally, we devised a grid plan in order to optimize electricity distribution between the different production lines including privately owned photovoltaic setups and combustion generators for an opt in/opt out system.

This study, if applied correctly would make the Lebanese government able to provide for its people while solving other issues such as waste management and the environmental crisis that Lebanon is going through.

Acknowledgements

It was an honor to work with Dr. Said Chehab, once of the most renowned professors at ESIB for being our supervisor during this project and setting us on the right path time and time again while also being very supportive of the work we achieved.

We would also like to thank Dr. Sabine Saad for her contribution after being recommended to us by Dr. Chehab.

It is also important to give credit to the people and organizations from which we sourced crucial information: the Ministry of Energy and Water, Electricité du Liban, the International Renewable Energy Agency, engineer Georges Boueri and once again, Dr. Said Chehab, whose publications and reports have made this work possible.

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Acronyms

RnE	Renewable Energy
WHO	World Health Organization
EDL	Eleciricité du Liban
LBP	Lebanese Pound
CoM	Council of Ministers
MEW	Ministry of Environment and Water
MoF	Ministry of Finance
IPPs	Independent Power Producers
CO2	Carbon Dioxide
MWh	Megawatt hours
DC	Direct Current
AC	Alternative Current
PV	Photovoltaic
COVID19	Coronavirus disease of 2019
Kwh	Kilowatt hours
c$	Cents
US	United States
UK	United Kingdom
Ft	Feet
°F	degree Fahrenheit
°C	Degree Celsius
EGS	Enhanced geothermal systems
MSW	Municipal Solid Waste
GW	Gigawatt
IEA	International Energy Agency

TWh	Terawatt hours
MW	Megawatt
KW	Kilowatt
GWEC	Global Wind Energy Council
GWR	Global Wind Report
IRENA	International Renewable Energy Agency
Kwh	Kilowatt hours
LCOE	levelised cost of electricity
LL	Livre Libanais
GWh	Gigawatt hours
LED	Light emitting diode
WtE	Waste to Energy
T/d	Tons/day
kJ	Kilojoule
Kg	Kilogram
USD	U.S dollars
kWp	Kilowatt peak
NEEREA	National Energy Efficiency and Renewable Energy Action
NREL	National Renewable Energy Laboratory
GHI	Global Horizontal irradiance
M^2	Square meter
MWp	Megawatt peak
CSP	Concentrated Solar Power
PT	Parabolic Trough
CR	Central Receiver
MWel	Megawatt electric

PS20	Smart Power Station
DNI	Direct Normal Irradiation
O&M	Operation and Maintenance
HTF	Heat Transfer Fluid
We	Watt electric
m/s	Meters per second
Km	kilometer
N/A	Not applicable
PPP	Public private partnership
BOO	Build own and operate
BOT	Build operate and transfer
BOOT	Build operate own and transfer
IPP	Independent power producers

1 Introduction

Renewable energy (RnE) production is at an all-time high and is only set for even more growth in the coming years [1]. These energy production methods are becoming more efficient and affordable to both governments and the general public. A lot of research is being conducted in that domain due to their crucial part in creating a sustainable civilization, as it is the only structure capable of allowing humanity to prosper without facing the dire consequences of our seemingly endless growth. This energy is present in many forms: geothermal heating, hydrogen cells (for electric cars), solar panels, etc. This study will focus on the feasibility of integrating green energy in the pre-existing Lebanese electricity network on a national scale. Lebanon has been suffering of electricity shortages for almost half of a century now, with a government incapable of providing 24 hours of electricity and having the citizen resort to private generator owners to consistently have one of the most basic needs in the 21st century.

In addition to that, and according to the World Health Organization (WHO), the air pollution concentration in Lebanon is three times the recommended maximum on average, especially in the more urbanized area such as Beirut, Zahle, Saida and Baalbeck [2]. Both of these issues cannot be eradicated but at least mitigated by transitioning a part of the electricity production from traditional combustion to different types of RnE.

The aim of this project is to achieve 50% green energy of the general usage in Lebanon by 2050. The study will focus on different ways to produce electricity with RnE and finally select the most suitable options for Lebanon's needs. The criteria for the selection will be as follows: cost efficiency, bulk production, its energy efficiency and their suitability to fit the geographic and topologic situation of the country. The verdict will be made using an algorithm that will be developed to compare the different prices of kilowatt hour production and the return-on-investment time of each one of the chosen energy sources.

2 Project Facts and Figures

List all the project members, their disciplines, and the topic they have worked on.

Name	Affiliation	Topic
Anthony Najjar	Génie Mécanique	Implementation of CSP and PV
Gilbert Chedid El Helou	Génie Mécanique	Implementation of Biomass and Offshore Wind Farm
Sarkis Mardirossian	Génie Mécanique	Research and Requirements
Samer Khallouf	Génie Logiciel	Developed Economic Study Algorithms
Clara Chelala	Génie Logiciel	Developed Economic Study Algorithms

Table 1 Project Members

Summarize the project meetings

Meeting Number	Participants	Place	Discussed topics
1	All Members (Supervisor Present)	ESIB – Mar Roukos	Project constraints, software tools, architecture plans, supervisor expectations
2	All Members	ESIB – Mar Roukos	Further discussion on implementation, Economic Study
3	All Members (Supervisor Present)	Teams	Recapitulation in order to continue
4	Mechanical Engineering Students	Mansourieh	First Implementations and Summary of background research
5	Mechanical Engineering Students (Supervisor Present)	ESIB – Mar Roukos	Briefing with supervisor concerning results of previous meeting.
6	All Members	Ain Saadeh	Economic study, use of algorithms
7	All Members (Supervisor Present)	ESIB – Mar Roukos	Briefing with supervisor concerning results of previous meeting.
8	All Members	Zouk	Finalization of Economic study

Table 2 Project meetings

3 Background/Research

With the increasing threat that is climate change and resource scarcity, research teams around the world are working in order to ensure the development of humanity by replacing parts of our daily lives by their sustainable counterparts. For instance, internal combustion engines are more and more being replaced by electric motors in cars [3] for the most part and hydrogen fuel cell in some instances. This is due to the fact that combustion engines, despite being more efficient and easier to maintain, run on non-renewable energy in the form of gasoline that is burnt, creating more air pollution, alongside being from a finite source that is being exploited much faster than in replenishes.

The same transition is being made to the production of electricity itself. Since it was first discovered and experimented on by the likes of Nikola Tesla and Thomas Edison in the late nineteenth century, electricity has been mostly produced through combustion of coal and other fossil fuels [4] that suffer the same disadvantages as the gasoline used in cars: pollution and uncontrolled exploitation of the Earth’s reserves. However, fossil fuel-based electricity was not the only one we knew about as a lot of researchers were looking into alternatives. For instance, in 1872, William Armstrong discovered hydroelectric power which generates electricity from the movement of water streams, which led to the opening of the first hydroelectric power station in 1882 [5]. In 1927, that the first wind turbines were made available for purchases, but were still too expensive and not efficient enough, as well as requiring a good amount of wind to actually be useful.

During the twentieth century, a lot of advancements were made possible thanks to solar power especially in space exploration where other ways of generating energy were not available [6]. The real surge in RnE generated electricity started in the 1990's when it was made progressively available to the public sector. One can name the offshore wind farm in Denmark, built in 1991 as one of the first real success stories of such methods [7].

In the following thirty years, renewable energy would see its production skyrocket, passing benchmarks such as 100GW for solar energy as of 2013, with the popularity one rising as countries distance themselves from fossil fuel energy as RnE became increasingly efficient, with the aim of reducing air pollution and limit the need to rely on importing the materials used to run non-renewable energy plants. All this exponential growth in the RnE field was possible from investments from countries and companies alike. Despite the pandemic, the world's renewable energy capacity increased by 45 percent in 2020, part of a "unprecedented boom" in wind and solar energy, according to a new International Energy Agency research. It is the highest yearly pace of growth since 1999 [8].

Notably, here are five of the biggest renewable energy companies in the world: the one that stands at the top is none other than Ostred A/S(DNNGY) a Denmark-based multinational that mainly relies on wind power. It develops and builds offshore wind farms. It has a revenue of $51.45 billion and net income of $7.68 billion. Iberdrola SA (IBDRY) stands at second place. It is a Spain-based multinational company that provides electric utilities. Its specialization is clean energy that includes onshore and offshore wind, pumped hydro, solar photovoltaic and battery storage. It has a revenue of $36.80 billion and a net income of $3.34 billion. At third place, we have JinkoSolar Holding Co. Ltd. (JKS), a Chinese solar power company. It mostly produces silicon ingots and wafers, solar cells and solar modules. It has a revenue of $33.95 billion and a net income of $163.1 billion. In fourth place, Vestas Wind Systems A/S(VWDRY) a Denmark-based energy company. It develops, manufactures and installs wind turbines. It installed wind turbines in numerous countries across the globe. It has a revenue of $15.2 billion and a net income of $490 million. Finally, we have Siemens Gamesa Renewable Energy SA(GCTAY) a Spain-based wind engineering company that mostly sells inshore and offshore wind turbines, turbine gearboxes, off-grid and other related equipment. It has installed products and technology in over 90 countries. It has a revenue of $9.48 billion and a net income of -$920 million. [9]

4 Requirements and Constraints

4.1 Functional Requirements

Since this project is not about designing a physical product, there are no hardware requirements to it. It consists of the study of different ways of producing electricity from renewable sources and how to implement them in Lebanon.

The functional requirements begin with a full analysis of the current electricity distribution network in Lebanon, more specifically what Electricité du Liban provides. It will involve the repartition of the electricity supply and demands across the country to know how to later transition 50% of that production into the chosen RnE sources. Besides that, the private generator sector which currently delivers far more than EDL as well as the private RnE production, currently on the rise, have to be taken into account and either be kept unchecked or replaced by state provided electricity.

The analysis will be accompanied by a study of the different ways of producing electricity from renewable sources for the purpose of looking at their implementation within the Lebanese territory and the possibility of doing so, depending on the requirements of each source.

Finally, an algorithm was developed to compare the costs and consistency of the different approaches that can be taken to complete the objective by giving the area required for the farms and calculate the time of return on investment of the project once fully implemented. In addition, a smart grid system was devised that will connect small local installations of RnE sources to the main network (Feed In/Feed Out) with smart counters to regulate the pump/absorb energy according to the demand of the population.

4.2 Constraints

First off, the numbers used for the production and revenue of the plants will be that of 2018, 2019 and 2020 simply because the newer data is not yet available. This is an issue because 2021 saw a drastic change in the way electricity distribution works, where the power supply was cut to three hours a day and sometimes there was none at all due to the fuel crisis. This sector was incredibly unstable, and the data would be completely different from the previous years.

Secondly, as of November 2021, 82% of Lebanon is considered to be living in poverty [10] which means that the already rampant tax and bills evasion is only going to get worse in an already bankrupt and almost failed state. Realistically, implementing this project would require a third party to donate enough money for the first investments and expecting people to pay their electricity bills for the income calculations to be correct.

Finally, with the steep decline of the value of the Lebanese Pound over the last two years, the amounts discussed will differ in currencies where anything related to the Lebanese state will be accounted for in LBP while the price of the hardware (plants, solar panels, windmills, etc.) will be in US Dollars.

This project also must align with all the norms required by the Lebanese Government when it comes to building, distributing and setting up a network as cited in the law 462, and later overshadowed by law 288 of 2014 which stated that the Council of Ministers (CoM) and the recommendations of the The Ministry of the Environment (MEW) and the Ministry of Finance (MoF) would license Independent Power Producers (IPPs), thus encouraging the private sector's investment in RnE [11].

5 Project Management

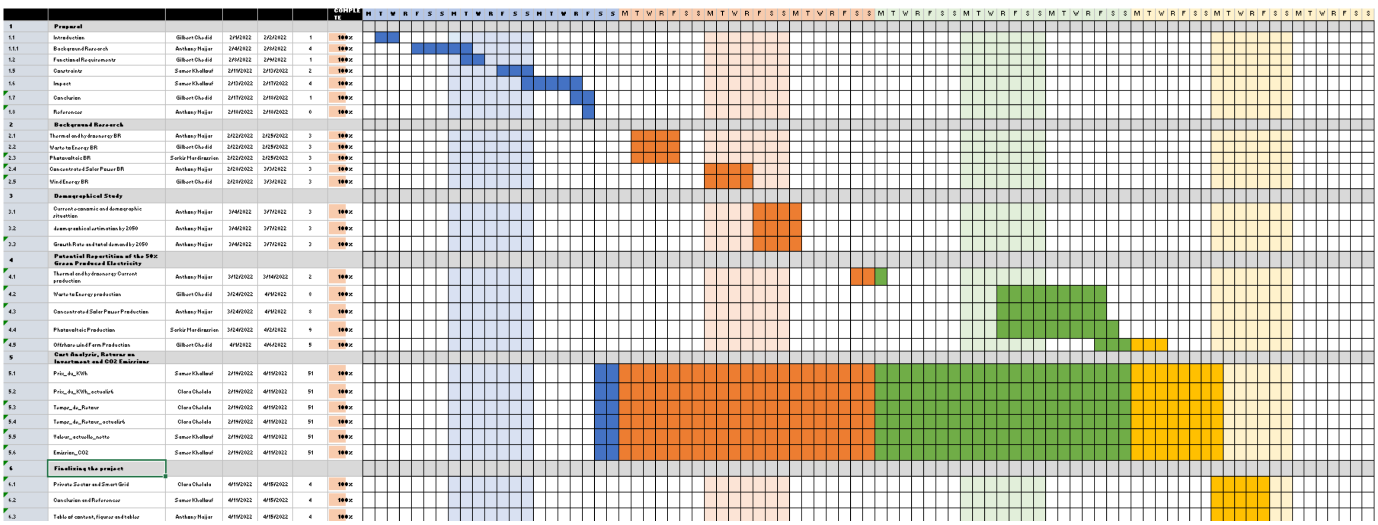


Figure 1 Gantt Chart

6 Proposed Solution

6.1 Skills for Engineering Practice

In order to complete this project, the following engineering skills were used:

- Algorithm and Interface Development
- Demographic and Economic Estimations used to find out the expected growth rate
- Economic Actualization used in the economic analysis
- Energy Calculations in the implementation process
- AutoCAD drawings for the wind farm sizing possibilities

To develop our interfaces, we chose to use python since our main goal is to draw bar charts and do mathematic calculations and python is the best programming language for this task. We used numerous libraries from python: the first being tkinter to create our interfaces and create a good design, the second is matplotlib to draw our bar charts and finally the math library to be able to do complex mathematical calculation. The github platform was also used in order to send/receive the newly updated version of the application more easily.

The application developed can be divided into five main interfaces: the first being the home page where the user can freely navigate between the calculators that he desires. The second is the calculator of the cost of the KWh of each technology both in cashflow (cost of KWh formula in the cost analysis section) and dynamic way (leveled cost cost of KWh). The third, is the calculator of the return on investment of each technology both in cashflow (time of return on investment) and dynamic way (leveled time of return on investment). The fourth is the calculator of emission of CO2 of each renewable energy source and finally the last one is the cumulative discounted profit (equation: leveled yearly benefit) for each renewable energy source.

6.2 Solution Specific Research

1. Energy Around the World, General Overview

Fossil Fuels

Because of their significant carbon emissions, or the amount of carbon dioxide released into the atmosphere, fossil fuels are sometimes known as dirty energy sources. They are made up of the fossilized, buried remains of animals and plants from millions of years ago. Fossil fuels produce energy when they are burned. [13]
There are three main type of fossil fuels; petroleum, coal and natural gas.

• **Petroleum** is an umbrella term that includes products such as crude oil, which is refined into more familiar fuels such as gasoline, jet fuel, kerosene, and diesel.

• **Coal** is a rock that is found at the earth's surface and is one of the most abundant fossil fuels on the planet. Surface mining (clearing away the top layers of rock and soil using machinery) and underground mining are both used to extract it (using machines and miners to remove coal deep underground).

• **Natural gas** is extracted in the same way as oil is. It is a mixture of gases trapped beneath the earth's surface. Drilling and fracking advancements have revealed massive natural gas reserves.

The primary cause of global warming is fossil fuels. When fossil fuels or dirty energy are consumed, they produce significant amounts of toxic byproducts, particularly carbon dioxide, which trap heat in the atmosphere and contribute to climate change. Fossil fuels can also pollute the air, water, and oceans, resulting in hazardous pollution. The most effective strategy to reduce harmful carbon pollution that harms the environment is to replace fossil fuels with renewable energy for power generation.

On the other hand, renewable energy includes sources such as sun and wind that occur naturally and continuously and can play a big role by reducing greenhouse gas emissions.

In comparison to fossil fuels, renewable energy, often known as clean energy, is becoming a more essential source of power. Renewable energy is clean, safe, efficient, and unlimited; it can be obtained practically anywhere in the world because every country has access to sunlight and wind; and it is unquestionably less expensive economically and environmentally than fossil fuels. [14]

The following tables show the emission factor for each technology, renewable and nonrenewable technologies:

Technology	Emission factor [Tonnes of CO2/MWh]
Heavy fuel	0.778
Diesel oil	0.778
Natural gas	0.443
Wind	0.001
Hydro	0.01
Solar PV cells	0.032
Biomass	0.23

SOURCE OF ENERGY	FOSSIL FUEL	ALTERNATIVE	RENEWABLE	EMISSIONS	LAND USE
Biomass	✗	✓	✓	☁☁☁	🌲🌲🌲🌲🌲
Coal	✓	✗	✗	☁☁☁☁☁	🌲🌲🌲
Hydro	✗	✓	✓*	☁	🌲🌲🌲
Natural gas	✓	✗	✗	☁☁☁	🌲
Nuclear	✗	✓	✗	☁	🌲
Petroleum	✓	✗	✗	☁☁☁☁	🌲🌲
Solar	✗	✓	✓	☁	🌲🌲
Wind	✗	✓	✓	☁	🌲

Figure 2 characteristics for different source of energy [15]

Table 3 CO2 emission factor for renewable and nonrenewable technologies

It is obvious that producing electricity using renewable technologies is healthier for the environment than dirty energy.

The most popular renewable energy sources are:

1) **Solar energy**
2) **Wind energy**
3) **Hydro energy**
4) **Tidal energy**
5) **Geothermal energy**
6) **Biomass energy**

1) **Solar energy**

Figure 3 Solar panels installation

Solar energy is a gradually popular way to supplement your energy usage because sunlight is one of the most abundant and freely available energy resources in the planet. The earth receives in one hour an amount of solar energy equivalent to the total energy required by the planet for a whole year. This amount of solar energy varies accordingly to the time of the day, the season of the year and the geographical location of each country.

Private solar systems, through rooftop panels, are placed to generate power for homes and private businesses. Solar farms can generate electricity for thousands of homes by using mirrors that concentrate or focus the radiations of the sun across acres of solar cells.

Solar panels are considered as an important source of power because they can work even through clouds. The more sunlight you get, though, the more energy you'll create.

North facing rooftops are not suitable for such technologies because panels should be south-facing or south-west facing to receive the desired amount of sunlight every day.

Photovoltaic systems convert sunlight into electricity. Solar panels are arranged together in series and each panel comes with a thin layer of silicon cells, a glass casing surrounded by a unique film and wiring and a metal frame. Solar panels receive and absorb the radiations of the sun, and through an inverter for conversion from DC to AC, the sunlight will be converted into usable electricity. The generated power can feed your home directly or can easily be stored in batteries for later usage during the hours of darkness. The excess electricity produced can be directly sold to the grid.

On top of the solar cell, you'll find a small semiconductor wafer composed of two layers of silicon. One of the layers has a positive charge and the other has a negative one. Both generate an electric field. Light energy from the sun hits the photovoltaic solar cell momentarily; the cell is energized, causing electrons to separate from the atoms in the semiconductor wafer. The loose electrons are then driven by the electric field around the water, creating an electrical current. Finally, solar panels convert solar energy into electricity.

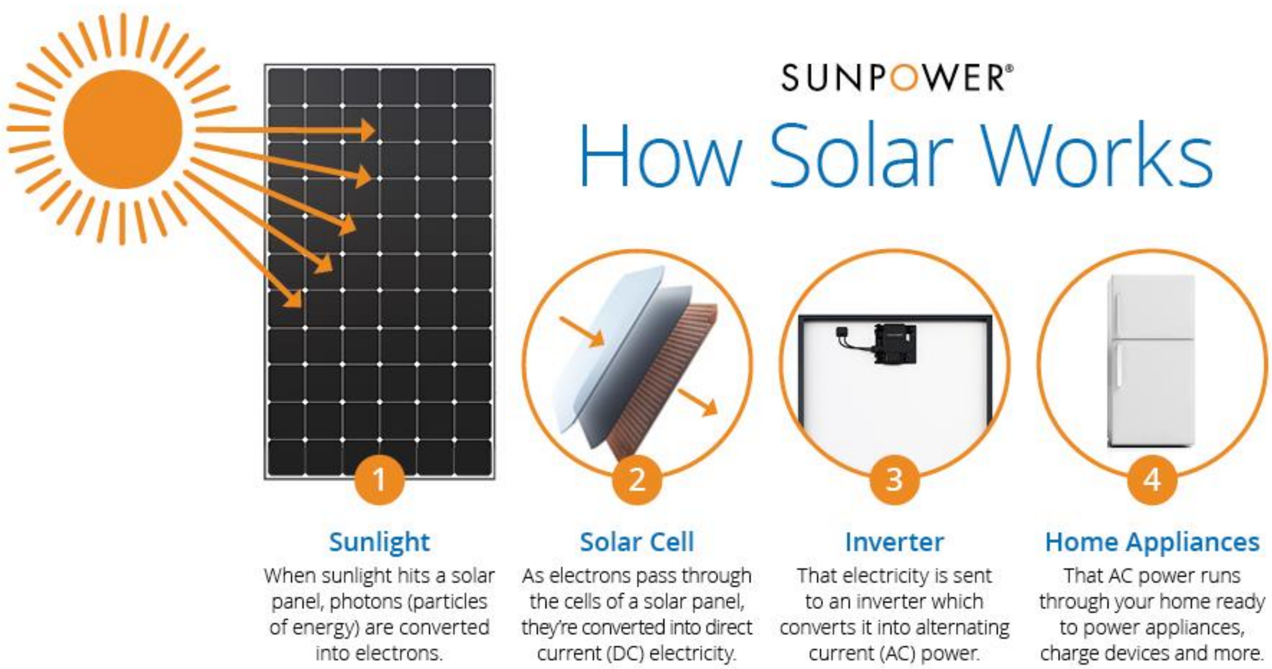


Figure 4 How solar power works in 4 steps

Advantages of solar energy

1) Renewable, clean and environmentally friendly

Solar energy is renewable, clean and has zero emissions. Solar energy is also one of the most effective sources of renewable energy because of the reliable amount of the

sun the world gets. Energy generated by solar panels is clean energy because it does not produce any greenhouse gasses emissions.
This technology is healthy for the environment and is not harming the planet. Solar panels are eco-friendly.

2) Reduce the cost of the electricity bills

You will not be charged for the energy you generate with your solar panels because the sun's energy is renewable and free.

Being self-sufficient by generating your own electricity and not relying on the grid for power; alternatively, you can sell the extra electricity you generate to the grid and receive payment for the excess energy you produced.

3) Independence / own generated energy after dark

First, you will not be suffering from any power cut or any maintenance by the grid on their power lines. Second, if you invest in home solar battery storage, you may be less reliant on the national grid and you can benefit from the power generated during the day and stocked within the batteries to be used at night.

4) Low maintenance costs

Solar panels don't require much care; a simple cleaning a couple of times a year would suffice. Solar panels are installed at an angle which allows rain to run off freely taking all the dust and dirt away.

Most reliable solar panel manufacturers offer 20-25 years' warranty, because PV panels should last at least 25 years and the inverter lasts approximately 10 years.

5) Property value

Solar energy systems are usually a good investment for your home. Installing them on your property will make your home more valuable than one without.

6) More advanced and more affordable year after year

Every year, solar panels are becoming more and more affordable whilst also maintaining the quality or even a better quality with a lower price. The cost of panels is decreasing every year even with a better efficiency and new technologies.
Just to mention a small increase in panels costs due to the shipping crisis in 2021 caused by COVID19.

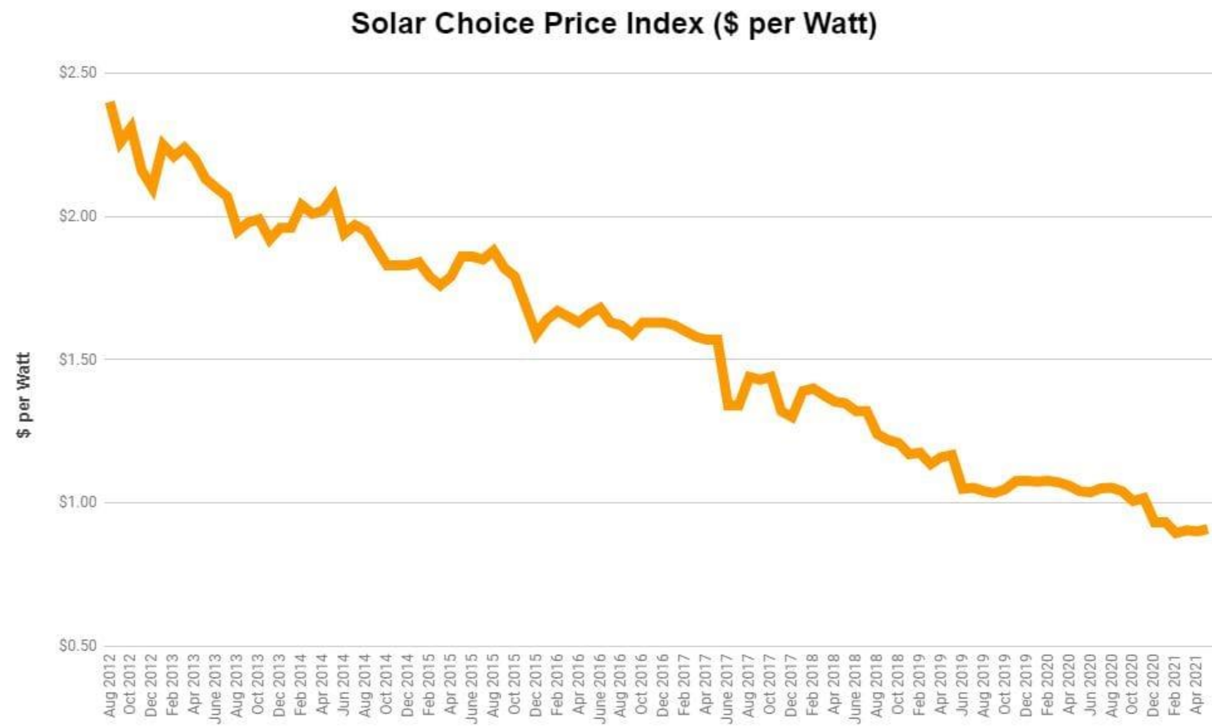


Figure 5 The decrease in solar panels price over the last 10 years

7) No permit required

Since solar panels are considered "permitted for development," you usually don't need a permit to install them on your roof.

Disadvantages of solar energy

1) Cost

As mentioned before, solar panel prices are going down over the year and will for sure go down more and more in the future. But paying for solar panels, batteries for storage, wiring, inverter and the installation cost are fairly high and not affordable for some.

If you want to create electricity during the day and profit from the surplus during the night, you'll need to store it in huge batteries, which are quite expensive.
In some cases, it is smarter to use solar energy during the day and take energy from the grid during the night.

2) Weather dependent

The effectiveness of a solar system decreases during gloomy and wet days. Solar panels must be exposed to sunlight in order to create solar energy.

3) Low energy conversion rate

The PV capacity factor is around 30% max. Solar panels can only generates 25 to 30% of the sun's energy into power.

4) Associated with pollution

Transporting and installing solar systems can have an indirect impact on the environment due to greenhouse gas emissions during the manufacturing process.

Solar energy, on the other hand, pollutes the environment significantly less than other alternative energy sources.

Figure 6 Private solar panels installed on roofs

2) Wind energy

Figure 7 Wind farm

Wind generation can be used in both residential and commercial properties.
People used to create energy with old-fashioned windmills. Tall turbines are now employed to generate electricity. Wind energy turns the turbine's blades, which feeds an electric generator to generate electricity from wind, a freely and natural available resource.
Compared to fossil fuels, Wind energy is a clean energy that generates electricity using the wind's natural strength, so wind turbines are environmentally friendly and will not harm the planet.

Wind turbines are rotary devices that draws power and produce electricity from a fluid motion. The spinning blades turns the shaft connected to a rotor to produce electricity.
Due to recent technologies, if more power is needed to be generated, a gearbox within the wind turbine accelerates the rotation speed with a limitation of 16 rotations per minute for safety measures.

Advantages of wind energy [16]

1) Renewable, clean and environmentally friendly

Wind energy is renewable and one of the cleanest forms of energy because it does not rely on fossil fuels to power the turbines. Turbines run strictly on the power of wind generated so wind energy does not lead to climate change by emitting greenhouse gases during the production process.

2) Advances in technology

As technology improves, wind turbines are available in a wide range of sizes. New designs available that will generate even more power, require less maintenance and run more quietly and safely.

3) Can be built on existing farms

Farmers and ranchers can continue to work the land because the wind turbines use only a fraction of the land so it does not disrupt the farm’s production. For the usage of the property, wind power plant owners pay a fee to the farmer or rancher, providing additional income to the landowner.

4) Wind creates jobs

The production of wind energy provides new work opportunities all over the world. Wind turbines require technicians, and by 2050, wind might provide over 600,000 jobs in manufacture, installation, maintenance, and support services.

5) Cost-effective

The Kwh is sold at around 1 to 2.5c$ because wind energy systems have low operating expenses because there are no associated fuel costs.

Disadvantages of wind energy

Figure 8 Wind turbine

1) Threat to wildlife

Wildlife has been found to be harmed by wind turbines. Birds, bats, and other flying creatures have a little chance of surviving when they are struck directly by a revolving wind turbine blade.

2) Noisy

Wind turbines are usually placed in rural areas where most people don't live because they are quite noisy. For offshore wind turbines, noise is not an issue.

3) Unpredictable / unreliable

The wind is not consistent. Wind energy cannot be generated on a regular basis; it can only be generated when the wind blows.

It's hard to predict the amount of energy wind turbines can collect or generate at a certain time.

In this case, an energy reserve source is required as a backup plan to meet the electricity demands of the population in case the winds die down for a long period of time.

4) Expensive upfront Cost

These gigantic constructions, which can reach hundreds of feet in height, necessitate a significant upfront investment. The installation of wind turbines in rural locations necessitates additional investment in underground lines to transport power to more populous areas such as towns and cities. The initial installation and construction stage accounts for the majority of the expense, but after that, as long as there is wind, wind energy creates an unending source of energy.

5) Associated with pollution

Wind energy only emits greenhouse gases indirectly during the production and transportation of wind turbines, as well as during the installation process.

3) Hydro energy

Figure 9 Hydro energy

Hydro energy is one of the most renewable energy resources commercially developed and one of the oldest and largest sources of renewable energy. Hydropower plant consists mainly of a water reservoir, dams, penstocks, turbines and generators. The water is stored in the dams and the quantity going to the turbine is controlled by operators. Then, the water from the reservoir goes to the turbines via the penstock and the dam gates. Further cleaning takes performed at the reservoir's intake filtration system to ensure that the water is free of particles that might damage the blades.

The turbine converts the kinetic energy of falling water into mechanical energy. the turbine links with a shaft to the generator's motor that finally converts the mechanical energy to electricity.

Hydro energy is more reliable than solar and wind power and the electricity to be stored for future uses when the population demands reach their peak.

To conclude, the water is stocked in a large reservoir. Controlling the gate of the dams, a certain quantity of water moves to the turbine that produces mechanical energy from the kinetic energy of the water arriving from the tank. Then, the generator linked to the turbine produces electricity as shown in the figure below [17]:

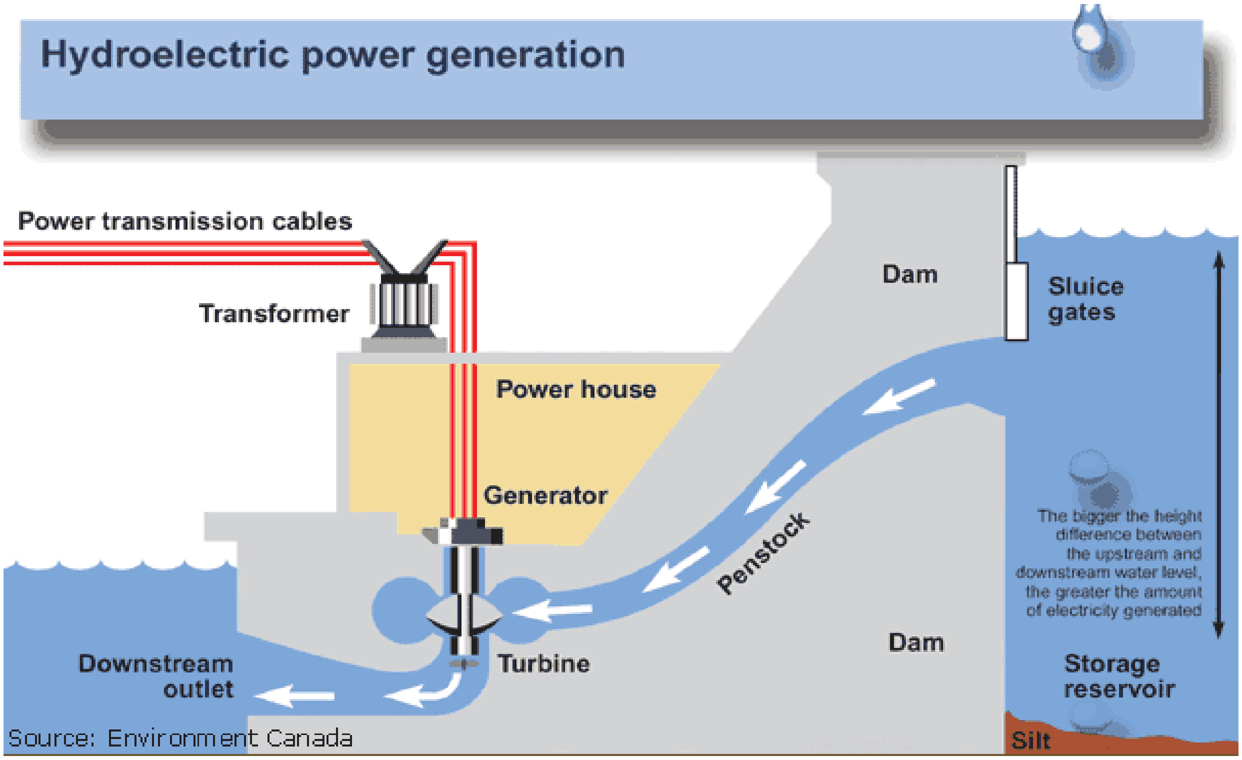


Figure 10 Hydroelectric power generation

Advantages of hydroelectric energy

1) Renewable, clean and low emissions

Water is a free and natural replenishing resource. Hydroelectric energy, mainly powered by water, is a renewable energy source. To generate electricity, a hydropower plant is powered by water so there is no pollution emitted and it does not produce carbon dioxide or any greenhouse gasses emissions that drives global climate change.

2) Reliable and adjustable

To regulate the amount of water needed to create electricity, hydropower facilities are built either on an actively running river or with a dam. Water flow is very predictable and reliable and the output of electricity can be easily controlled and managed. If energy is needed to answer to the demands of a certain population, more water will flow into the plant for electricity production. If not, less electricity will be produced by managing the quantity of water flow arriving to the turbine.

3) Safe

Hydro power is a safe technology that generates electricity. Water is the only fluid used to power to hydropower plant, there is no risk of oil spills or gas pipes breaking and causing damage.

Disadvantages of hydro power

1) Environmental consequences

The biggest disadvantage of hydroelectric energy is the negative impact it can have on the environment. During the construction process, dams can seriously harm or damage the environment. To construct a dam, new roads and electricity lines must be installed in addition to the displace of natural habitats.

Dams can obstruct fish movement, especially for species that rely on rivers to spawn, such as salmon. Dams can even affect biological cues that tell fish when it's time to migrate. Some dams have tried to compensate for this hydroelectric energy deficit by building fish ladders or fish elevators to help migratory fish reach their spawning grounds.

The final environmental disadvantage of hydroelectric electricity is water quality. Dams reduce water flow, which reduces oxygen levels in the water. Lower oxygen levels downstream can be caused by lower oxygen levels behind the dam. When there is less oxygen in the water, some fish species have a harder time surviving, which has an influence on river habitats.

2) Expensive to build

Hydroelectric power plants don’t cost much to operate, but it is so expensive to build. A hydroelectric power plant can cost millions of dollars or even more like the Itaipu dam which took 18 years to be build and 18 billion dollars. It costs an average of 600 $ per kilowatt to be build.

3) Limited reservoirs

You cannot build a dam anywhere you please. In reality, most viable sites for hydroelectric dam construction have already been utilised. In addition to that, a hydraulic dam with a small reservoir may not generate enough power, so it may not provide sufficient profit to make the project worthwhile.

4) Drought potential

Large dams are built across a river to generate electricity and store water in a reservoir. In fact, this can reduce river water flowing downstream and cause drought below the dam. If there is not enough water flowing into the plant, the generation of power will be severely reduced because of the drought.

Hydro power is a 100% renewable energy source that can generates electricity during the day and during the hours of darkness.
Hydroelectric power is more consistent than solar power because water is rushing through the turbines 24/7 whereas the sun only shines during the day.

Wind power is another reliable source of renewable energy, although wind turbines are more expensive to maintain than hydropower facilities.

Hydropower is also superior to biofuels in terms of environmental effect after the facility is built and operating smoothly. Producing energy using water does not produce CO_2, however biofuels necessitate the felling of trees and plants that will be burnt as fuel.
In conclusion, hydropower is a renewable energy that generated electricity 24/7 with limited environmental impacts and reliable way to produce clean energy.

4) Tidal energy

Figure 11 Tidal energy

Tidal energy, which uses twice-daily tidal currents to power turbine turbines, is another sort of hydro energy. Although tidal flow is not continuous, it is very predictable and can thus compensate for periods when the tide current is low, unlike some other hydro energy sources.

Although tidal and wave energy are still in their infancy, the ocean will always be regulated by the moon's gravity, making harnessing its power a viable alternative. Some tidal energy systems, such as tidal barrages, which are positioned in an ocean bay or lagoon and work similarly to dams, may have an impact on wildlife. Wave power is built on dam-like structures or ocean floor–anchored devices that are on or near the water's surface, similar to tidal power. [18]

How Does Tidal Energy Work?

In a nutshell, tidal energy is the gravitational and kinetic energy contained inside our planet's huge bodies of water. The ebb and flow of water is caused by the gravitational attraction of the Moon, Sun, and Earth's rotation.

These celestial forces transfer a mind-boggling amount of water every day. And when there's water moving, there's kinetic energy to be harnessed.

The energy created by all this rushing water may be harnessed using a turbine that turns kinetic energy into electrical energy. This method of energy generation is comparable to hydroelectricity; however, it does not require falling water.

Unlike wind or solar power, tidal energy is relatively predictable, which sets it apart from many other kinds of renewable energy. The weather may often have a significant impact on the efficiency of many environmentally friendly electricity systems.

The tides, on the other hand, are consistent and follow a predictable pattern all across the planet, which is a tremendous asset for any would-be energy provider.

Simple Definitions:

1. Kinetic energy: The amount of energy that an item or mass (such as a body of water) has as a result of its motion. Dropping a ball from the top of a skyscraper, for example, would generate kinetic energy.

2. Gravitational energy: Gravitational potential energy is the potential energy released when one smaller item collides with another larger object. There is a lot of potential gravitational energy before you drop a ball from the top of a building, for example, because gravity will pull it to the ground.

How Is Tidal Energy Produced?

You must first transform kinetic energy into electrical energy before you can collect tidal energy.

The easiest method to do this is to use a turbine that spins from the physical force of the tides and turns the flow of the water into useful power. There are three types of tidal turbine systems now available:

Tidal Barrage: The most efficient means of capturing tidal energy is through tidal barrages. They necessitate the building of a dam-like structure that drives water through a bottleneck where a turbine is located at high speeds. Higher water velocity equal more kinetic energy, which translates to more power. This is similar to a hydroelectric dam system in many aspects.

Tidal Turbines: This system works in a similar way to a wind turbine. A simple turbine is placed in the water. The rotors may be driven by the water running over it. Although it produces less energy than others, this kind is perhaps the simplest of all the systems and has a lower installation cost.

Tidal Fences: Tidal gates are similar to tidal turbines in design, but they have one key difference: a different rotor. These devices employ a turnstile-like construction that spins in lockstep with the flow of water. Several versions of this design have been presented, but the most common is a spinning cylinder form that stands vertically.

The Newbie: Floating Tidal Turbines

This sort of design is still undergoing testing and is not yet available for commercial usage. A floating barge with turbines on its underbelly is used in the system.

The turbines are able to spin in the current that flows near the water's surface. This concept avoids the need for any form of seabed building, making it easier, cheaper, and less destructive to the environment than any other method now in use.

This promising technique might allow tidal energy farms to be built everywhere on the planet.

Advantages of Tidal Energy

1. Clean and Renewable

Tidal energy is as clean and renewable as any other renewable resource currently accessible. When compared to other renewable energy sources, it produces no pollutants and takes up very little physical area.

2. Predictable and Reliable

In most areas, there are two high tides and two low tides per day. Unlike many other renewable resources, this cycle can be easily predicted and is not vulnerable to unforeseen variations. Some systems also gather energy from tidal currents regardless of which way they are flowing, allowing energy generation to continue indefinitely.

3. Long-Lasting Equipment

Tidal energy systems have a long lifespan and are naturally resistant to aging. Most tidal systems are expected to last 75-100 years on average. Solar panels, on the other hand, often disintegrate after 25-30 years. This saves time, energy, and money and is more cost-effective when done on a big scale.

4. Effective at Low Speeds

Even if the water flowing over or through them is moving slowly, tidal energy systems may generate electricity. Because water is 1,000 times denser than air, it can drive a turbine even at a slow speed.

Disadvantages of Tidal Energy

1. Environmental Impact

While putting tidal generators beneath the ocean may be handy for people, it is not so for all aquatic creatures. Because the systems rely on turbulent water to operate, a substantial foundation is required. This form of underwater building has the potential to destroy habitats. The tidal barrage, which uses dams to obstruct the passage of sea life and potentially devastate aquatic ecosystems, is the worst culprit.

2. High Construction Costs

Building buildings that can survive the turbulence and corrosive nature of sea water is not a cheap endeavor. Other renewable resource alternatives are less expensive up front. While tidal energy systems have a lengthy life cycle and eventually pay for themselves, governments are more concerned with their 5-year budget than a 60-year forecast. The initial investment in these systems is sometimes the most significant flaw in potential initiatives.

3. Scarcity of Suitable Locations

Not every scenery near a beach is suitable for a tidal energy project. They require a highly exact collection of pieces in order to perform correctly and efficiently. For example, the height of the sea at low and high tide. One of the key reasons for their lack of popularity is the shortage of suitable areas for establishing tidal energy systems.

4. It Can Be Very Inconsistent

Some say that engineering defects and technical problems such as high turbine failure rates, failures to generate energy in low water circumstances, and strong currents prohibit turbines from functioning effectively. Because it is dependent on the tide, tidal power is also unreliable. Because the tides are not always consistent, the electricity is unreliable.

5) Geothermal Energy

Figure 12 Geothermal energy

Geothermal energy may be utilized to heat houses or create power by utilizing the natural heat under the earth's surface. Geothermal energy, while harnessing a power lying beneath our feet, is of minor relevance in the UK as compared to nations like Iceland, where geothermal heat is considerably more freely available.

One of the renewable energies taken from the earth's core is geothermal energy. The heat generated during the radioactive decay of elements and the actual creation of the planet provides power. Within the earth's core, this energy is stored in fluids and rocks.

Extreme temperatures of above 4000 degrees' Celsius melt certain rocks within the earth's core, resulting in the production of magma. Furthermore, the heat causes the mantle to act in a flexible fashion, and because it is lighter than the surrounding rock, a portion of it travels higher. You've utilized geothermal energy if you've ever rested in a hot spring. Due to the gradual disintegration of radioactive particles in rocks at the planet's core, the earth's core is roughly as hot as the sun's surface [19]. Deep well drilling brings extremely hot subsurface water to the surface as a hydrothermal resource, which is then pushed via a turbine to generate energy.

If the steam and water used by geothermal facilities are pumped back into the reservoir, emissions are normally negligible. While there are techniques to build geothermal plants without subsurface reservoirs, there are fears that they might raise the danger of an earthquake in locations that are already deemed geological hot zones.

Geothermal energy may be captured in a variety of ways, including:

- Geothermal power plants, which utilize heat from deep inside the Earth to produce steam, which is then used to generate electricity.

- Geothermal heat pumps, which use heat from under the Earth's surface to heat water or heat structures

Wells dug 1 or 2 miles down into the Earth are used to pump steam or hot water to the surface at a geothermal power plant. Because these are sites where the Earth is very hot close beneath the surface, you're more likely to locate one of these power plants in an area with a lot of hot springs, geysers, or volcanic activity [20].

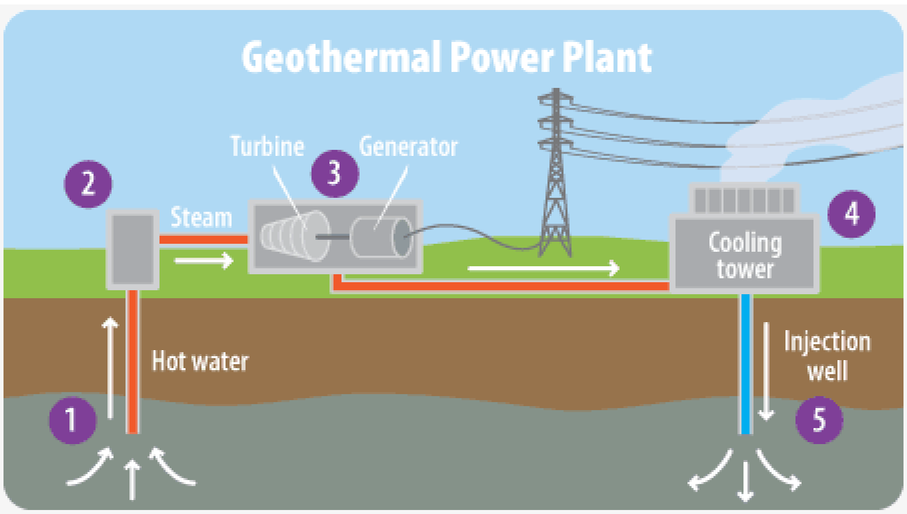


Figure 13 5 steps to generate geothermal power

1. Under tremendous pressure, hot water is pumped from deep underground through a well.

2. When water reaches the surface, the pressure drops, causing the water to condense and transform into steam.

3. The steam turns a turbine, which is connected to an electrical generator.

4. In a cooling tower, the steam cools and condenses back to water.

5. The cooled water is pumped back into the ground, restarting the process

Power plants aren't the only source of geothermal energy. Geothermal heat pumps may be used for a variety of purposes, including heating and cooling houses as well as warming swimming pools. Pumping water or a refrigerant (a specific sort of fluid) through pipes slightly below the Earth's surface, where the temperature is a constant 50 to 60°F, is how these systems transmit heat.

During the winter, the water or refrigerant collects heat from the Earth, which is then transferred to the building above by the pump. Some heat pumps may operate in reverse in the summer to assist cool buildings.

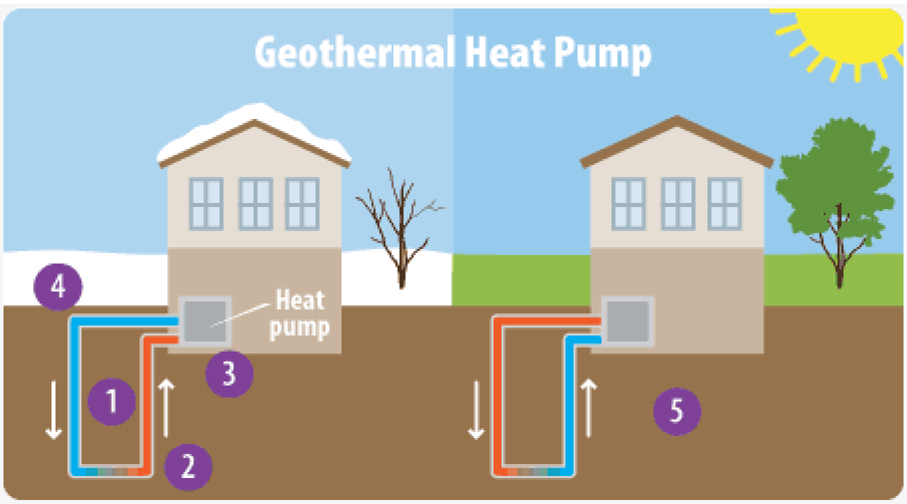


Figure 14 Geothermal heat pump in winter and summer

1. A loop of pipes transports water or a refrigerant.

2. When it's chilly outside, the water or refrigerant heats up as it goes through the subterranean portion of the loop.

3. The warmed water or refrigerant transports heat into the structure as it reaches the surface.

4. After the heat is transmitted, the water or refrigerant cools down. It's pumped back below, where it warms up again, resuming the cycle.

5. The system may run in reverse on a hot day. The water or refrigerant cools the building before being injected underground, where it absorbs further heat from the earth around the pipes.

Steam is used to generate energy in geothermal power plants. The steam is produced by hot water reservoirs a few miles or more under the earth's surface.The steam spins a turbine, which turns a generator, which generates energy. Dry steam, flash steam, and binary cycle geothermal power plants are the three types.

Dry Steam

Dry steam power plants extract steam from subsurface reservoirs. Steam is pumped straight from subterranean wells to the power plant's turbine/generator unit. In the United States, there are just two known subsurface sources of steam: The Geysers in northern California and Yellowstone National Park in Wyoming, which contains the well-known geyser Old Faithful.

The Geysers are the only dry steam plants in the country since Yellowstone is protected from development.

Flash Steam

The most popular are flash steam power plants, which employ geothermal pools of water with temperatures above 360°F (182°C). Under its own pressure, this extremely hot water rises via wells in the earth. The pressure drops as it rises, and part of the heated water boils into steam. After that, the steam is extracted from the water and utilized to drive a turbine or generator. Any remaining water and condensed steam are fed back into the reservoir, ensuring that this is a long-term resource.

To summarize, the flush plants extract high-pressures hot water from the earth and mix it with cold low-pressure water. Later, this condenses into steam, which powers the turbines that generate energy.

Binary Steam

Water-based binary cycle power plants operate at temperatures between 225 and 360 degrees Fahrenheit (107 and 182 degrees Celsius). The heat from the hot water is used to boil a working fluid, which is commonly an organic substance with a low boiling point. In a heat exchanger, the working fluid is vaporized and utilized to spin a turbine. The water is then warmed by being injected back into the earth. During the whole operation, the water and the working fluid are kept separate, resulting in minimal or no air emissions.

Enhanced geothermal systems (EGS) and low-temperature or co-produced resources are the two forms of geothermal resources that may now be employed in binary cycle power plants to generate electricity.

Enhanced Geothermal Systems

EGS generates geothermal energy by tapping into the Earth's deep geothermal resources, which would otherwise be uneconomical owing to a lack of water, a remote location, or a certain rock type. According to the US Geological Survey, the western United States has a potential EGS resource of 500,000 megawatts, which is almost half of the country's present installed electric power producing capacity [21].

- **Low-Temperature and Co-Produced Resources**

Temperatures of 300F (150C) or less are typical for low-temperature and co-produced geothermal resources. Binary cycle technology can be used to generate power from low-temperature resources. In the United States, co-produced hot water is a byproduct of oil and gas wells. The potential for this hot water to generate energy is being investigated, with the goal of lowering greenhouse gas emissions and extending the life of oil and gas operations.

Advantages of Geothermal Energy

1. Environmentally Friendly

Geothermal energy is less harmful to the environment than traditional fuels like coal and other fossil fuels. Furthermore, a geothermal power plant has a minimal carbon impact. While geothermal energy does produce some pollution, it is quite little when compared to fossil fuels.

2. Renewable

Geothermal energy is a renewable energy source that will persist till the sun destroys the Earth in 5 billion years. The Earth's heated reservoirs are refilled naturally, making it both renewable and sustainable.

3. Huge Potential

The present global energy consumption is roughly 15 terawatts, which is significantly less than the entire potential energy accessible from geothermal sources. While most reservoirs are now unusable, there is hope that as industrial research and development continues, the quantity of exploitable geothermal resources will grow. Geothermal power facilities may generate between 0.0035 and 2 terawatts of electricity, according to current estimates.

4. Sustainable / Stable

In comparison to other renewable energy sources such as wind and solar power, geothermal delivers a consistent stream of energy. This is because, unlike wind or solar energy, the resource is constantly accessible to be used.

5. Heating and Cooling

Water temperatures of over 150°C are required to operate turbines when geothermal energy is used to generate power. The difference in temperature between the surface and a ground source can also be utilized. Because the earth is more resistant to seasonal heat variations than the air, a geothermal heat pump may serve as a heat sink/source merely two meters below the surface.

6. Reliable

Because it does not fluctuate as much as other energy sources like sun and wind, the energy generated from this resource is simple to quantify. This implies we can accurately anticipate the electricity production of a geothermal plant.

7. No Fuel Required

There is no requirement for fuel since geothermal energy is a naturally occurring resource, unlike fossil fuels, which are a finite resource that must be mined or otherwise extracted from the ground.

8. Rapid Evolution

Geothermal energy is now undergoing a lot of research, which means that new technologies are being developed to better the energy process. There are a growing number of projects underway to strengthen and expand this sector of the economy. Many of the existing disadvantages of geothermal energy will be addressed as a result of this rapid progress.

Disadvantages of Geothermal Energy

1. Location Restricted

The most significant drawback of geothermal energy is that it is site dependent. Because geothermal facilities must be built where the energy is available, some locations will be unable to benefit from this resource. Of course, if you live in a region like Iceland, where geothermal energy is widely available, this isn't an issue.

2. Environmental Side Effects

Although geothermal energy does not generally emit greenhouse gases, many of these gases are trapped under the Earth's surface and released into the atmosphere during excavation. Although these gases are normally discharged into the environment, they are emitted at a higher rate around geothermal units. These emissions, however, are still far fewer than those connected with fossil fuels.

3. Earthquakes

Geothermal energy also has the potential to cause earthquakes. This is due to changes in the structure of the Earth as a result of digging. This issue is increasingly common with improved geothermal power plants, which drive water into the Earth's crust to develop fissures and allow for more resource extraction. However, because most geothermal facilities are located far from population centers, the effects of these earthquakes are minimal.

4. High Costs

Geothermal energy is a costly resource to exploit, with a plant with a 1-megawatt capacity costing between $2 and $7 million. Where upfront expenses are considerable, however, they can be recouped over time as part of a long-term investment.

5. Sustainability

To ensure the long-term viability of geothermal energy, fluid must be injected back into subsurface reservoirs at a quicker rate than it is drained. This implies that geothermal energy must be appropriately managed to ensure its long-term viability.

It is critical for industry to weigh the benefits and drawbacks of geothermal energy in order to maximize the benefits while minimizing the risks.

6) Biomass Energy

This is the process of turning plant-based solid fuel into energy. Although biomass is primarily a technique of burning organic materials to generate power, it is now a much cleaner and more energy-efficient process. Biomass creates electricity at a far lower economic and environmental cost by converting agricultural, industrial, and home waste into solid, liquid, and gas fuel.

Crops, waste wood, and trees are all examples of biomass, which is organic material derived from plants and animals. When biomass is burned, chemical energy is released as heat, which may be used to power a steam turbine to create electricity.

Biomass is frequently mischaracterized as a clean, renewable fuel and a more environmentally friendly alternative to coal and other fossil fuels for energy generation. However, current research suggests that many types of biomasses, particularly from forests, emit more carbon than fossil fuels. There are also unfavorable effects on biodiversity. Nonetheless, in the appropriate circumstances, some kinds of biomass energy might be a low-carbon solution. Sawdust and chips from sawmills, for example, may be used as a low-carbon energy source instead of fast decomposing and releasing carbon.

Biomass energy sources include :

• Wood and wood processing wastes, such as firewood, pellets, and chips, lumber and furniture mill sawdust and trash, and pulp and paper mill black liquor

• Agricultural waste materials and crops, such as maize, soybeans, sugar cane, switchgrass, woody plants, and algae, as well as agricultural and food processing residues

• Biogenic elements included in municipal solid waste, including paper, cotton, and wool goods, as well as food, yard, and wood trash

• Human sewage and animal manure

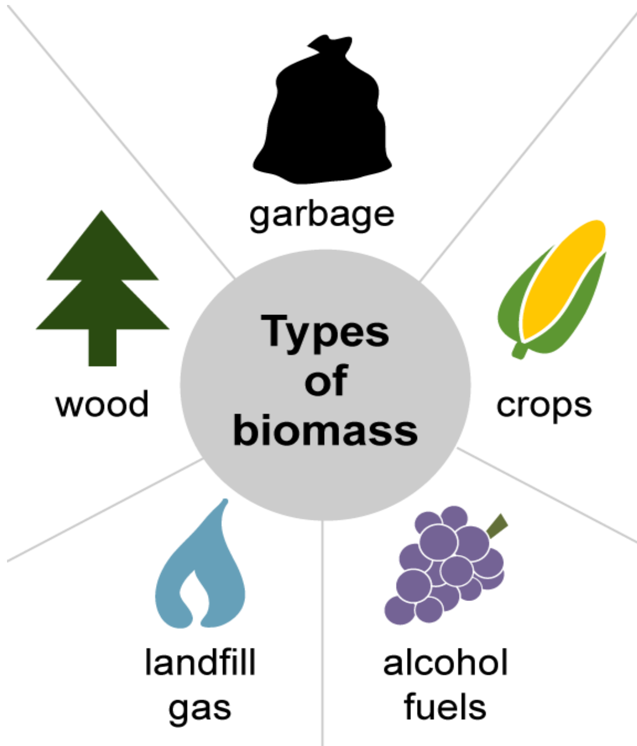


Figure 15 Different types of biomass

How Biomass Energy Works [22]

Agriculture, forestry, towns, colleges and universities, food processors, hospitals and medical centers, and a variety of other industries produce billions of tons of garbage each year. There were few safe and cost-effective options to use or dispose of garbage in the past. Today, however, the world has renewable energy technologies that can turn waste biomass energy resources into useful energy.

Biomass is an organic byproduct produced by plants, animals, and organic waste items such as rubbish, wood, crops, landfill gas, and alcohol fuels. The chemical energy in biomass is released as heat when it is burned, which may then be transformed into biofuels and/or biogas, and then into usable energy like fuels, electricity, or heat.

Photosynthesis is the fundamental process of biomass energy, often known as bioenergy. Chlorophyll is a pigment found in plants that absorbs carbon dioxide from the air and water from the ground. Some of the energy is transmitted when animals eat plants. Because the carbon dioxide and water are then released back into the atmosphere and utilized to grow more plants and crops to restart the cycle, we call it renewable energy.

Biomass as a source of energy has been shown to have various advantages over fossil fuels, including lowering greenhouse gas emissions. To make it, the organic material must go through a biomass conversion process, which can take various different forms.

Bio-digestion

Anaerobic digestion is another name for it. Bio-digestion is the process by which bacteria break down organic material in the absence of oxygen to produce biogas, which is then transformed into electricity.

Combustion

Organic matter is burned in this method to generate heat, which may then be utilized to generate electricity by heating water to create steam. Steam turns a shaft in a turbine, which activates a generator that generates energy.

Fermentation

With the aid of yeast, fermentation turns sugar from organic material into alcohol, usually known as ethanol.

Gasification

Organic matter is transformed to carbon dioxide, hydrogen, and carbon monoxide using heat (rather than combustion) and a little quantity of steam or oxygen in the gasification process. The outcome is a gas combination known as syngas or producer gas, which may be utilized for heating, power production, and a variety of other purposes.

Pyrolysis

Organic material decomposes at high temperatures without oxygen in pyrolysis. Organic matter does not burn in the absence of oxygen and instead degrades into a liquid called bio-oil or a solid called bio-char or syngas.

A waste-to-energy firm SynTech Bioenergy generates distributed, renewable heat and power using a gasification process that is similar to pyrolysis. On-site, fully automated compact generators measuring 30 ft × 30 foot (10m x 10m) are installed and managed remotely. A sophisticated thermal conversion inside the reactors produces ultra clean tar-free syngas from practically all forms of biomass, agricultural waste, and municipal solid waste without the need of flames or combustion (MSW). The completed syngas is used to power modified internal combustion engines and gas-fired micro-turbines, generating energy, power, and heat while leaving no carbon imprint.
The resulting electricity can be sold back to the grid or even used to meet a property's total energy requirements.

Biomass advantages and disadvantages

Biomass is a sustainable energy source made from the combustion of animal and plant waste. Agriculture, forestry, colleges/universities, governments, hotels, resorts, sports arenas, hospitals, and correctional institutions are just a few of the businesses that create trash that may be turned to heat and energy (see comprehensive list). [23]

According to research released in September 2017 by the US Energy Information Administration, bioenergy capacity will grow in 2018.

The following are some of the benefits of biomass energy:

1. **Biomass is always and widely available as a renewable source of energy.**

Because our civilization continually creates waste such as rubbish, wood, and manure, the organic elements required to produce biomass are unlimited.

2. **It is carbon neutral.**

Biomass fuels only emit the same amount of carbon into the atmosphere as plants receive during their life cycle as a natural element of photosynthesis.

3. **It reduces the overreliance of fossil fuels.**

Not only is there a finite supply of fossil fuels, but they also have environmental consequences, such as the emission of massive volumes of carbon dioxide into the atmosphere and pollution from extraction, transportation, and manufacturing.

4. **Is less expensive than fossil fuels.**

While fossil fuel production necessitates a significant investment in equipment such as oil drilling, gas pipelines, and fuel collection, biomass technology is far less expensive. Manufacturers and manufacturers are able to make more money with less production.

5. **Biomass production adds a revenue source for manufacturers.**

Producers of trash can add value by repurposing their waste into a more economical type of biomass energy.

6. **Less garbage in landfills.**

By burning solid waste, the quantity of rubbish placed in landfills is decreased by 60 to 90 percent, lowering landfill disposal costs and reducing the amount of land needed for landfills.

While biomass energy has several advantages, it also has significant drawbacks, including:

1. **Biomass energy is not as efficient as fossil fuels**

When compared to gasoline, some biofuels, such as ethanol, are inefficient. To boost its efficiency, it must be strengthened with fossil fuels. [24]

2. **It is not entirely clean**

While biomass is carbon neutral, the usage of animal and human waste increases the quantity of methane emissions released into the atmosphere, which is equally harmful to the environment. Furthermore, pollution produced by burning wood and other natural materials is comparable to pollution produced by burning coal and other forms of energy resources.

3. **Can lead to deforestation.**

Because wood is one of the most often utilized biomass energy sources, massive volumes of wood and other waste products must be burnt in order to provide the required quantity of electricity. While there is already sufficient wood waste, future deforestation is a possibility.

4. **Biomass plants require a lot of space.**

While it's difficult to find a plant in a suitable location in a city, enterprises may generate biomass energy using onsite hardware like the BioMax technology, which takes up a fraction of the space of a major facility.

While biomass energy has significant drawbacks, more research and development is being invested in the subject as a more generally available, less expensive, and beneficial alternative to traditional electricity and other energy sources.

Top 5 countries that produce the most solar energy 2019-2020

Several countries have led the way in harnessing the sun's energy and turning it into a sustainable source of electricity. The sun, by all accounts, is not going anywhere anytime soon.

Solar power installations are fast growing around the world as countries ramp up their renewable energy initiatives in an effort to reduce carbon emissions from electricity generation and find alternatives for fossil-fuel.

Solar photovoltaic is the most well-established of the low-carbon energy sources, and development costs are decreasing as the technology scales up.

Globally, the total installed capacity was roughly 627 GW by the end of 2019.

Solar, according to the International Energy Agency (IEA), is on course to establish new global deployment records. [24][28]

1. **China – 205 GW**

According to the IEA's Renewables 2020 report, China has by far the world's largest installed solar energy fleet, with 205 GW in 2019.

In the same year, solar energy generated 223.8 terawatt hours (TWh) of electricity in the country.

The Huanghe Hydropower Hainan Solar Park (2.2 GW) in Qinghai province is China's largest single solar project.

2. **USA – 76 GW**

In 2019, the United States has the world's second-largest installed solar capacity, with 76 GW providing 93.1 TWh of power.

As the government accelerates its renewable energy initiatives and aims to entirely decarbonize its power system by 2035, solar installations in the United States are expected to reach around 419 GW over the next decade.

3. **Japan – 63.2 GW**

According to the IEA's data, Japan ranks third among countries with the largest solar power capacity, with a fleet reaching 63.2 GW in 2019, generating 74.1 TWh of electricity.

Alternative energy sources such as solar and other renewables have grown in popularity after the Fukushima nuclear disaster in 2011, which caused Japan to drastically reduce its nuclear energy activities.

Nonetheless, depending on government policy and cost reductions, installed solar capacity in Japan could reach 100 GW by 2025.

4. Germany – 49.2 GW

With a national fleet of roughly 49.2 GW in 2019, Germany is the leading country in Europe for solar deployments, providing 47.5 TWh of electricity.

Competitive auctions have helped the industry in recent years, and the German government recently suggested raising its 2030 solar installation target to 100 GW, as part of a goal to achieve a 65 percent renewable energy mix by the end of the decade.

The 187-megawatt (MW) Weesow-Willmersdorf facility north of Berlin, created by German utility EnBW, is the country's largest solar project to date.

5. India – 38 GW

India has the world's fifth-largest installed solar capacity, with 38 GW built in 2019 and 54 TWh produced.

India's energy demand is predicted to rise faster than any other region in the coming decades, and as the world's third-largest carbon emitter, policies are being devised to transition the country away from coal and toward renewables.

Solar is expected to play a key role in the government's goal of 450 GW of renewable energy generation by 2030.

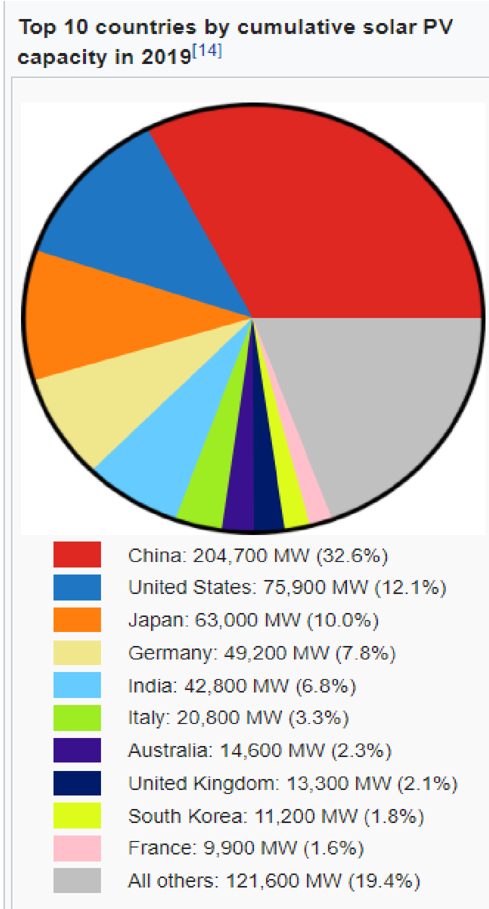


Figure 16 Top 10 countries generating solar PV energy in 2019 [25]

Year / Country	2016	2017	2018	2019	2020
	Total (MW)	Total (MW)	Total (MW)	Total (MW)	Total (MW)
China	78070	131000	175018	204700	254355
U.S	40300	51000	53184	60682	75572
Japan	42750	49000	55500	63000	67000
Germany	41220	42000	45930	49200	53783
India	9010	18300	26869	35089	39211

Table 4 Top 5 countries producing energy over the years using PV and expectations for 2020

Top five countries with the highest wind energy capacity in 2020

Wind energy capacity is quickly increasing around the world as countries shift away from fossil fuels and toward low-carbon alternatives in order to decrease emissions and limit global warming.

Onshore – which is by far the largest market – or offshore, utilizing either fixed-bottom turbines tethered to the sea floor or, on a considerably smaller scale, floating structures that can be based in deeper seas, the technology can be installed.

The whole global wind power fleet, both onshore and offshore, totaled 743 GW at the end of 2020, according to the Global Wind Energy Council (GWEC) in its Global Wind Report 2021.

That would prevent more than 1.1 billion tons of CO_2 from being released into the atmosphere, approximately equal to Japan's yearly carbon emissions as the world's fifth-largest emitter.

Wind markets, on the other hand, are continuing to grow as the industry matures and deployment costs fall, and GWEC estimates that current growth rates will need to triple globally by 2030 to fulfill mid-century climate targets [29].

As of 2020, the top five countries with the largest wind energy capacity are profiled below [26][30].

1. China – 288.32 GW

China has the world's greatest wind energy capacity, with slightly over 288 GW at the end of 2020, having installed 52 GW of new capacity, significantly more than any other country.

Onshore wind accounts for little over 278 GW of China's fleet, with offshore wind accounting for the remaining 10 GW.

In terms of the worldwide offshore wind market, China is second only to the United Kingdom in terms of scale.

As the UK strives to achieve carbon neutrality by 2060, wind and other renewable energy sources are expected to increase even more as coal units are phased out to satisfy decarbonization goals.

2. United States – 122.32 GW

The United States comes in second with roughly 122 GW of installed wind capacity, almost all of which is onshore.

In 2020, the country built 17 GW of new wind capacity, placing it second only to China and representing an 85 % growth year over year.

Although onshore wind power has been the dominant source of wind power in the United States to date, there are growing expectations for an increase in offshore projects in the next years.

President Joe Biden has set a goal of installing 30 GW of offshore wind capacity by 2030, and has enlisted the help of various government departments to monitor the industry's rapid growth as part of a larger drive to decarbonize the US electricity system by 2035.

3. **Germany – 62.85 GW**

With a national fleet of just under 63 GW of installed capacity, split between 55 GW onshore and 7.7 GW offshore, Germany is Europe's leading destination for wind power deployment.

According to trade organization Wind Europe, wind power contributed 27 percent of Germany's electricity in 2020, with onshore contributing 103 terawatt hours (TWh) and offshore providing 27 TWh.

By 2030, the government aspires to generate 65 percent of its electricity from renewable sources, and authorities plan to develop 71 GW of onshore wind capacity and 20 GW of offshore wind capacity to meet this goal. The country will build 1.67 GW of additional wind capacity by 2020.

4. **India – 38.63 GW**

India ranks fourth among countries with the most wind energy capacity, with over 39 GW of capacity located onshore.

Although the government currently has no offshore capacity, it has set goals to deploy 5 GW by 2022 and 30 GW by 2030.

Tamil Nadu, which is home to the country's largest wind farm, Muppandal, and Gujarat are the top two states in India for wind power generation.

New capacity increases decreased by more than half in 2020 compared to the previous year, owing to supply chain delays and lockdown limitations brought on by the Covid-19 epidemic. A big resurgence is projected in 2021, according to the International Energy Agency (IEA).

5. **Spain – 27.24 GW**

Spain has little over 27 GW of installed wind generating capacity, and the country's economy, like that of the United States and India, is dominated by onshore infrastructure. Wind is the country's primary source of renewable energy generation, with 1.4 GW of new capacity installed in 2020.

In terms of wind energy development, the areas of Castilla y León, Castilla La Mancha, Galicia, Andalusia, and Aragon are among the most active in Spain.

Iberdrola, a Spanish energy provider, recently announced plans to build the country's first commercial-scale floating offshore wind project, which will serve as a springboard for another 2 GW of offshore wind development off the shores of Galicia, Andalusia, and the Canary Islands.

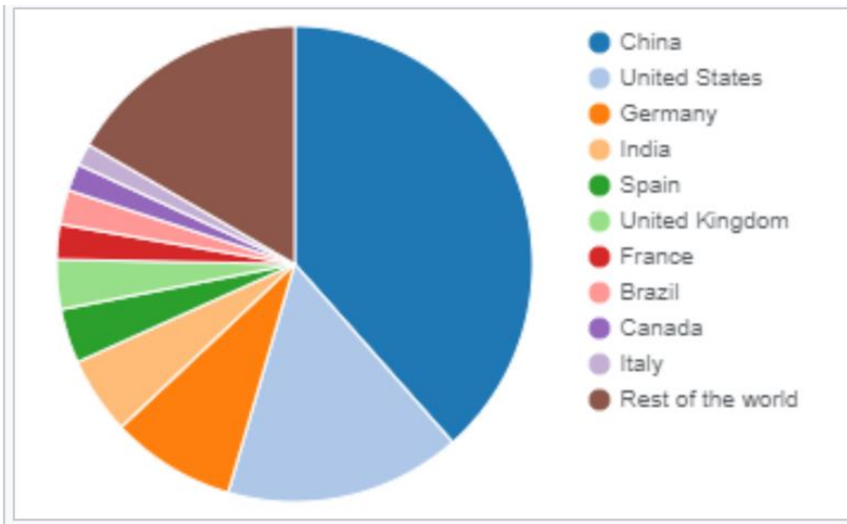


Figure 17 Top 10 countries by cumulative wind capacity in 2020

Year / Country	2016	2017	2018	2019	2020
	Total (MW)	Total (MW)	Total (MW)	Total (MW)	Total (MW)
China	168690	188232	211392	236320	288000
U.S	82183	89077	96665	105466	122320
Germany	50019	56132	59311	61357	62850
India	28665	32848	35129	37506	38559
Spain	23075	23170	23494	25808	27240

Table 5 Top 5 countries producing wind energy over the years

Top five hydropower producing countries in the world 2020

The gravitational force of flowing water is used to generate hydropower. Hydro plants can be ramped up and down fast to meet changing energy demands, making it a versatile source of electricity.

It has emerged as one of the most important renewable energy sources for lowering carbon emissions and fossil fuel dependence.

Hydroelectricity is today one of the most frequently used renewable energy sources, accounting for a major portion of the global power mix.

According to a research provided by the International Renewable Energy Agency, global hydropower capacity climbed from 960.5 gigawatts (GW) in 2008 to 1,270.4GW in 2017. (IRENA).

The world's top five hydropower producing countries:

1. **China – 356.4 GW**

Since 1996, China has remained the world's greatest hydropower producer in terms of hydroelectricity generation, capacity, and new projects. The 16 GW Wudongde and 10 GW Baihetan projects in China are now the world's two largest hydropower facilities in terms of capacity. China is the world's largest producer of hydroelectric energy, accounting for 28.5 % of global output.

2. **Brazil – 109.1 GW**

In 2020, Brazil is ranked second among the top 20 hydropower producing countries. The northern Amazon River basin provides much of Brazil's hydropower potential. Brazil has expected to add 3.8 gigawatts of hydropower capacity by 2018. The Belo Monte dam on the Xingu River will be completed in 2019 and will be Brazil's second-largest dam (and second-largest dam in the world).

3. **US – 102.8 GW**

With around 102.8 GW of total installed capacity as of 2020, the United States is one of the world's leading hydropower producers. The 6.81GW Grand Coulee hydropower project on the Columbia River in Washington is one of the world's largest hydroelectric power stations.

4. **Canada – 81.4 GW**

Canada is another of the world's largest hydropower producers, with a total installed capacity of around 81.4 GW as of early 2020. The Robert-Bourassa generating station and the 5,428MW Churchill Falls Generating Station are two enormous hydroelectric power facilities in Canada.

5. **India – 50.1 GW**

The Indian government has announced a number of initiatives to promote hydropower development, including the designation of large hydropower (>25MW) as a renewable energy source. This change will allow new, substantial projects to take advantage of the non-solar Renewable Purchase Obligation, which requires regional utilities to buy hydropower for a percentage of their electricity.

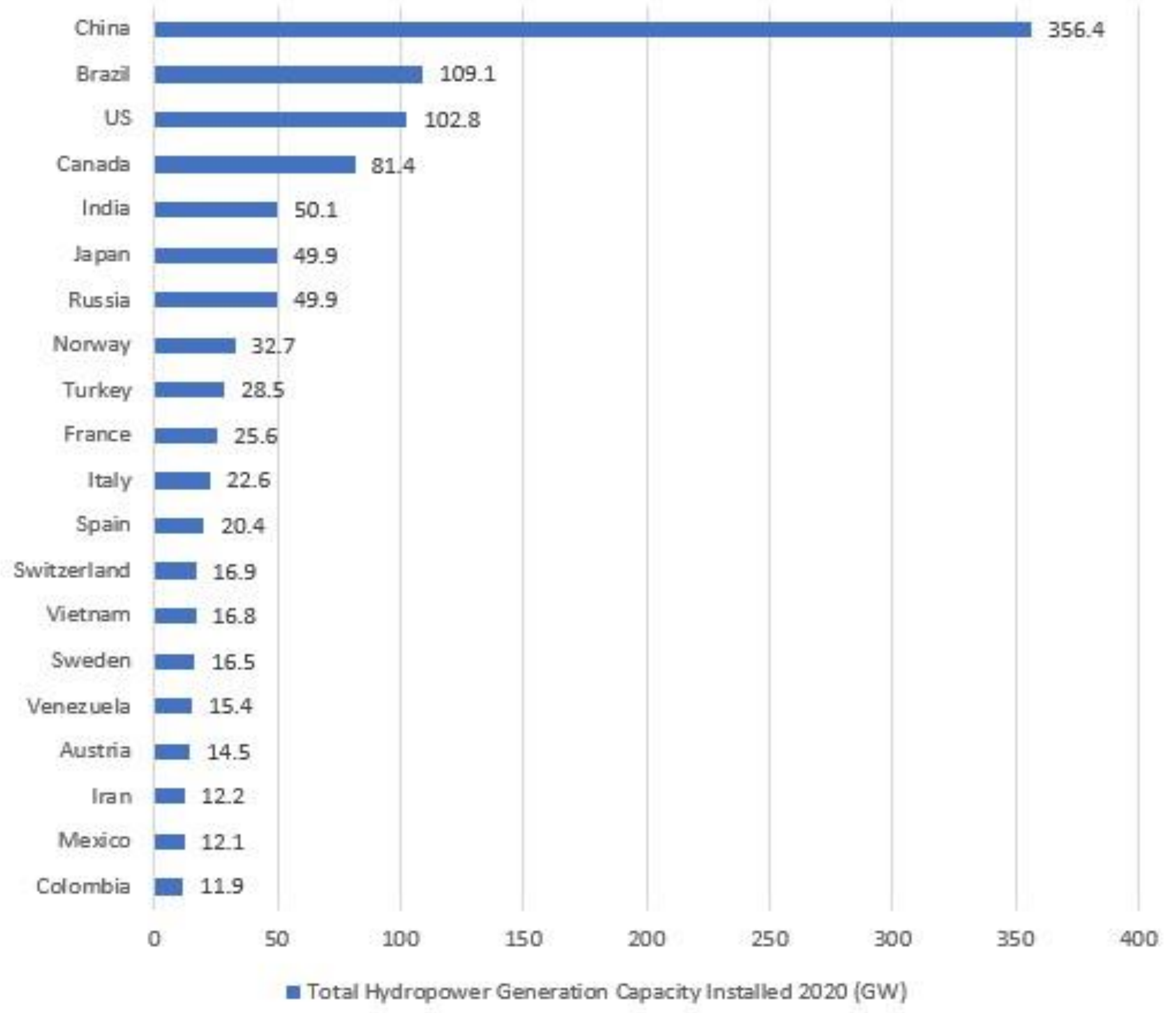


Figure 18 Total Hydropower generation capacity in GW installed in 2020

2. Energy in Lebanon, 2019-2050 estimation

A. Energies Used in Lebanon (2019), Current Supply and Demand

First off, below is a table which displays how the electricity bill is calculated in Lebanon. [33]

On monthly basis bill			On two months basis bill		
Tran.	Energy consumed. / kWh	Price L.B.P / kWh	Tran.	Energy consumed. / kWh	Price L.B.P / kWh
1	100	35	1	200	35
2	200	55	2	400	55

3	100	80	3	200	80
4	100	120	4	200	120
5	> 500 kW	200	5	> 1000 kW	200

Table 6 How electricity bill is calculated in Lebanon

In Lebanon, the electricity sector is suffering from supply shortages for years. In 2017, the maximum electricity generation capacity was 2000 megawatts far less than the peak demand of 3400 megawatts. In 2020, the peak electricity demand in the country was 3500 megawatts but the total grid capacity was only 2200 MW so we are still in deficit. Early 2022, Lebanon is only producing 700 MW or even less while the population needs are around 3600 MW. Lebanon has no other choice, the lack in energy could come from the construction of clean and renewable energy. Here is how this electricity was provided in 2016:

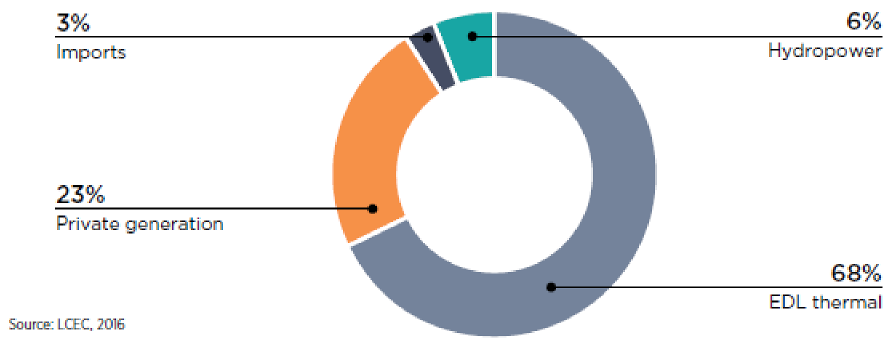


Figure 19 Electricity generation mix in Lebanon [40]

EDL's recent electric capacity report:

A - Thermal Power Plants: [34]

There are 7 power plants of this type:

1) Zouk		
Unit name	Put in service year	Installed Capacity (MW)
Zouk 1	1984	145
Zouk 2	1985	145
Zouk 3	1986	145
Zouk 4	1987	172
Reciprocating Engines	2017	198
Power Ship	2012	198
Total		1003

Table 7 Zouk mosbeh installed thermal capacity

2) Jieh		
Unit name	Put in service year	Installed Capacity (MW)
Jieh 1	1970	65
Jieh 2	1970	65
Jieh 3	1980	72
Jieh 4	1981	72
Jieh5	1981	72
Reciprocating Engines	2017	72
Power Ship	2012	198
Total		616

Table 8 Jieh installed thermal capacity

3) Sour		
Unit name	Put in service year	Installed Capacity (MW)
Sour 1	1996	35
Sour 2	1996	35
Total		70

Table 9 Sour installed thermal capacity

4) Baalback		
Unit name	Put in service year	Installed Capacity (MW)
Baalback 1	1996	35
Baalback 2	1996	35
Total		70

Table 10 Baalback installed thermal capacity

5) Zahrani		
Unit name	Put in service year	Installed Capacity (MW)
Zahrani 1	1998	160
Zahrani 2	1998	160
Zahrani 3	2001	145
Total		465

Table 11 Zahrani installed thermal capacity

6) Deir Ammar

Unit name	Put in service year	Installed Capacity (MW)
Deir Ammar 1	1998	160
Deir Ammar 2	1998	160
Deir Ammar 3	2002	145
Total		465

Table 12 Deir Ammar installed thermal capacity

7) Al Hreesha		
Unit name	Put in service year	Installed Capacity (MW)
Al Hreesha 1		75
Total		75

Table 13 Al Hreesha installed thermal capacity

In conclusion, the total thermal Capacity to generate in Lebanon is 2764 MW

B - Hydraulic Power Plants:[35]

1. **Litani** Power Plants consist of three plants.

Awali	
Unit name	Installed Capacity (MW)
No. 1	36
No. 2	36
No. 3	36
Total Awali	108

Table 14 Awali hydraulic installed capacity

Joun	
Unit name	Installed Capacity (MW)
No. 1	24
No. 2	24
Total Joun	48

Table 15 Joun hydraulic installed capacity

Abdel Aal	
Unit name	Installed Capacity (MW)
No. 1	17
No. 2	17
Total Abdel Aal	34

Table 16 Abdel Aali hydraulic installed capacity

Total Litani (MW)	190

2. **Bared** Power Plants consist of two plants.

Bared 1	
Unit name	Installed Capacity (MW)
No. 1	4.5
No. 2	4.5
No. 3	4.5
Total Bared 1	13.5

Table 17 Bared 1 hydraulic installed capacity

Bared 2	
Unit name	Installed Capacity (MW)
No. 1	1.2
No. 2	2.5
Total Bared 2	3.7

Table 18 Bared 2 hydraulic installed capacity

Total Bared (MW)	17.2

3. **Safa** Power Plants (Rishmaya)

3. Safa.		
Unit name	Put in service Year	Installed Capacity (MW)
No. 1	1932	3.3
No. 2	1932	3.3
No. 3	1956	6.8

Table 19 Safa hydraulic installed capacity

Total Safa (MW)	13.4

4. **Nahr Ibrahim** Power Plants consist of three plants.

Nahr Ibrahim 1	
Unit name	Installed Capacity (MW)
No. 1	7.5
No. 2	7.5
Total Nahr Ibrahim 1	15

Table 20 Nahr Ibrahim 1 hydraulic installed capacity

Nahr Ibrahim 2	
Unit name	Installed Capacity (MW)
No. 1	5
No. 2	5
No. 3	2.5
Total Nahr Ibrahim 2	12.5

Table 21 Nahr Ibrahim 2 hydraulic installed capacity

Nahr Ibrahim 3	
Unit name	Installed Capacity (MW)
No. 1	1.5
No. 2	1.5
No. 3	1.5
Total Nahr Ibrahim 3	4.5

Table 22 Nahr Ibrahim 3 hydraulic installed capacity

Total Nahr Ibrahim (MW)	32

The total Hydraulic Generation in Lebanon is about 252.6 MW

Total Generation (MW)	
Thermal	**2764**
Hydraulic	**252.6**
Total	**3016.6**

Table 23 Total thermal and hydraulic electricity generation in MW in Lebanon

The overall installed capacity of Lebanon's hydro-power is currently 253 MW (around 8.7% of total nationally produced power in Lebanon), with an actual generating

capacity of 180 MW max due to their old age, to the lack of maintenance and often decline in water supplies. The plants operate at drastically reduced output levels since most of them have exceeded their expected technical lifetime [32].
The majority of engineers agree that hydroelectric dams function properly for 50 years. The longest-living operating dams have lasted more than 100 years due to the good maintenance over the years. The average lifespan of a hydropower facility is between 50 and 100 years.
By upgrading, maintaining and increasing the efficiencies and capacities of **existing** facilities, hydropower can continue to support Lebanon's growing energy needs. New hydraulic stations are not needed in this study; the existing dams need only to be well maintained.
Hydro turbines are relatively low-stressed pieces of machinery and operate under very steady loading conditions with no sudden load changes. If regularly maintained, mainly by lubricating the bearings, this helps extend the service life of the turbine.
Drive systems (gearboxes or belts) will require regular oil changes as well as the bearings in all of the rotating machinery. Most hydro hardware manufacturers claim a 25-year lifespan, though this is normally because they have to set a number, and in many cases the same manufacturers have many turbines that are 50+ years old and still operating reliably and efficiently.

The LCOE (leveled cost of electricity) of hydropower is estimated to be around $9c (135 LL) per KWh in 2009. The long term viability is confirmed as the leveled cost is inferior to the projected selling price of $12c (180 LL) per KWh to EDL in 2018.

The Following Table categorizes hydro generation applications in terms of size & capacity.

Category	Description
Large hydro	More than 100 MW and usually feeding into high-voltage electricity grid.
Medium hydro	15 -100 MW - usually feeding into the grid.
Small hydro	1 -15 MW - usually feeding into the grid.
Mini hydro	100 kW - 1 MW; either stand-alone schemes or more often feeding into the grid.
Micro hydro	From 5 kW up to 100 kW; usually provides power for a small communities in remote areas away from the grid but may be connected to the grid.
Pico hydro	From a few hundred watts up to 5kW. Stand-alone or grid connected.

Table 24 Different hydraulic categories

In this study, new hydroelectric stations are not needed to be installed as mentioned above but this graph shows the average installation cost for a hydropower plant worldwide from 2010 to 2020 and how much it costs in Lebanon.

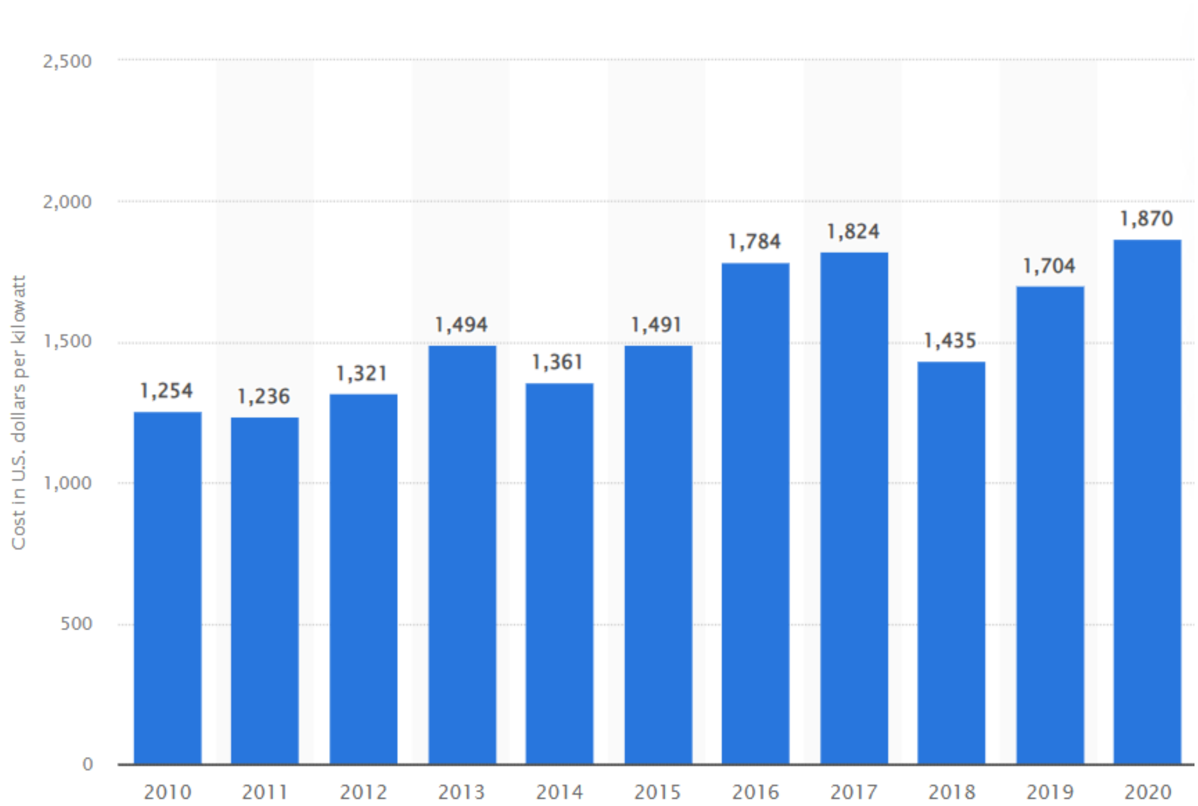


Figure 20 Cost in dollars per kilowatt over the last decade

Hydropower technology	MW Range	Installed cost ($/Kw)
Conventional hydro	50 average	$1,000-$5,000
Micro hydro	< 0.1	$4,000-$6,000
Run of River	10	$1,500- $6,000
Pumped storage	>500	$1,010-$4,500

Table 25 Hydropower technologies installation cost

The installed cost is approximately 4000-4400 $/Kw in Lebanon. Each installed MW costs around 4 million $ in Lebanon. This technology is so expensive despite the availability of water in Lebanon, with a load factor that does not exceed 30%. Therefore, this study will include other methods such as CSP, PV, offshore wind turbines and waste to energy.

The total hydroelectric production was 632 GWh in 2006 and in 2019, it reached 970.039 GWH (6.47% of total energy on Lebanese grid), depending on the amount of annual rainfall and maintenance programs.

B. Demand Growth Rate and Total Demand by 2050

Demographically speaking, in Lebanon the population is expected to decrease from now to 2050 going from 6.8 million to 6.5 million or even less based on studies and statistics mentioned in the table below.

Year	Population	Demographic Growth Rate %
2023	6,585,111	-0.81
2024	6,485,342	-1.1
2025	6,397,248	-1.29
2030	6,194,844	-0.64
2035	6,241,511	0.15
2040	6,376,401	0.43
2045	6,467,872	0.29
2050	6,528,164	0.19

Table 26 Growth rate in Lebanon from 2022 to 2050

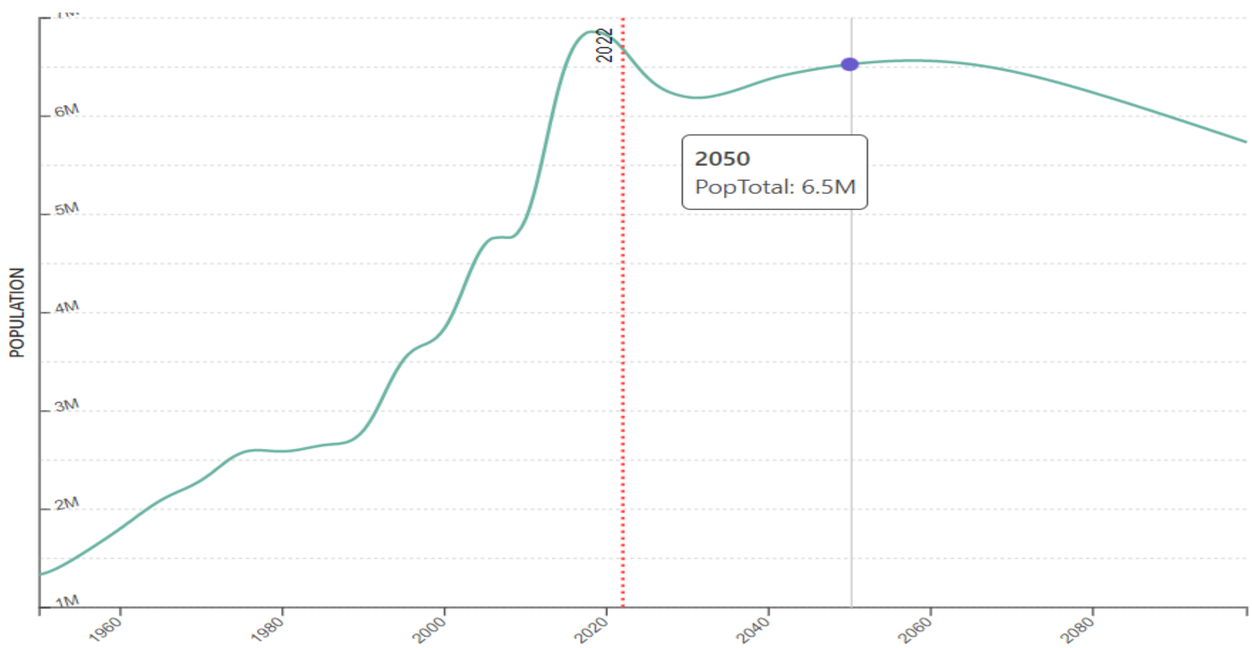


Figure 21 Graph showing the decrease of the population in Lebanon by 2050 [37]

In spite of poverty and poor medical access that lead to an overpopulation in a normal country and a normal situation, the population in Lebanon is not expected to grow due to the large number of immigrants because of the economic crisis in the last few years. In this case, the electric demand is going to be affected and lower than before [38].

However, given an economical and technological development, it is expected that the average person will consume more energy and will be having more new appliances in their home over the years.

Double glazed windows were developed to provide better insulation than the traditional glazing. When it comes to energy efficiency, double glazed widows absolutely come out on top because they can easily reduce heat loss or heat gain by almost 30% in comparison to single glazed windows and therefore the energy bill. A standard house can save approximately 200 to 250 dollars per year with double glazing. In addition to that, wall insulation, from the inside or the outside, can also save around 15-20% on heating and cooling energy so the energy consumption will also decrease. Moreover, the energy consumption can be reduced by using appliances with a better electric efficiency such as refrigerators, dishwashers, heat pumps, ceiling fans, clothes washers as well as energy saving gadgets for your home like eco chargers, LED light bulbs and programmable thermostats.

Whereas, new stations and new businesses will appear in the coming years due to the economical, technological and industrial development to meet consumer needs. As a result, the electric demands will increase and so will the electric power production in Lebanon.

The world is also moving towards electric vehicles to protect the environment and by that an increase in the renewable energy production because the environmental benefit of electric cars depends on the electricity being generated by renewables because it does not make sense if the cars are charged on stations generating dirty energy.

Because all these factors mentioned before, the growth rate in Lebanon will be settled at 2% from now to 2050 on average because the number range will be between 0 and 5% instead of 2 and 7%.

Needs (MW)			
Year	Best Case Scenario 0%	Normal Growth 2%	Worst Case Scenario 5%
2019	1.80E+03	1.80E+03	1.80E+03
2020	1.80E+03	1.84E+03	1.89E+03
2021	1.84E+03	1.87E+03	1.98E+03
2022	1.87E+03	1.91E+03	2.08E+03
2023	1.91E+03	1.95E+03	2.19E+03
2024	1.95E+03	1.99E+03	2.30E+03
2025	1.99E+03	2.03E+03	2.41E+03
2026	2.03E+03	2.07E+03	2.53E+03
2027	2.07E+03	2.11E+03	2.66E+03
2028	2.11E+03	2.15E+03	2.79E+03
2029	2.15E+03	2.19E+03	2.93E+03
2030	2.19E+03	2.24E+03	3.08E+03
2031	2.24E+03	2.28E+03	3.23E+03
2032	2.28E+03	2.33E+03	3.39E+03
2033	2.33E+03	2.38E+03	3.56E+03
2034	2.38E+03	2.42E+03	3.74E+03
2035	2.42E+03	2.47E+03	3.93E+03
2036	2.47E+03	2.52E+03	4.13E+03
2037	2.52E+03	2.57E+03	4.33E+03
2038	2.57E+03	2.62E+03	4.55E+03
2039	2.62E+03	2.67E+03	4.78E+03
2040	2.67E+03	2.73E+03	5.01E+03
2041	2.73E+03	2.78E+03	5.27E+03
2042	2.78E+03	2.84E+03	5.53E+03
2043	2.84E+03	2.90E+03	5.81E+03
2044	2.90E+03	2.95E+03	6.10E+03
2045	2.95E+03	3.01E+03	6.40E+03
2046	3.01E+03	3.07E+03	6.72E+03
2047	3.07E+03	3.13E+03	7.06E+03
2048	3.13E+03	3.20E+03	7.41E+03
2049	3.20E+03	3.26E+03	7.78E+03
2050	3.26E+03	3.33E+03	8.17E+03

Table 27 Electricity demand from 2019 to 2050 with a 2% growth rate

6.3 Implementation of the Solution

In Lebanon, most energy sources can be used, however the expected scale is not massive. The chosen renewable energies are: Waste to Energy, Photovoltaic, Concentrated Solar Power and Offshore Wind electricity productions of which PV is expected to take up the largest part.

1. Potential Repartition of the 50% Green-Produced Electricity

A. Waste to Energy Production

Just as coal and other fuels can be burnt in plants to generate electricity, the same can be done with municipal solid waste also known as biomass. Treated in 2500 plants worldwide, biomass can be burned, releasing heat, turning water into steam in a boiler and finally turning the blades of a turbine in order to produce electricity, in other words using the same process as fossil fuels. Over 420 million tons of waste are burned in order to generate energy worldwide every year, making up to 15% of the global electricity production.

Plants can range from micro industries to massive establishments depending on the capacity that can be treated and how much power is to be generated. Although they involve burning, WtE plants pollute much less than their fossil fuel counter parts which come at 0.778 tons of CO_2 emitted per MWh produced for heavy fuel and diesel oil and 0.443 tons/MWh for natural gas, while biomass sits at 0.03 tons of CO_2 per MWh. It also holds an advantage over the other fuels because it is not considered a finite source, as municipal waste is discarded every day and is usually burned out in the open or thrown into the ocean. In other words, this option tackles two issues by managing waste while supplying populations with electricity, making it the second most popular energy production method after fossil fuels.

This is also very convenient in Lebanon, a country which has suffered from trash related issues for more than a decade and electricity shortages since the late twentieth century. In fact, a huge waste landmass is sitting in the Karantina area and is only getting bigger with no plans to get rid of this huge environmental hazard. And that is only the top of the iceberg that is the Lebanon waste crisis.

Waste Management	World	Lebanon (2011)
Landfill and open dump	59.8%	83%
Incineration without recovery	1%	0%
Recycled and Composted	22%	17%
Incineration with recovery	15.2%	0%

Table 28 Waste management in the world and in Lebanon

The first column of numbers is widely available while the second was sourced from a 2011 study by George Boueri [39]. This study will be used throughout this part as it practically designs and contains a cost analysis of a potential Waste to Energy plant based in Beirut near the Karantina. A very similar plant to the one designed would be the best forward, however taking into consideration newer technology and a larger population.

The study however, revolves around waste management more than it is about producing electricity, especially considering, at the time, the looming threat of trash overflow which eventually led to a crisis back in the mid-2010s. The part concerning the electricity sector was already developed and this part will briefly show the Lebanese trash crisis which only got worse after the document was completed.

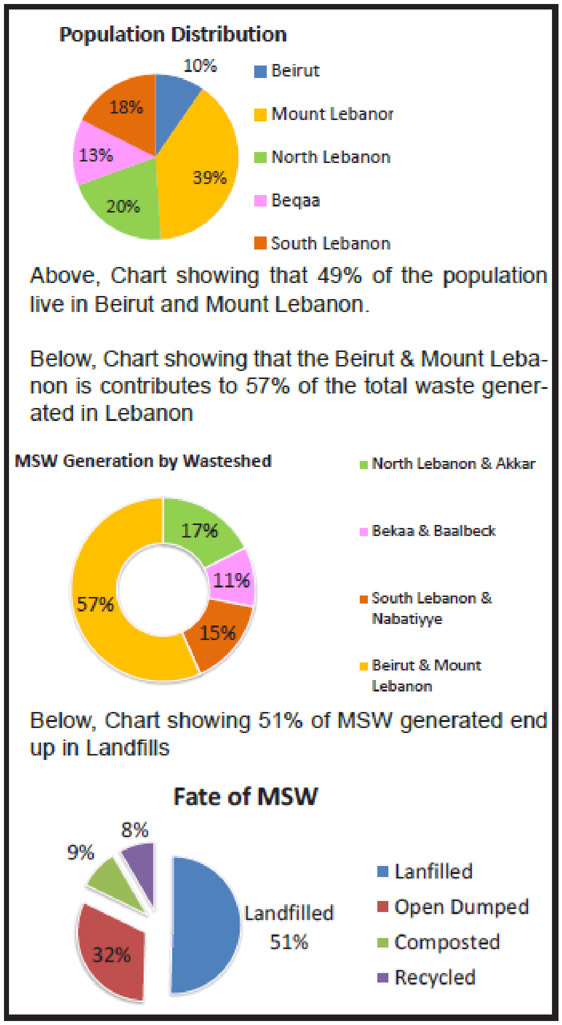


Figure 22 Information concerning MSW in Lebanon

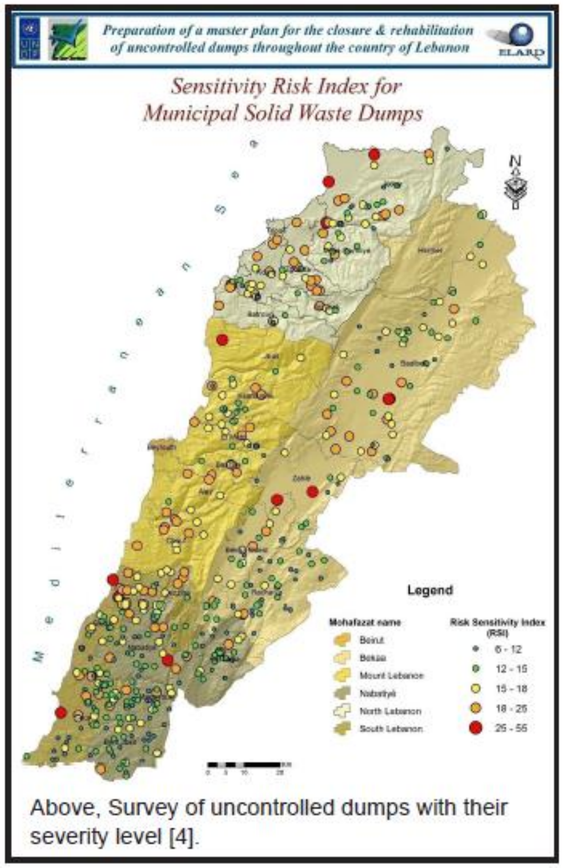


Figure 23 Survey of uncontrolled dumps with their severity level

In the following years, a lot of dumps were closed and trash was left on the street after a stop of operations at the only waste management company in Lebanon, Sukleen, which stopped operating in 2015 after the closing of a major landfill. Nonetheless, even with Sukleen or its successor, City Blu, trash in Lebanon is still badly disposed of as seen in the graphs, almost all Municipal Solid Waste (MSW) is landfilled or thrown into open dumps, polluting the environment as well as the air in the vicinity, a major risk factor of multiple diseases including but not limited to lung cancer, which develops after years of exposure to extremely unsanitary air.

This process will help towards achieving the end goal which is less pollution overall from two standpoints: the first being production of electricity using a method that has emissions of net zero as well as treating waste accordingly, thus protecting the environment and the Lebanese population from another ecological crisis.

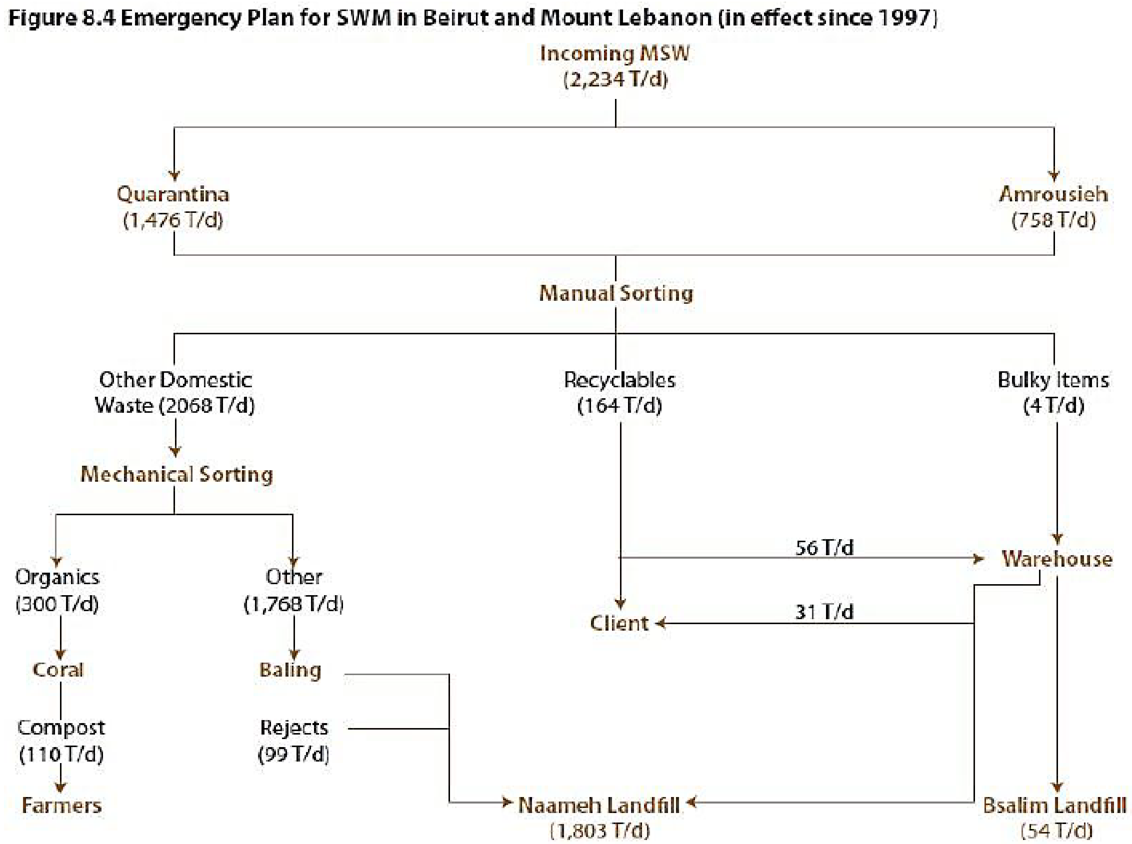


Figure 24 Diagram map of the waste management stream in Beirut and Mount Lebanon

Boueri designed this graph which shows how trash is sorted in Beirut and Mount Lebanon in terms of tons/day. However, given the fact that this project is realized at the national scale and more than 10 years later, only the proportions will be taken into consideration. Out of 2234 tons/day, 1857 are tossed in landfills and never repurposed, which amounts to 83%, matching the number shown above. Assuming that no change has taken place since then (if it didn't get worse), it is possible to estimate how much trash is produced across Lebanon daily and how it is treated.

The Center for Local Resource Development in Lebanon states in 2015 that there is about 0.9 to 1 kg of waste for every person Lebanon per day. Which means that for the current population of 6.856 million, the country produces a total of around 6513 tons of waste per day

In order to find out how much electricity that would make, Boueri calculated the average heat value in kJ of 1 kg of waste, considering the following repartition:

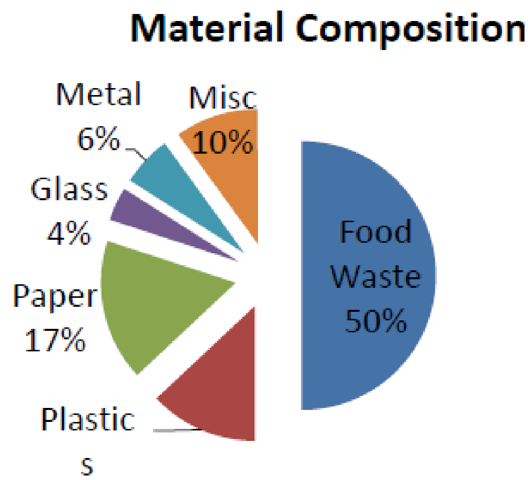


Figure 25 Chart showing the average material composition of MSW in Lebanon

On average, the heat value of each of those materials would be:

Material	Composition (%)	Heat Value (kJ/kg)
Food waste	50	4647
Plastic	13	32531
Paper	17	16730
Glass	4	0
Metals	6	0
Miscellaneous	10	4000

Table 29 The composition and the heat value generated by burning different materials

Multiplying these values by the corresponding coefficient then summing them gives the average heat value for trash in Lebanon of:

$$4647 * 0.5 + 32531 * 0.13 + 16730 * 0.17 + 4000 * 0.10 = 9800\ kJ/kg$$

Using an average of plants worldwide, Boueri found a direct link between the calorific value of waste and the net electricity output after being treated given in the table below:

Heat value (kJ/kg)	Net electricity output* (Kwh/ton)
7,000	350
8,000	450
9,000	550
10,000	650
11,000	750

Figure 26 The net electricity to be sold commercially

A linear interpolation of the 9800 kJ/kg in this table will result in a total of **630 KWh/ton** since these values are tied by the relation: $NEO = 0.1HJ + 350$. However, this only applies above the heat value threshold of 7000 kJ/kg which is the minimum a WtE plant can process in order to give a power output.

Given these numbers, it is now easy to calculate the potential production of a single waste to energy plant. In his report, Boueri used 2234 tons/day, which only covers Beirut and Mount Lebanon and takes into account the 2011 population of Lebanon which grew massively since then, especially after the Syrian Civil War which started that same year.

With the new number of 6513 tons from all over Lebanon, and estimating that not all of it can be collected and burned, multiple plants of the same size as that designed by Boueri will be required, or one big plant would be doing all the work. However, taking into account the lack of space for a massive plant in Lebanon and from a logistical point of view, it would be smarter to have multiple – more specifically three – plants operating in the North, Beirut and the South respectively, as it will make collection easier since the waste will not have to be transferred on long routes and can simply be treated nearest to where it is picked up from.

Assuming the proportions will not change, 17% of the MSW will still be composted and recycled, leaving 83% to be burned, which, considering the 6513 tons/day, will amount to **5406 tons/day** of trash to be burned and used as fuel. In a year, the total mass of MSW that can be treated will amount to **1973190 tons**. These numbers, however, take into consideration a constant flow that is produced everyday while glossing over already present landfills, some of which can be extracted from and emptied over the years. This means that, using three plants at maximum capacity (2500 tons/day, this number can go even higher depending on the current state of the technologies), the daily MSW input can be treated with space left for $7500 - 5406 = 2094$ tons of remaining capacity which can be filled by using the waste from present landfills, producing even more electricity and ridding the local community of stacks of MSW. Unfortunately, not all landfills can be done the same as some have been buried beneath soil and extracting the waste would not be practical.

In terms of numbers, the total energy output would be:

- Scenario 1: Using only the 5406 tons/day to produce electricity.
- Scenario 2: Running all three plants at maximum capacity, fueled by existing landfills, which can be exploited for a large number of years (7500 ton/day).

The following numbers take into consideration a load factor of 95% to accommodate for the maintenance time and unexpected downtime of the facility.

	Capacity (Tons/Day)	Capacity (Tons/Year)	Energy Production (KWh/Year)	Power Equivalent (MW)
Scenario 1	5406	1973190	1243109700	141.8
Scenario 2	7500	2737500	1724625000	196.7

Table 30 2 scenarios for the total energy output in Lebanon

The three plants have to be spread around Lebanon in the following way:

Figure 27 Three waste to energy plants to be installed in Lebanon by 2050

In the north, a facility would treat the MSW coming from the city of Tripoli and the surrounding regions as well as the northern part of the Bekaa Valley, including Baalbek.

A plant in Beirut, and more specifically the Karantina District, would operate using MSW from Beirut itself and Mount Lebanon, as designed by George Boueri.

Finally, a plant between the Sidon and Tyre would use the waste coming from the Governates of Southern Lebanon, including the Nabatieh Governate.

B. Photovoltaic Production

Expected to be the largest part of the production, photovoltaic generated electricity is on the rise, as Lebanon currently holds the title of the country with the largest growth in the PV production per capita. Because of the crisis and the global rise in fuel prices, blackouts have become more and more common to the point that the average Lebanese household has only 12 hours of electricity per day, with only 2 or 3 hours' worth of power being provided by EDL. For this reason, more and more citizens are installing PV panels on their roofs in order to compensate for the lack of provided electricity.

The growth in PV production is thus due to people having to provide for themselves instead of an environmentally friendly initiative.

This was not always the case, however, as efforts to provide more electricity through PV production were made by the government during the 2010s as seen in the graph below:

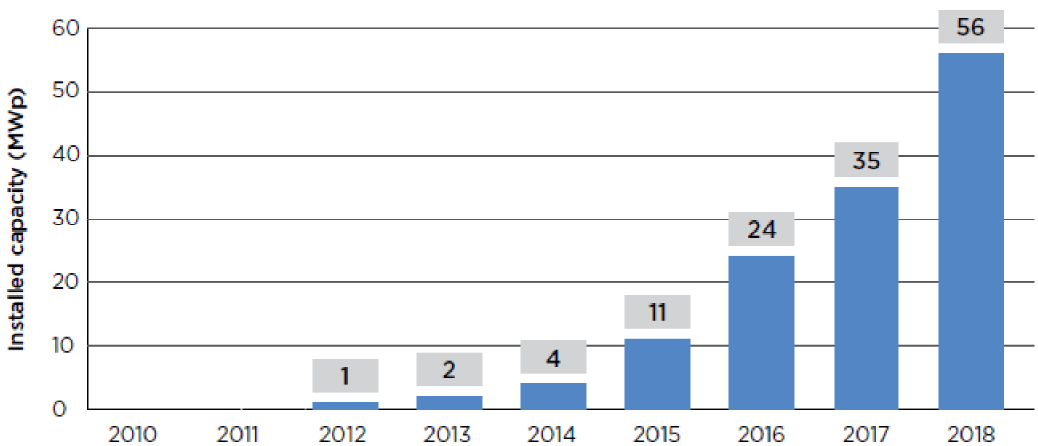


Figure 28 PV installed capacity in MW in Lebanon [40]

This graph comes from a study conducted by a joint effort between the Ministry of Energy and Water in Lebanon (MEW) and the International Renewable Energy Agency (IRENA) was on track to provide Lebanon with clean, renewable energies. The study, released in 2020, aimed for 30% renewable energy in Lebanon by 2030 by concentrating most of the expected production in PV. The expected success of this energy source and the reason it is the most commonly used is thanks to the high sunlight density in the Lebanese territory and especially the Bekaa Valley which also happens to be a perfect location for large panel layouts since it is a plain with large empty areas comprised of publicly owned and private owned lands.

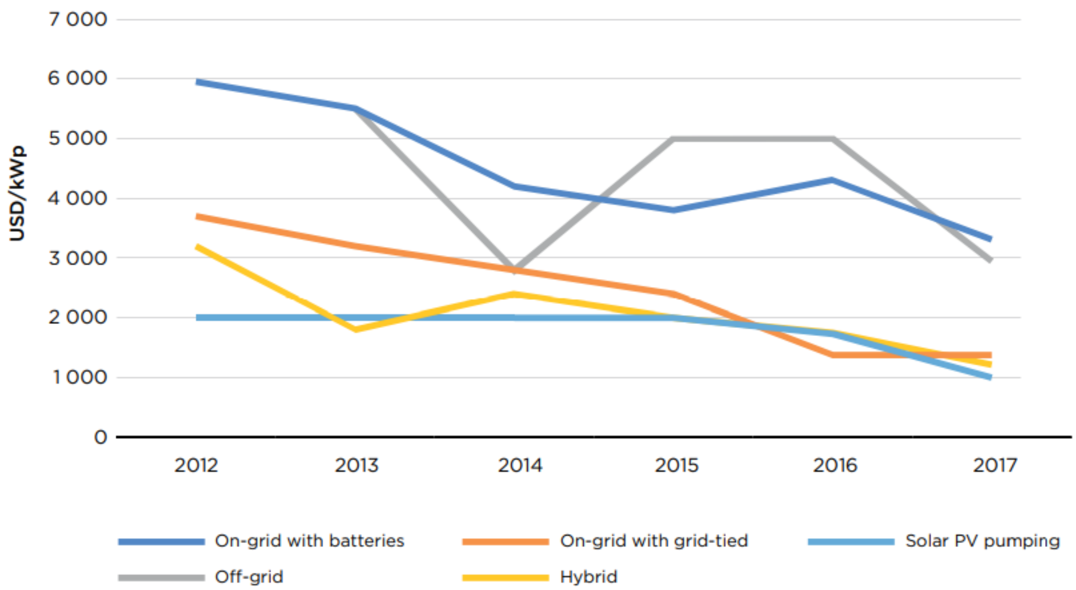


Figure 29 Yearly average solar PV turnkey price in Lebanon

The size of a solar panel system has an impact on how much it costs to install. Because the panels may be acquired in bulk, larger solar projects will often have a cheaper cost per watt.

PV applications have decreased all across the world. Prices for hybrid applications with backup battery storage that are connected to the energy grid have reached roughly USD 1 200 per kWp. Off-grid systems saw the biggest price drop, dropping nearly 46% from over USD 5 000 per kWp in 2013 to roughly USD 3 000 in 2017.

Prices in the market for on-grid applications with grid-connected batteries and backup battery storage declined from roughly USD 6 000 per kWp in 2013 to around USD 3 300 in 2017, a 39% decrease. Because they employ battery storage, both systems are more expensive than on-grid and solar pumping systems.

On-grid with grid-tied systems prices declined from USD 3 700 per kWp in 2013 to USD 1 400 in 2017, representing a nearly 57% fall in price, while solar PV pumping prices fell by roughly 50% between 2014 and 2016, owing to an increase in the number of installations and their size. Furthermore, all of these prices were calculated using NEEREA data, which shows costs that are greater than market pricing due to financing and study expenditures.

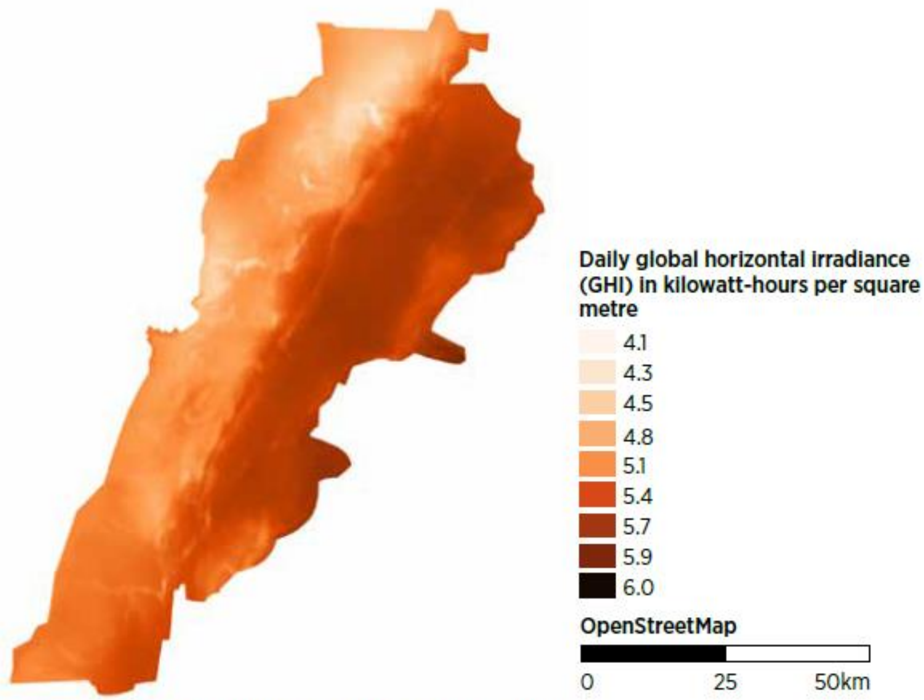
Concerning **the lifespan of PV**, the industry norm for the life of solar panels is 25 to 30 years. However, this does not imply that power generation would halt in 25 years; rather, it indicates that energy output has decreased by a substantial amount, as determined by manufacturers.

Solar panels will last decades if they are not harmed by wind, dust, or other environmental causes. Solar panels do not have any moving parts and are generally damaged by external causes such as poor shelving or harsh weather.

Solar panel output declined by 0.8% each year on average, according to research by the National Renewable Energy Laboratory (NREL) in 2012. The solar panel degradation rate is the term for this rate of deterioration. While the rate of deterioration varies depending on the panel brand, premium manufacturers offer rates as low as 0.3%. More efficient technologies have been developed in the years after the study was done in 2012, with many newer panels witnessing only a 0.5% decline in power production per year or even less than 0.5%.

The average cost of generating electricity for a photovoltaic (PV) system is only $0.06-0.08/kWh. No other technology on the market is as cost-effective as photovoltaic systems in a sunny country like Lebanon.

The **load factor** is ranged between 14 and 19%.



Source: IRENA (n.d.), Global Atlas for Renewable Energy; World Bank; 1 km Global Horizontal Irradiation.

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Figure 30 The daily global horizontal irradiance (GHI) in kilowatt hours per square meter in Lebanon

As can be seen above, the whole Bekaa Valley is irradiated by at least 5.7 kWh/m^2, making it optimal for installing PV farms in the plains there.

In May 2017, the Lebanese government called an auction to install PV farms all over Lebanon. The goal was to have 12 farms, each producing 10 to 15 kW of power from solar panels. Each company involved would have to offer a unique, privately owned spot of land that would contain the farm, owned by the company, and would provide the power to EDL to be redistributed later on. The call resulted in around 265 separate entities expressing the interest in the project for a total of 3500 MWp (Mega Watt peak), showing how much power could actually be installed if need be. IRENA's total estimation however, states that 87 636 MWp of power could actually be installed across Lebanon, but this number is just the maximum in a scenario in which lands are used for no other purpose. By November 2017, 42 offers were presented by a total of 138 companies (contractors and their subcontractors), for a total power production of around 500 MW of which the government wanted around 180. However, this was only the first among multiple auctions which would eventually rack up the amount of PV produced electricity.

The plan was to have around 2500 MW by 2030 which is very realistic considering the initial numbers were further above that.

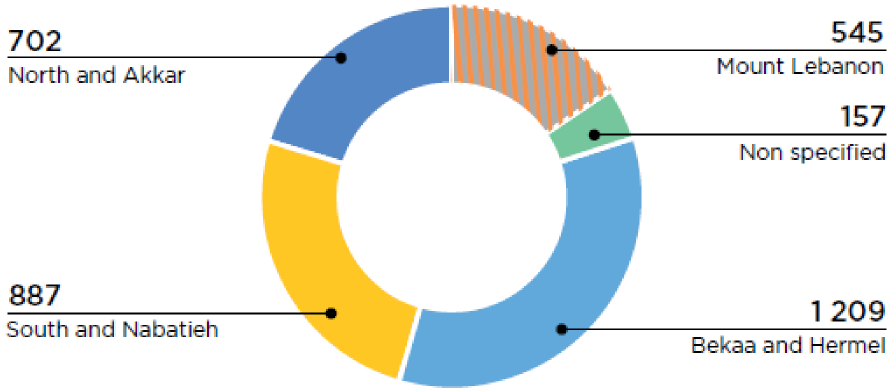


Figure 31 Total capacity per region in response to the EOI of the first round of PV projects

In terms of location, this is how the first 3500 MW were to be distributed, with the inner regions (North and Akkar, South and Nabatieh, Bekaa and Hermel) amounting to around 2800 MW, or 80% of the total production, due to the power density in those areas as well as the presence of large, unexploited plains.

C. Concentrated Solar Power Production

CSP systems consists of three major units:

1) **Solar field**
2) **Thermal storage**
3) **Power block**

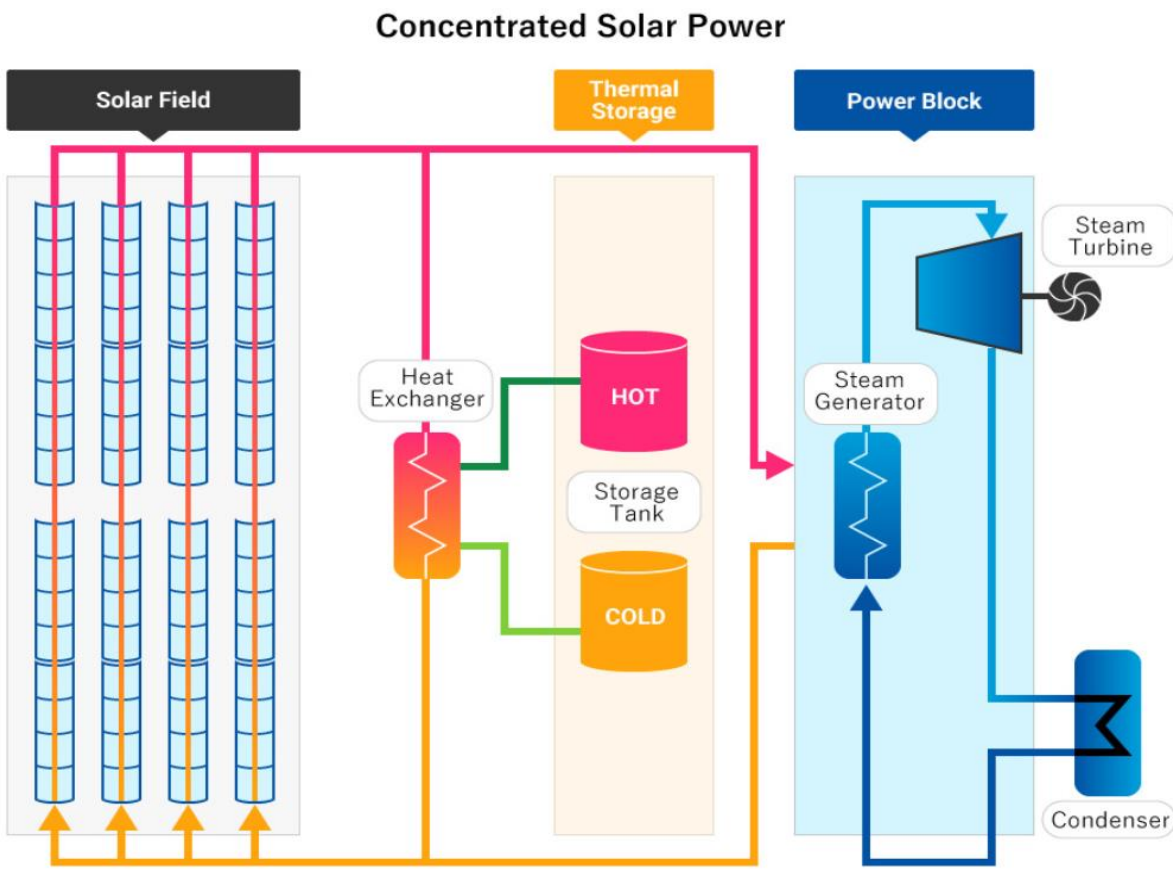


Figure 32 Concentrated Solar power three major units

The solar Field is made up of multiple mirrors or lenses that receive sunlight and concentrate direct solar radiation onto a receiver, converting solar energy into thermal energy; the light is transformed into heat, which is then used to drive a turbine. The thermal storage is connected to a power block that generates electricity and stores heat energy.

When compared to other renewable energy sources, thermal energy storage is one of the most appealing elements of CSP since it allows for the production of power during the hours of darkness, ensuring electrical supply reliability.

There are four type of CSP technologies [41] [42][44]:

1) Parabolic trough

CSP trough systems, also referred as parabolic trough systems, are long and curved mirrors that concentrate or focus the sunlight on thermally efficient receiver tubes located at the focal center of each mirror as shown in the figure below. A motor rotates the mirrors to follow the position of the sun and to receive sun's radiation for a longer period of time during the day. To limit intermittency and improve dispatch capability, these systems may have a heat transfer fluid typically synthetic oil, molten salt or steam that circulates in the tubes to absorb the heat received from the sun before passing through several heat exchangers to produce steam. For temperature lower than 200°C the heat transfer fluid is a mix of demineralized water and ethylene – glycol. For temperature between 200 and 500°C, synthetic oil and molten salts are used as a heat transfer fluid. The steam spins a conventional steam cycle turbine to generate power.

Without storage, a parabolic trough plant costs around 4600 $ per KW, with a capacity factor of 25%. Adding six hours of heat energy storage, the cost will automatically increase and the installation cost is between 7000 and 10000 $ per KW with a capacity factor of 50%. These days, a capacity factor of around 70% is reached.

The Levelized Cost of Electricity of parabolic trough plants today is in the range of 0.20 USD to 0.33 USD per kWh depending on their location or if they include energy storage or not.

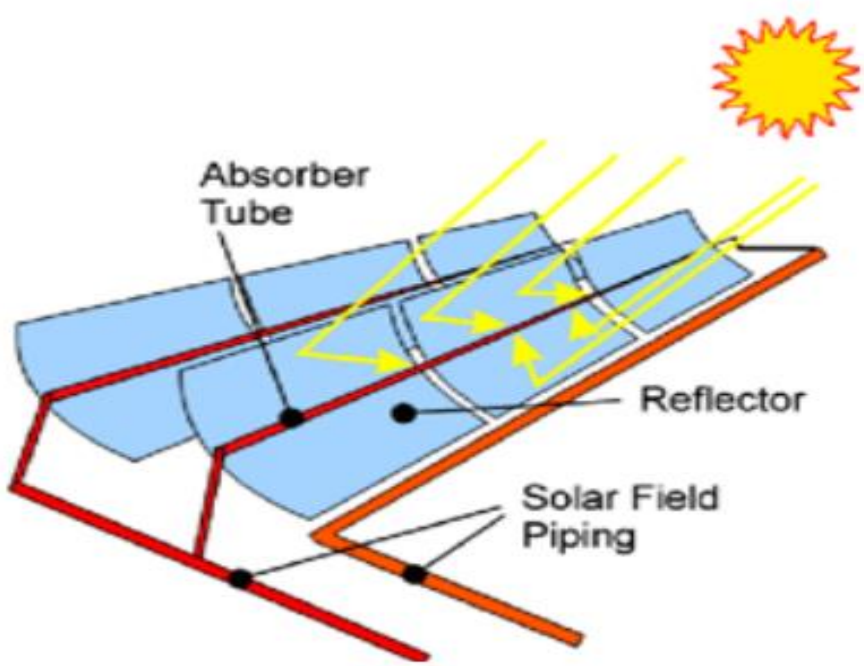


Figure 33 Parabolic trough

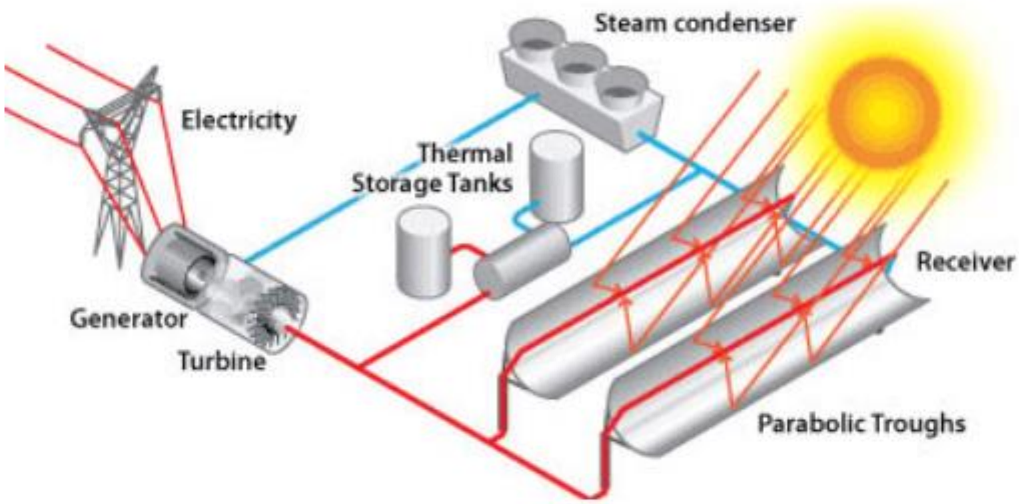


Figure 34 Generating power from a parabolic trough plant

2) Linear Fresnel reflector

Linear Fresnel reflector systems are made up of nearly flat mirrors array that reflect the sunlight onto elevated linear absorbers or receiver tubes. The thermal fluid used with this technology is normally water through the tubes and is converted into steam at around 270 ˚C. To eliminate the need of high cost heat exchangers, steam can also be produced directly in the solar field.

This technology uses less land and lower manufacturing than parabolic trough and a capacity factor of 60%.

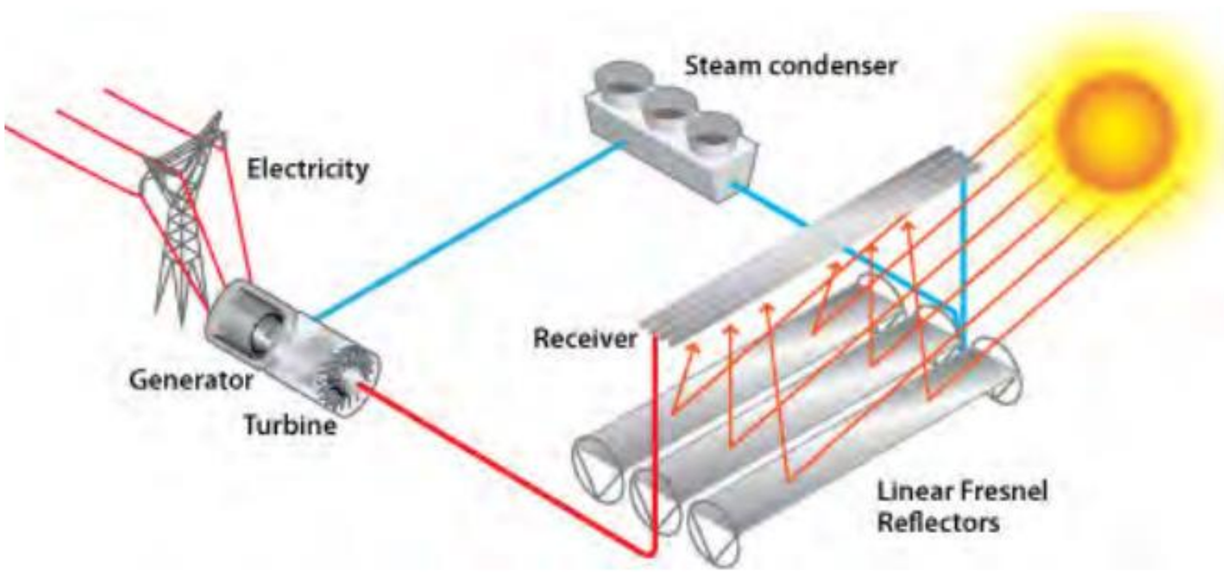


Figure 35 Generating power from a linear Fresnel reflectors plant

3) Parabolic dish

Parabolic dish, or dish engine, systems are individual units comprised of a solar concentrator, a receiver, and an engine or generator.

The parabolic dish reflector focuses the sunlight into a receiver at the focal point of the dish. The heat transfer medium (fluid or gas) in the receiver is heated at around 750˚C and drives a small piston, Stirling engine or micro gas turbine attached to the receiver to generate electricity directly at the dish. The dish follows the radiation of the sun during the day. Every dish generates between 10 and 25 KW. This technology does not require a heat fluid.

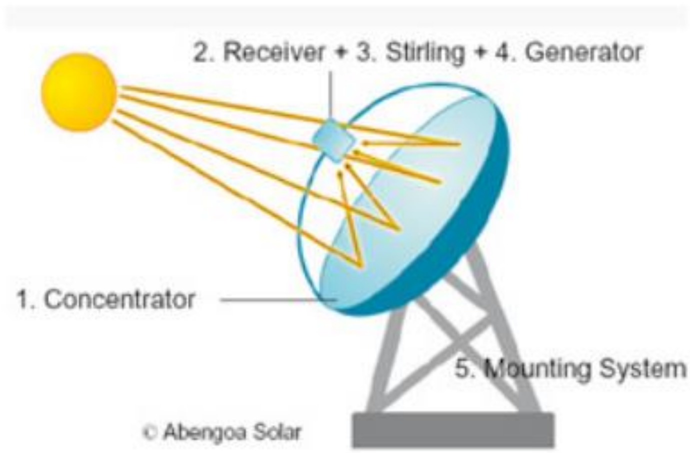


Figure 36 Parabolic dish

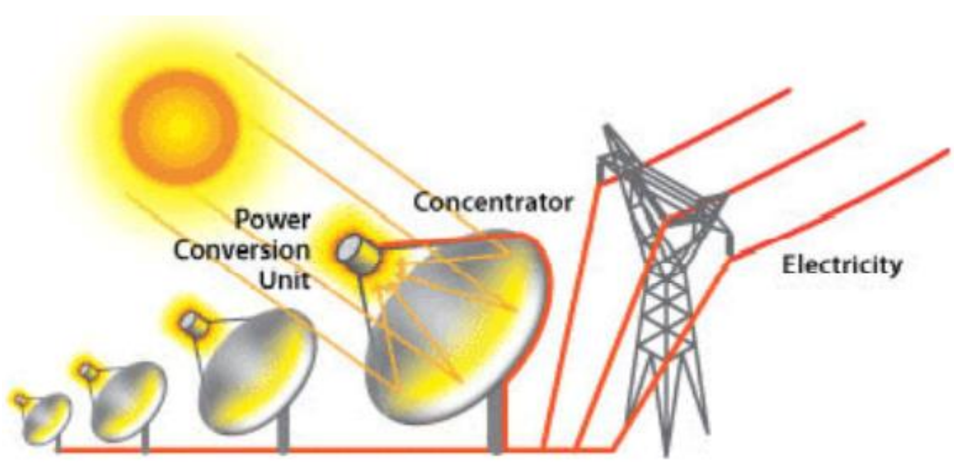


Figure 37 Generating power from a parabolic dish

4) Central receiver

Central Receiver Systems, or Solar Towers systems, use a large collection of mirrors, called heliostats, to follow the sun during the day. The sunlight is reflected from the mirrors and directed to a central receiver on top of a tower in the heliostat array's center. In current gas and steam combined cycles, pressurized gas or air at roughly 1000°C can also be used directly to drive efficient gas turbines. Molten salt towers elevate the working temperature to between 550 and 650°C and provide the possibility of very low-cost storage, allowing solar energy to satisfy peak demands and have high capacity factor.

The PS20 station, designed by Abengoa Solar in Seville, Spain, is the world's largest CSP tower system currently in service. A 531-foot solar tower and 1,255 heliostats are part of the 20-megawatt installation, which went online in April 2009.

The installation cost ranges between 6300$ and 10500$ per KW with energy storage up to 15 hours.

This technology has a capacity factor of 95% and an LCOE of 0.16 to 0.27$ per KWh depending on their location and the size of the thermal energy storage.

Just to mention that the maximum distance from the farthest heliostats to the receiver easily exceeds 1 kilometer in power plants of some 10 MWel of capacity.

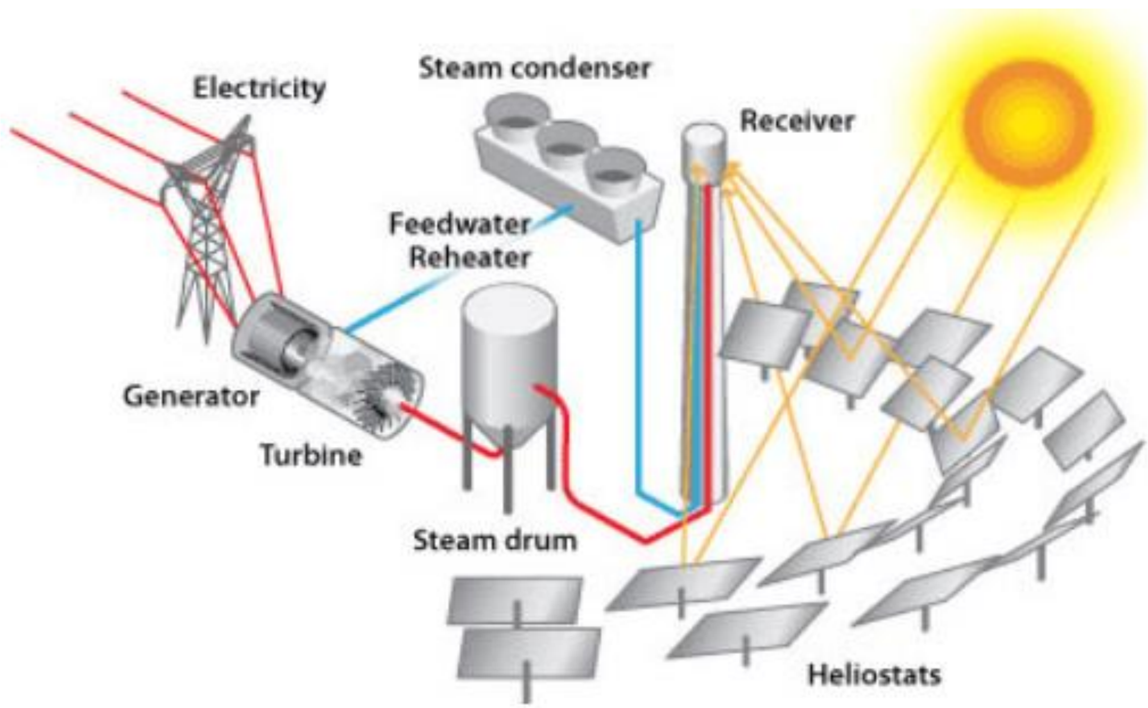


Figure 38 Generating power from a central receiver plant

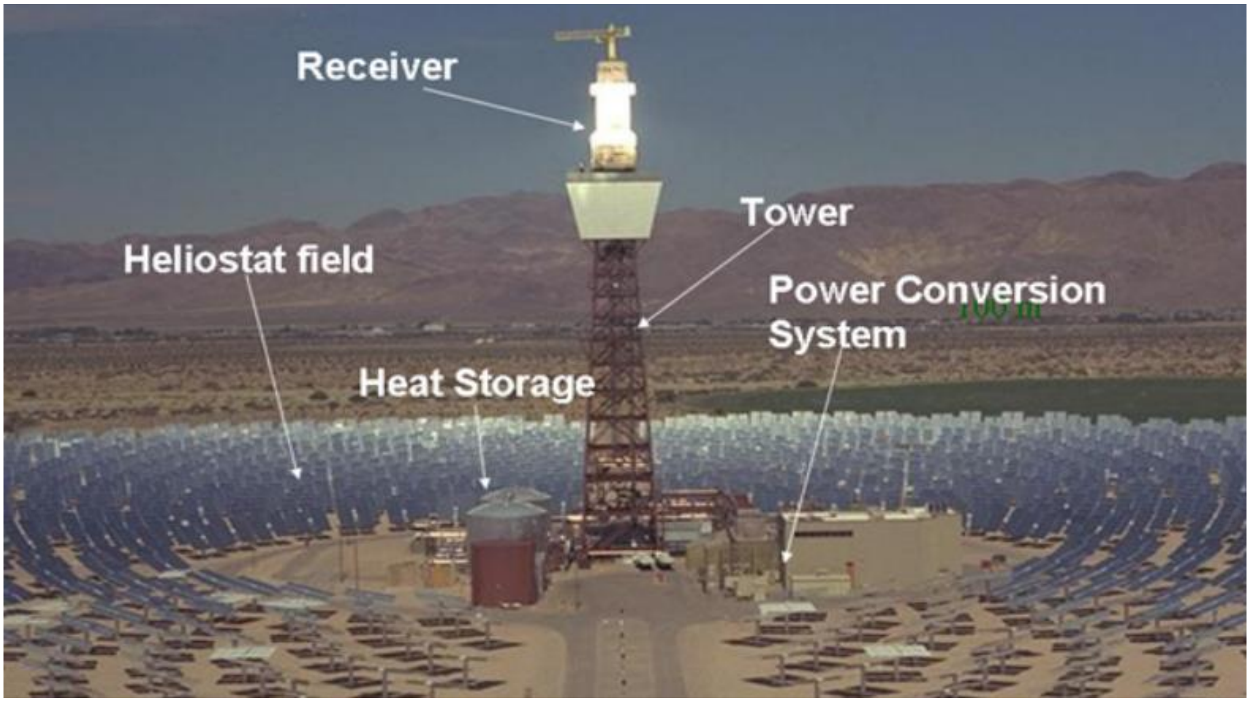


Figure 39 Different components for a central receiver

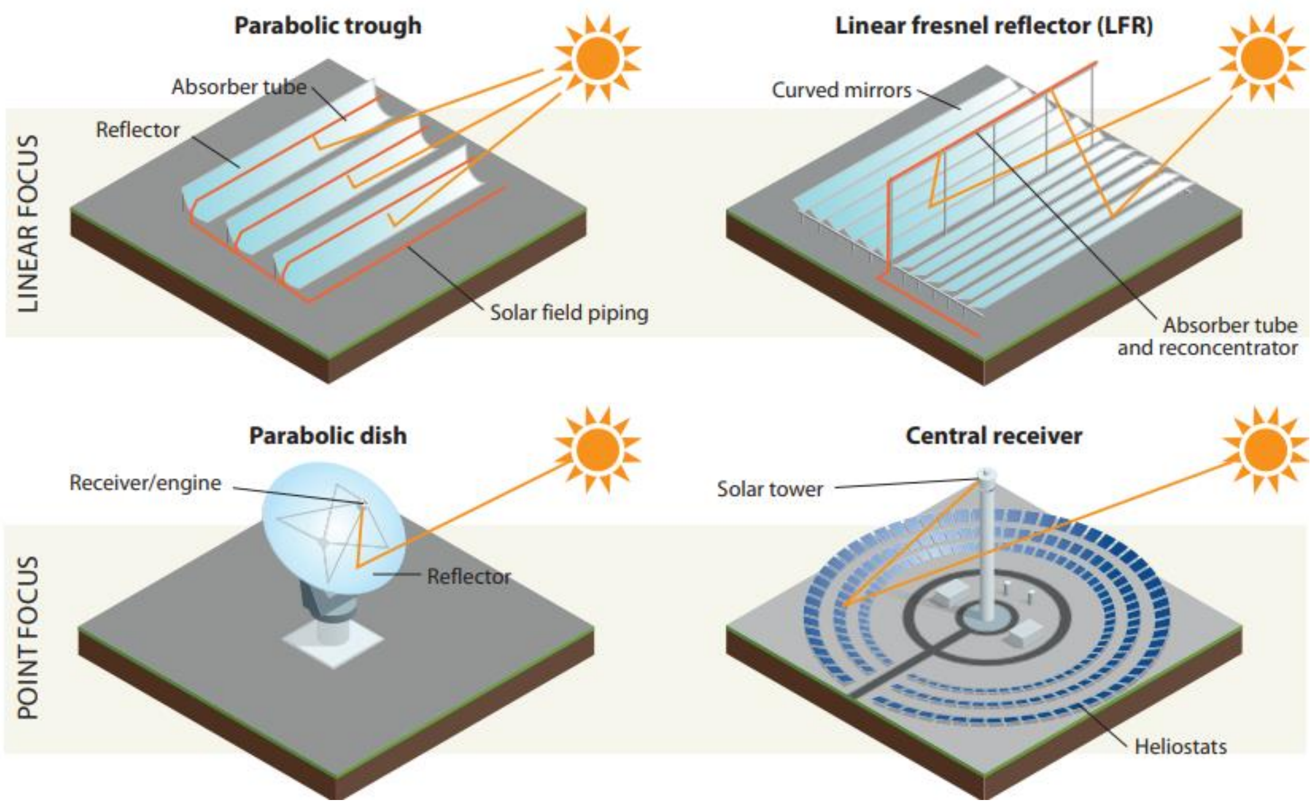


Figure 40 Four type of CSP technologies

Concerning the lifespan of CSP, normally solar PPAs lives only 20 to 25 years. But in 2017, ACWA Power, a developer that is no stranger to innovative deal structures, developed a power PPA that can operate for around 35 years [43].

CSP installation costs worldwide ranged between 4700 and 10600 dollars per kilowatt between 2010 and 2020. In 2020, the average installation cost of CSP systems was 4725 $ per kilowatt installed.

The levelised cost of energy ranges from 0.17 to 0.25 dollars per kWh, mostly dependent on the quality of the solar resource. In 2020 the average levelised cost of energy of new CSP was 18.2 c$ per KWh.

However, CSP is a relatively new technology and based on the algorithm developed in this project, the price of energy production is 5.6c$ per kWh. This decline in its price is due to the its exponential development.

It's worth noting that the LCOE of CSP facilities is inversely proportional to the DNI. The predicted LCOE of a CSP plant will decrease by 4.5% for every 100 kWh/m2 /year that the DNI surpasses 2 100, assuming a base of 2 100 kWh/m2 /year.

Lebanon benefits of sunlight as shown in the table below:

Month	GHI (KWh /m^2)	DNI (KWh /m^2)	Temperature (°C)
Jan	95	139	4.6
Feb	105	123	4.9
Mar	174	202	7.7
Apr	205	218	11.9
May	246	262	16
Jun	260	288	19.4
Jul	261	288	21.3
Aug	237	266	21.2
Sep	193	230	19.2
Oct	149	192	15.9
Nov	105	156	10.6
Dec	87	136	6.7
Year	2119	2501	13.3

Figure 41 Lebanon benefits of sunlight over the year

CSP potential for Lebanon [45] [46] [47] [48]

CSP technology require a solid and unpopulated land with a minimum area of 1 km^2. The land slope should be less or equal to 3% and the direct normal irradiance larger or equal to 2100 kwh/m^2/year. Many areas have direct normal irradiance (DNI) of over 2,100 kWh/m2 /y, which is ideal for CSP. For example, Hermel has a DNI of 2,445 kWh/m2 /y and all the studies show that Hermel has a significant potential for CSP and would the most suitable region for a CSP plant. Four different scenarios for this CSP plant:

1. Parabolic trough without storage
2. Parabolic trough with 7.5 hours of storage
3. Central receiver with a 0.5 hours of storage
4. Central receiver with 15 hours of storage

The first technology will be the parabolic trough

Technical input parameters	units	PT with storage	PT without storage
Solar field			
Site		Hermel	Hermel
Longitude	°	36.39	36.39
Latitude		34.39	34.39
Solar multiple		1.99	1.05
DNI	kWh/m2/y	2445	2445
Total aperture surface	m2	509,440.00	268,800.00
Required ground surface	km2	1.99	1.05
Length of a single collector	m	150	150
HTF temperature at field entrance	°C	291	291
HTF temperature at field exit	°C	391	391
Heat transfer and power block			
Design Net electrical output	MW	50	50
Heat loss factor piping	W/m2	0.02	0.02
Storage capacity	hours	7.5	0
Thermal capacity of storage	kWh	1,082,530.00	1,391.00
Storage efficiency	%	95	95
HTF temperature in storage discharging	°C	371	371

Table 31 Technical inputs for a parabolic trough in Hermel with storage and without storage

***Solar multiple** is defined as the ratio between the thermal power produced by the solar field at the design point and the thermal power required by the power block at nominal conditions: This parameter represents the solar field size related to the power block, in terms of nominal thermal power.

Operation & maintenance input	units	PT with storage	PT without storage
Labor costs per employee	$/year	33000	33000
Number of persons without maintenance field		25	25
Number of persons for field maintenance		15	8
Water costs per MWh electricity produced	$/MWh	1.43	1043
O&M equipment costs percentage of investment	%	1	1
Fix O&M cost associated to the power block	$/Kwe	30	30
Variable O&M cost associated to the power block	$/MWh	2.75	2.75
Cost input			
Specific investment cost for solar field	$/m2	242	242
Specific investment cost for power block	$/kwe	1650	1650
Specific investment cost for heat storage	$/kwh_th	44	44
Specific cost for civil works	$/m2	11	11
Financial parameters			
Annual insurance cost	%	1	1
Lifespan	years	30	30
Dept. interest rate	%	6	6
Surcharge of construction	%	10	10
Surcharge for engineering & management	%	5	5
Surcharge of contingencies	%	5	5

Table 32 O&M, cost input and financial parameters for the parabolic trough plant in Hermel

Annual Capacity Factors varies from 22-27% for the plants without heat storage to 38 - 50% for the plants with 7.5 hours of heat storage. This Capacity factor indicates that, on an annual basis, for the 0 to 24 full load scheme, the parabolic trough plant with HTF and a 0 or 7.5 h thermal storage is able to deliver about 22-27% in case of 0 hour about 38-50% in case of 7.5h of the demanded electricity from solar heat.

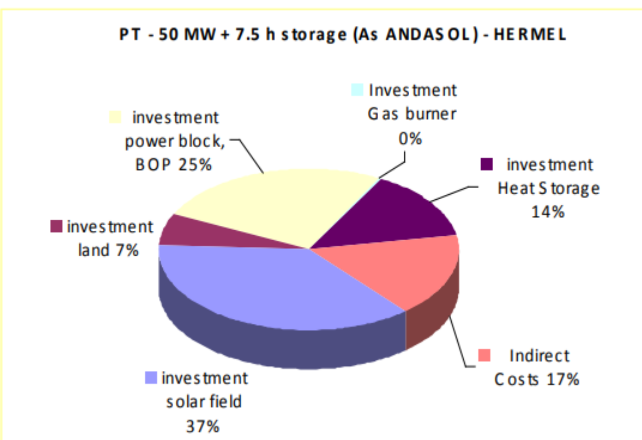
Economical results	Units	PT with storage	PT without storage
Fixed charge rate	%	8.26	8.26
Investment solar field	$	123,200,000.00	65,050,000.00
Investment power block	$	85,500,000.00	85,500,000.00
Investment heat storage	$	47,630,000.00	60,000.00
Investment land	$	22,000,000.00	11,600,000.00
TOTAL investment in plant construction	$	278,330,000.00	162,210,000.00
Indirect costs	$	56,000,000.00	33,000,000.00
TOTAL investment + indirect cost	$	334,330,000.00	195,210,000.00
Specific investment	$/kWe	6,685.00	3,900.00
Annual O&M costs	$	6,315,000.00	4,571,000.00
Annual financing & insurance costs	$	28,000,000.00	16,000,000.00
LCOE	$/kWh	0.20	0.23
Total cost of water used	$/year	287,100.00	149,000.00

Table 33 Economical results for the parabolic trough plant in Lebanon

The total investment for the parabolic trough with 7.5 hours of heat storage is around 350 M$. It is less expensive to use a PT plant without heat storage; it costs approximately 200 M$. A 50 MW PT plant capacity with storage costs more than a 50 MW PT plan without storage, it takes more land space but has a lower LCOE of 20 c$/kWh compared to plants without heat storage with a LCOE equal to 23 c$/kWh.

The specific cost of the installation is about 3900 $ / kW electric for the case without storage and about 6700 $ /kW electric for the PT plant with storage.

For a parabolic trough with a 7.5 hours of heat storage, the annual electricity productions for Hermel is 180 GWh with a load factor of 41%.



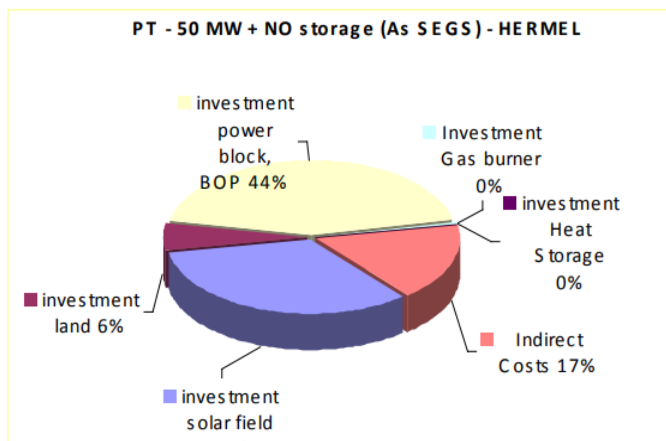


Figure 42 Investments for a PT with storage and without storage

The second technology will be the central receiver:

Technical input parameters	units	CR with storage	CR without storage

Solar field			
Site		Hermel	Hermel
Longitude	°	36.39	36.39
Latitude		34.39	34.39
Solar multiple		3	1.3
DNI	kWh/m2/y	2445	2445
Total aperture surface	m2	304,520.00	150,600.00
Required ground surface	km2	1.5226	0.753
Total number of heliostats		2648	1255
Aperture Surface per heliostat	m2	115	120
HTF temperature at field exit	°C	565	250
Mean concentrated solar flux on receiver aperture	kW/m2	500	350
Absorptivity of solar receiver	%	93	93
Heat transfer and power bloc			
Incident thermal power on receiver	kW	149000	73000
Power block parasitic	%	3	3
Design Net electrical output	MW	20	20
Efficiency of the power bloc	%	40	30
Storage capacity	hours	15	0.5
Thermal capacity of storage	kWh	806,899.00	34,307.00
Storage efficiency	%	98	95
HTF temperature in storage discharging	°C	560	240

Table 34 Technical inputs for a central receiver in Hermel with storage and without storage

As shown in the table above, for the same nominal power of 20 MW electric, the central receiver plant requires more aperture surface than a CR plant without heat storage. A central receiver with heat storage for 15 hours is more efficient and has a load factor of approximately 90 to 95%. With 15 hours' storage, the plant can operate for 24 hours in summer so the annual capacity factor can reach 75% in Lebanon.

The annual electricity produced (with solar only) with a central receiver with 15 hours of heat storage is 112 000 MWh. However, the annual electricity produced (with solar only) with 0.5 hours of storage is 49 120 MWh, less than half respect to the previous case.

Annual Capacity Factors, varies within 30-43% for the plants with only 0.5 h heat storage and are estimated from 70% to 90% for the CR plant with 15 hours of heat storage in the different sites.

For a central receiver plant with a 15 hours of heat storage, the annual electricity production is 131.5 GWh with a load factor of 75%.

operation & maintenance input	units	CR with storage	CR without storage
Labor costs per employee	$/year	53000	53000

Number of persons without maintenance field		20	20
Number of persons for field maintenance		15	4
Water costs per MWh electricity produced	$/MWh	1.43	1043
O&M equipment costs percentage of investment	%	1	1
Fix O&M cost associated to the power block	$/Kwe	30	30
Variable O&M cost associated to the power block	$/MWh	2.75	2.75
Cost input			
Specific investment cost for solar field	$/m2	205	205
Specific investment cost for power block	$/kwe	1760	1800
Specific investment cost for heat storage	$/kwh_th	32	72
Specific cost for civil works	$/m2	4.5	4.5
Specific investment for receiver	$/KWth	253	94
Financial parameters			
Annual insurance cost	%	1	1
Lifespan	years	30	30
Dept interest rate	%	6	6
Surcharge of construction	%	10	10
Surcharge for engineering & management	%	5	5
Surcharge of contingencies	%	5	5

Table 35 O&M, cost input and financial parameters for the central receiver plant in Hermel

economical results	Units	CR with storage	CR without storage
Fixed charge rate	%	8.26	8.26
Investment solar field	$	62,260,000.00	30,500,000.00
Investment power block	$	33,500,000.00	36,300,000.00
Investment receiver	$	37,000,000.00	7,000,000.00
Investment in tower	$	5,720,000.00	4,600,000.00
Investment heat storage	$	26,300,000.00	2,550,000.00
Investment land	$	1,300,000.00	660,000.00
TOTAL investment in plant construction	$	166,080,000.00	81,610,000.00
Indirect costs	$	33,200,000.00	17,000,000.00
TOTAL investment + indirect cost	$	199,280,000.00	98,610,000.00
Specific investment	$/kWe	11,000.00	5,000.00
Annual O&M costs	$	4,750,000.00	3,000,000.00
Annual financing & insurance costs	$	17,000,000.00	8,350,000.00
LCOE	$/kWh	0.20	0.23
Total cost of water used	$/year	180,000.00	80,000.00

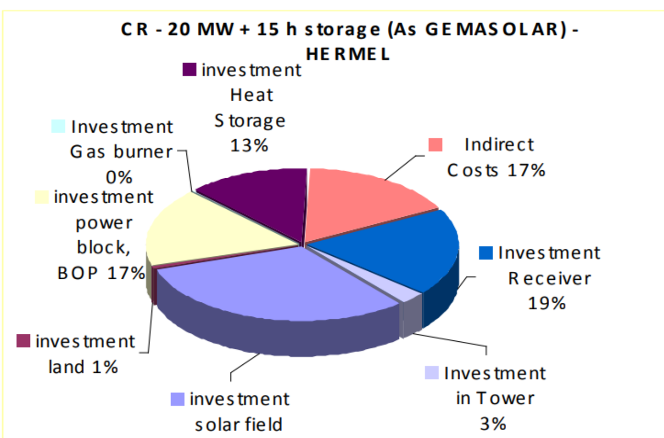
Table 36 Economical results for the CR plant in Lebanon

For the 20 We CR plant with 15 hours of heat storage, the total investments of 200 M$ is double of the 20MWe CR plant without storage whose total investment is about 100 M$.

The specific cost of the installation is about 5500 $ /kW electric for the case without THS and about 11 000 $ /kW electric for the central receiver plant with 15 hours of heat storage. This number depends strongly on the capacity factor of the plant (up to ~90-95%). Designing the plant with a lower capacity factor requires a smaller field and smaller storage system but the LCOE would slightly increase.

environmental parameters	Units	CR with storage	CR without storage
CO2 emissions	kg/kWhe	0.50	0.50
Water required for mirror washing	L/kWhe	0.3	0.3
Water required for thermodynamic cycle	L/kWhe	5	5
Annual CO2 mitigation	tons/year	52,633.00	23,642.00
Annual water required	m3/year	710,567.00	323,324.00

Table 37 The environmental comparison between a CR with storage and without storage



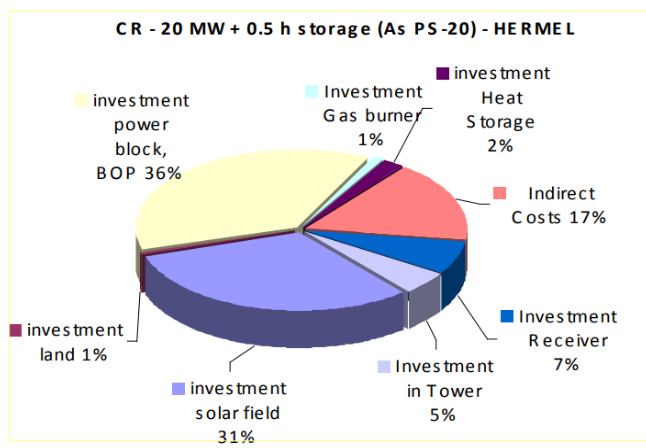


Figure 43 Investments for a CR with storage and without storage in Hermel

D. Offshore Wind Farm

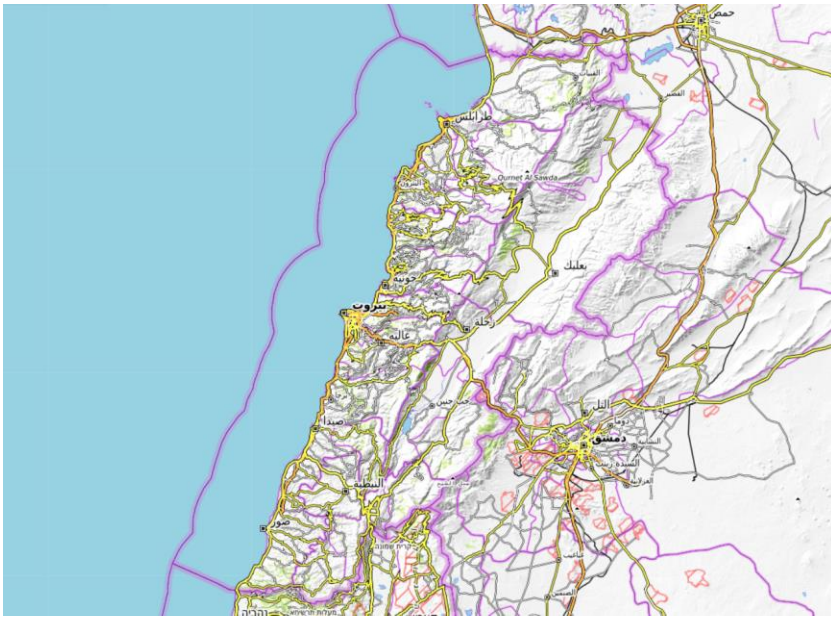


Figure 44 Maritime borders of Lebanon

Lastly in terms of the public sector, offshore wind farms will be a boost in the results that still comes very short of the initially anticipated produced 50% of electrical energy through renewable matters. Lebanon is a coastal country with widely available – although disputed – maritime territory, which makes using offshore wind farms an option.

In order to define where – and if – this implementation is possible, the first thing to look at is the mean wind speed and power density on the Lebanese coast in [49] to find out how these numbers.

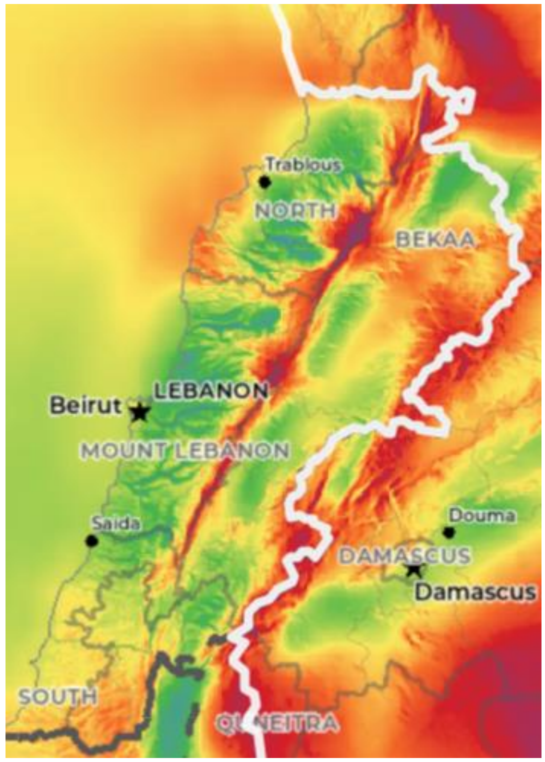


Figure 45 Mean wind speed in Lebanon

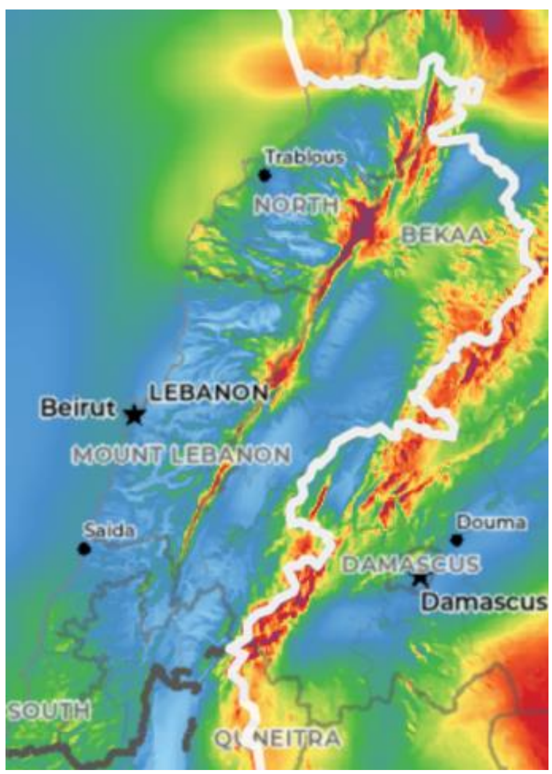


Figure 46 Mean power density in Lebanon

Before elaborating anything, the first thing that catches the eye is the color scheme that is about the same on the entire Lebanese coast but changes starting from Byblos and going north. Having said that, the next step is to take a look at the numbers:

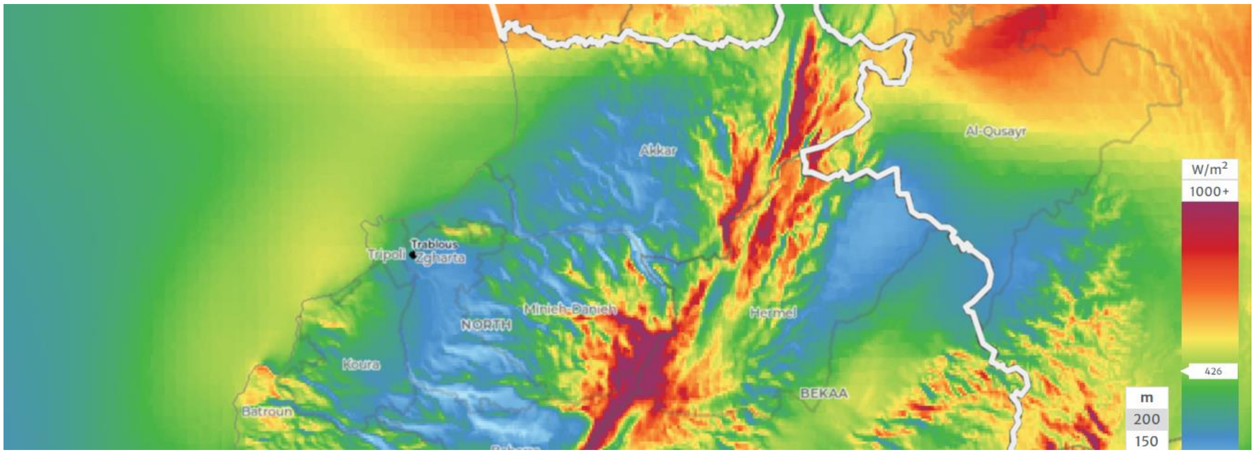


Figure 47 Mean wind speed over northern Lebanon

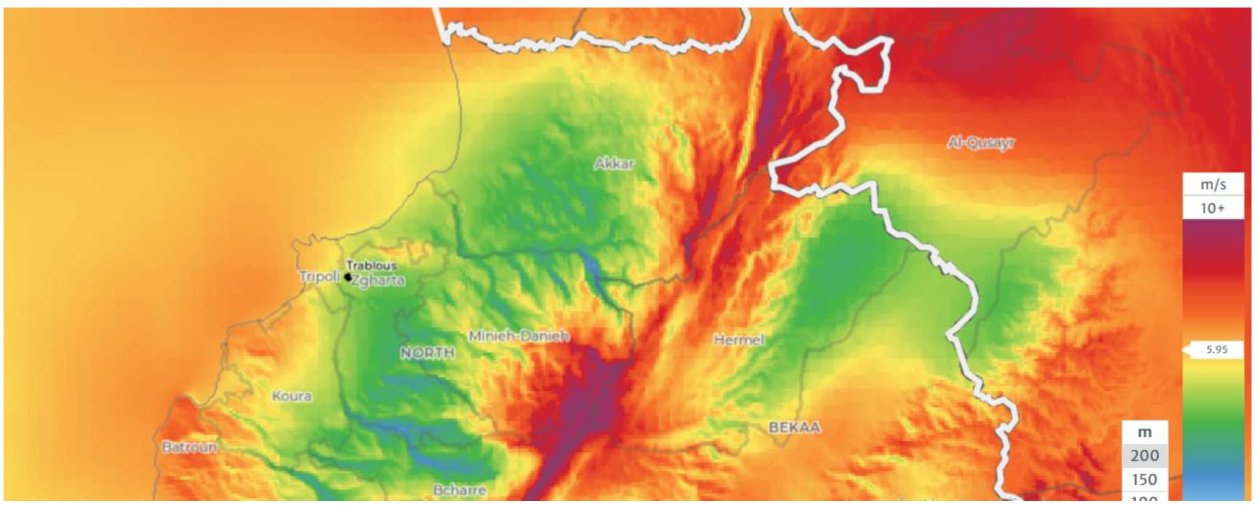


Figure 48 Mean power density over northern Lebanon

The pictures show the value of the wind speed and power density in these regions. Power density, which is the amount of wind energy present in a select area, which can be collected by turbines, hovers around 450 W/m2, going up to 500 in certain areas, while wind speeds are around 6 m/s.

For reference, it is possible to take a look at the wind farms in northern Europe and compare the Lebanese coast to that area which holds the most wind farms in the world.

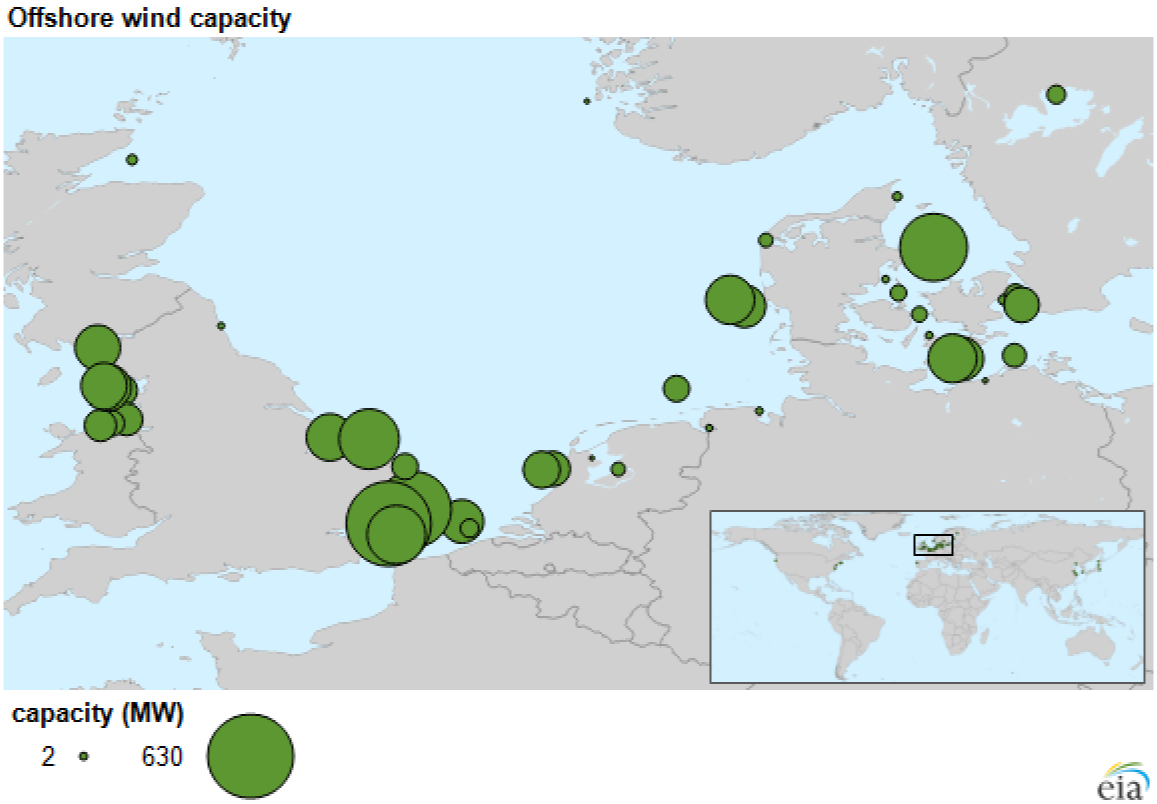


Figure 49 Offshore wind farms in northern Europe

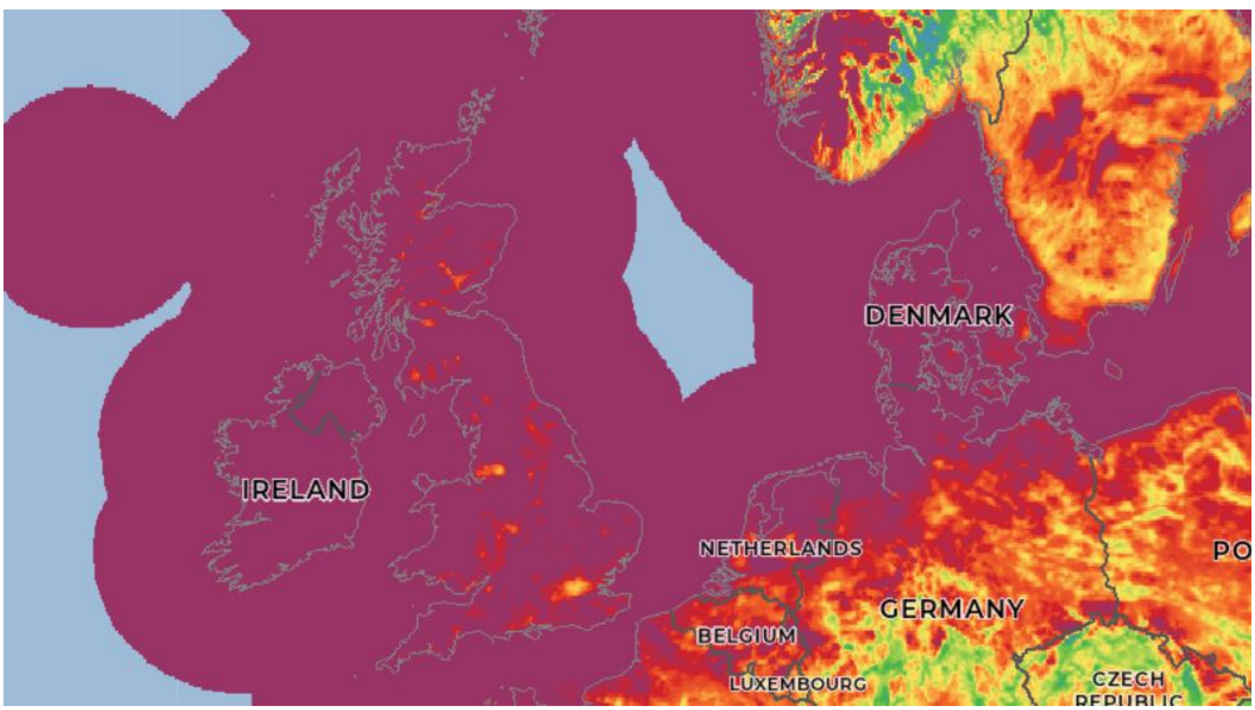


Figure 50 Mean wind density in Northern Europe

In these very windy regions, the mean wind density is above 1000 W/m2 which make them ideal, coupled with the fact that the water depth is less than 60 meters, allowing for sturdy foundation rooted in the sea soil, being the reason why this is the most exploited area in the world in terms of offshore wind farms.

	Northern Europe	Lebanon
Mean Power Density (W/m2)	1100	500
Mean Wind Speed (m/s)	10.5	6

Table 38 Mean power density and mean wind speed comparison between northern Europe and Lebanon

When compared with these regions, Lebanon is not in a very good spot when it will come to estimating efficiency. However, these numbers still fit within the required standards of a minimum of 350 W/m2 power density meaning that, even if it is far from optimal, installing a wind farm on the northern Lebanese coast is possible.

More specifically, here is the pinpointed region that could serve as the waters in which the turbines will be installed.

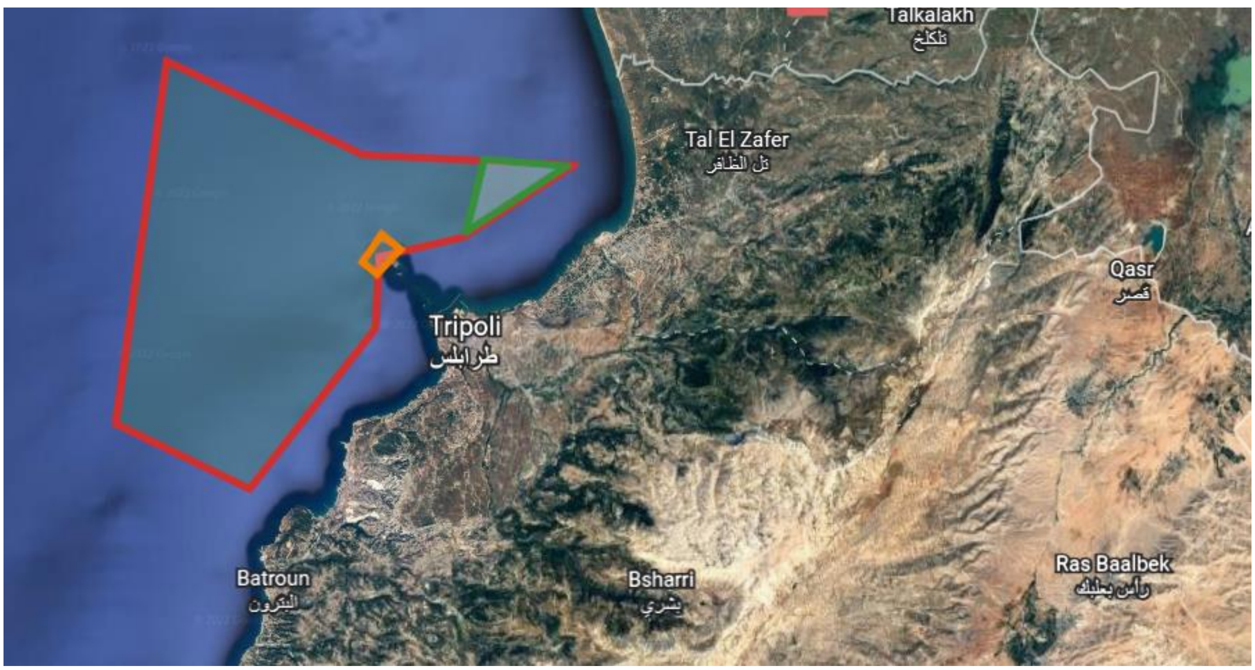


Figure 51 The region that could serve for offshore wind turbines

The red lines outline the zone where the wind density makes it possible to use wind power in order to generate electricity, limited by the maritime borders and the peak power density in the region, as well as the fact that offshore wind farms should not less than 5 km and optimally 10 to 15 km from the coast. Unfortunately, it is not possible to go further than 5 km from the coast due to the narrowness of the Lebanese maritime border and the nature of the seafloor of the Mediterranean which goes from relatively shallow (<60 m below sea level) to deep (~400m) in very short distances. In fact, it is mostly composed of underwater cliffs very close to the shores and the only spots with shallow waters are islands.

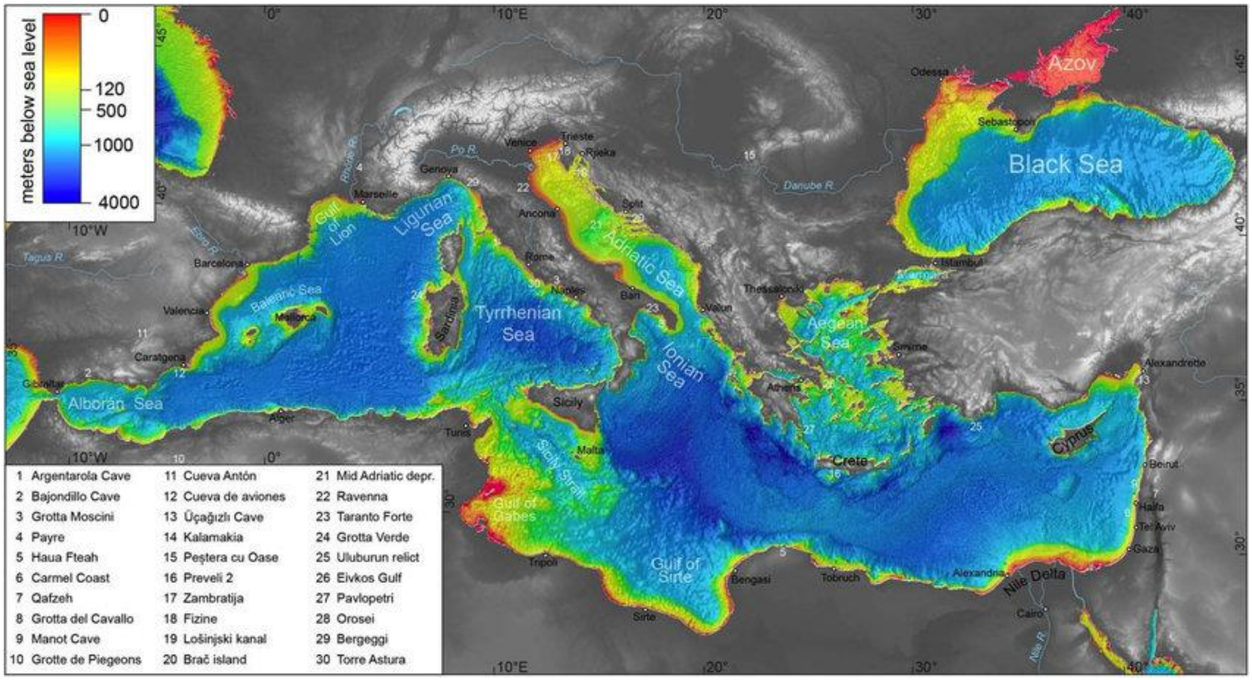


Figure 52 Seafloor depth map of the Mediterranean sea

The orange and green areas however, are the specific regions where a wind farm can be built as of right now. This is due to the fact that these are the water is relatively shallow there due to the presence of a bay north of Tripoli (green) and the Palm Islands (orange). The distinction between the two is the fact that the bay has no specific denomination and can thus be used freely while the Palm Islands are a nature reserve which would cause issues since the environmental impact of a wind farm is not to be neglected. This area would require ecological studies in order to be cleared for use.

Finally, the rest of the considered area, in red, can be exploited using technology that is still under development and testing, but is estimated to be employed in before the end of the decade, meaning that it can be expected to be used within the available timeframe before 2050. The types of installations used are as displayed below, starting with shallow (<20 m), transitional (20m<Depth<40m) and deep water (>40 m) with the last setups being defined as the new technology.

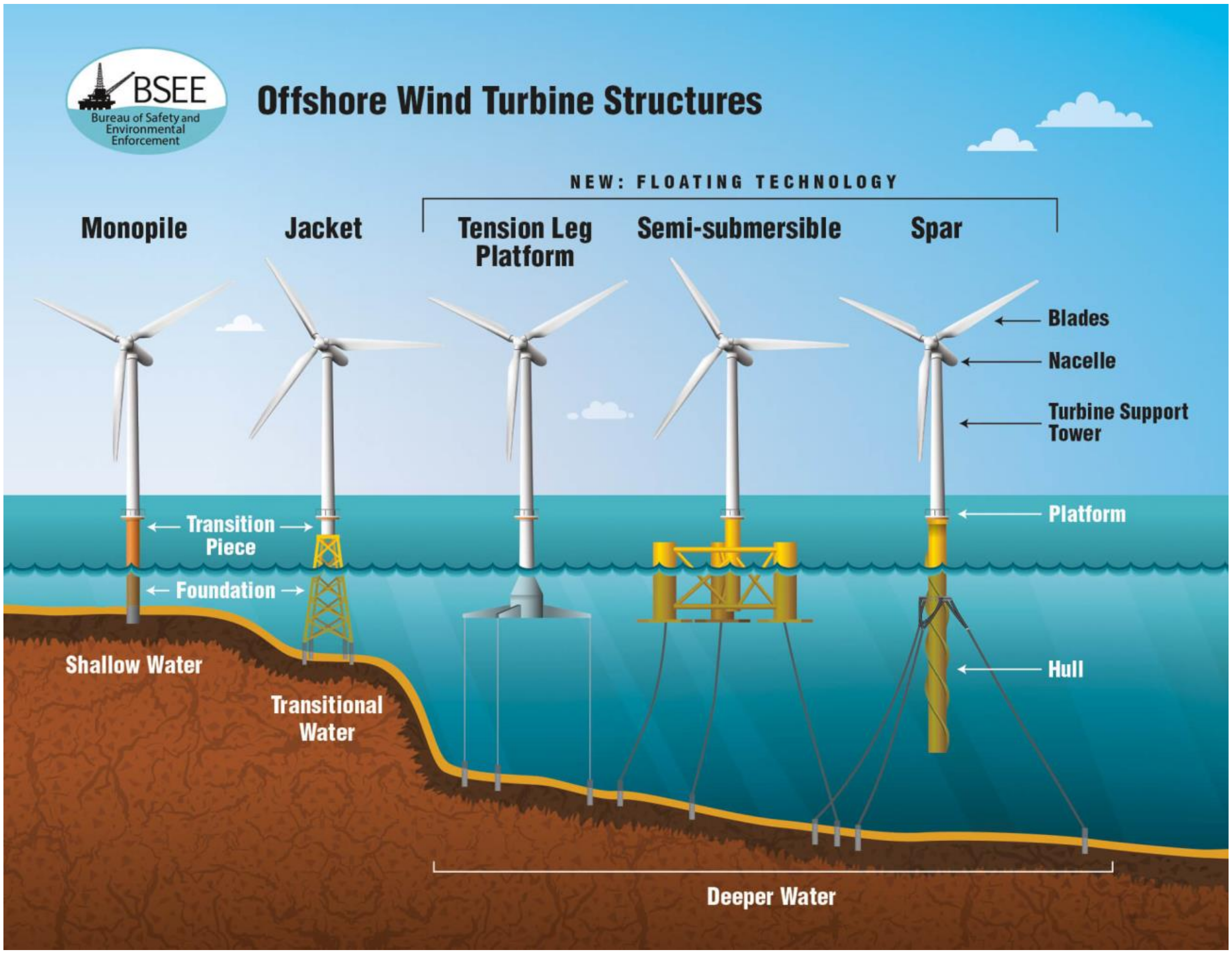


Figure 53 Offshore Wind turbines structures

A single wind farm would be composed of all three types of structures since the Mediterranean goes from shallow to deep very quickly and it would be better to install different types together rather than installing multiple setups in order to convey the produced electricity back to shore.

All in all, when it comes to Lebanon, designing and installing an efficient wind farm is no easy task, but this study relies on technologies that are expected to see the light of day in the next 10 years, as they will make this installation profitable and estimations are rather optimistic, since only 7 years ago a 3 MW turbine was something very advanced while, as of today, turbines are reaching 15 MW and a 3 MW turbine is considered something rather mediocre and no longer efficient.

Unit chosen

In order to accommodate for the medium to low wind speeds of the subject area, the chosen turbines must be designed specifically this. The list of the newest and most efficient turbines is comprised of the following models:

- Siemens Gamesa SG 5.8-170
- Vestas V162-5.6 MW
- Enercon E-160 EP5
- GE 5.3-158
- Goldwind GW155-3.3 MW
- Nordex N149/4.X series
- Senvion 4.2M148 EBC

However, the work is cut out since, while those turbines which fit the wind requirements, only one fits the terrain: Nordex N149/4.X series is the only offshore-ready turbine among all of the above mentioned models.

Specifications of the Nordex N149/4.0-4.5 [50]

The installation specification of this turbine will reveal whether or not it is suitable for the project:

Specification	Value	Convenience
Rated Power	4.0 – 4.5 MW (project specific up to 4.8 MW)	Yes
Cut-in wind speed	3 m/s	Yes
Cut-out wind speed	20 m/s (up to 26 m/s)	Yes
Offshore	Yes	Yes
Onshore	Yes	-
Diameter	149.1 m	-
Swept Area	17460 m^2	-
Grid Frequency	50/60 Hz	Yes
Hub Height	Up to 164 m	-
Noise Pollution	106.1 dB @ 4.5 MW	Yes

Table 39 Specifications of the Nordex N149/4.0-4.5

As mentioned, the nominal power and wind speeds match the terrain conditions. Moreover, the grid frequency is suitable for Lebanon in which the people are provided electricity at 50 Hz. This turbine can thus be installed fittingly in order to generate energy for EDL.

Cost Analysis

The prices for these models are undisclosed to the general public so this turbine will be estimated as any other, at around 1 300 000$/MW for the turbine only. Adding to that would the costs of installation, the total would come at around 5000$/kW for median wind speeds of 9 m/s and 4000$/kW for 7.5 m/s. With 6 m/s winds on average, so the case of Lebanon, the cost would come at around 3000 $/kW or 3 000 000 $/MW for the regular installation (Green and Orange areas) for the product and installation only. Unfortunately, due to the absence of any offshore wind turbines in the Lebanese territory, it is not possible to have an accurate estimation of the costs of transport, added costs that include taxes and any permit required.

According to www.wind-energy-the-facts.org, turbines, support equipment and their installation should amount around 80% of the total project cost, which means that after deciding the number of turbines and total power generated, the cost will be divided by 0.8 to include everything from start to finish such as electrical equipment, transport and surveying and construction management.

For the non-anchored installations, the price will be estimated as the same since it is still new technology and is therefore more expensive but requires much less material to be built.

Available Space – Anchored Turbines

Northern Bay

For the anchored turbines, all available space will be used. In usual configurations, turbines are placed 7 rotor diameters apart, meaning that for the selected model, the distance between each two turbines should be set around 1 km.

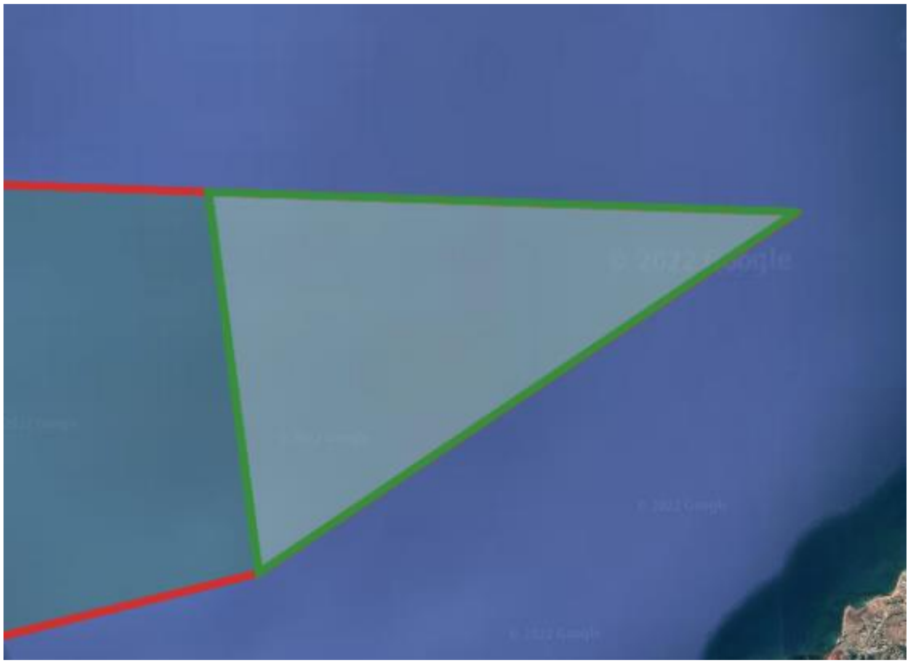


Figure 54 Shallow water exploitable zone

Starting with the northernmost area, and after replication of the exact dimensions, using AutoCAD allows to find out how many turbines can be placed within this sector, with 1 km of distance between them:

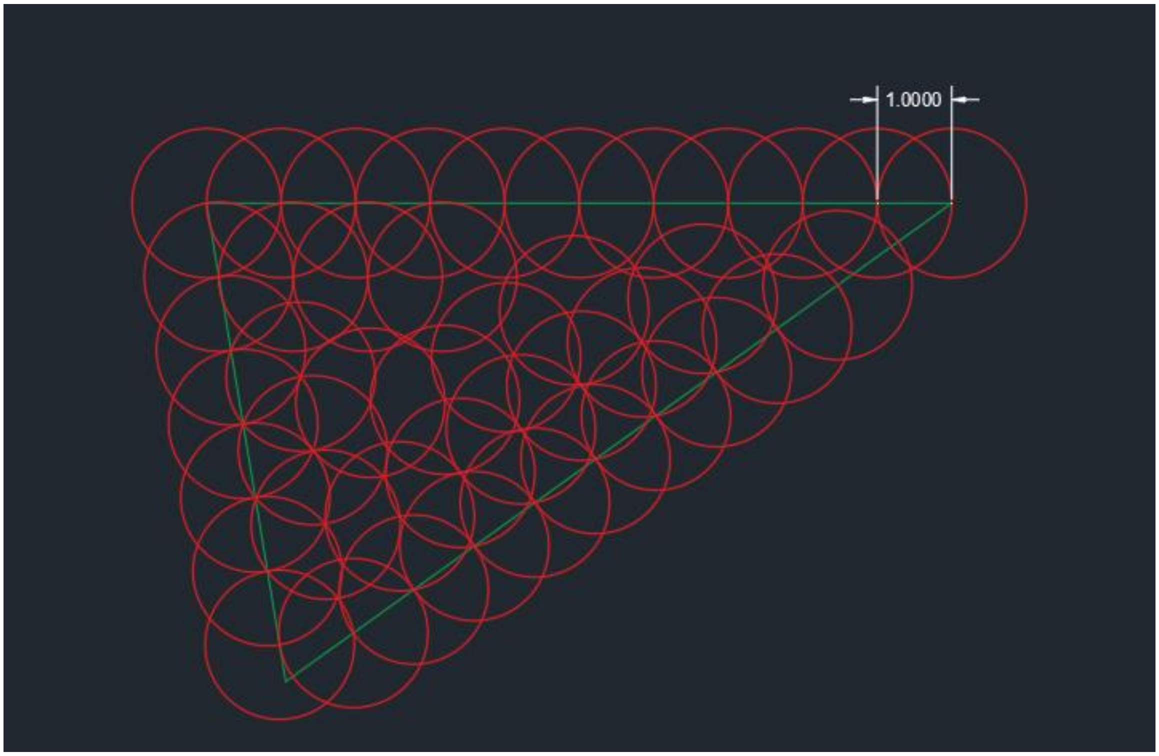


Figure 55 The number of turbines that fits in the green zone using AUTOCAD

Each circle in red represents the boundary of the vicinity of a turbine (located at its center) in which no other turbine should be placed. Within this area, the possible number of turbines is 42 which, in normal conditions, would amount to between 168 and 189 MW of power.

Palm Island Nature Reserve

As mentioned above, the Palm Island Nature reserve location is a bit tricky since it involves a protected area. However, studying the water depth in the vicinity, it was found out to be possible to install 7 turbines in the shallow waters surrounding the island in a way that the nearest turbine would be further than 2 km from the island, point at which it should not affect it negatively or even be heard there.

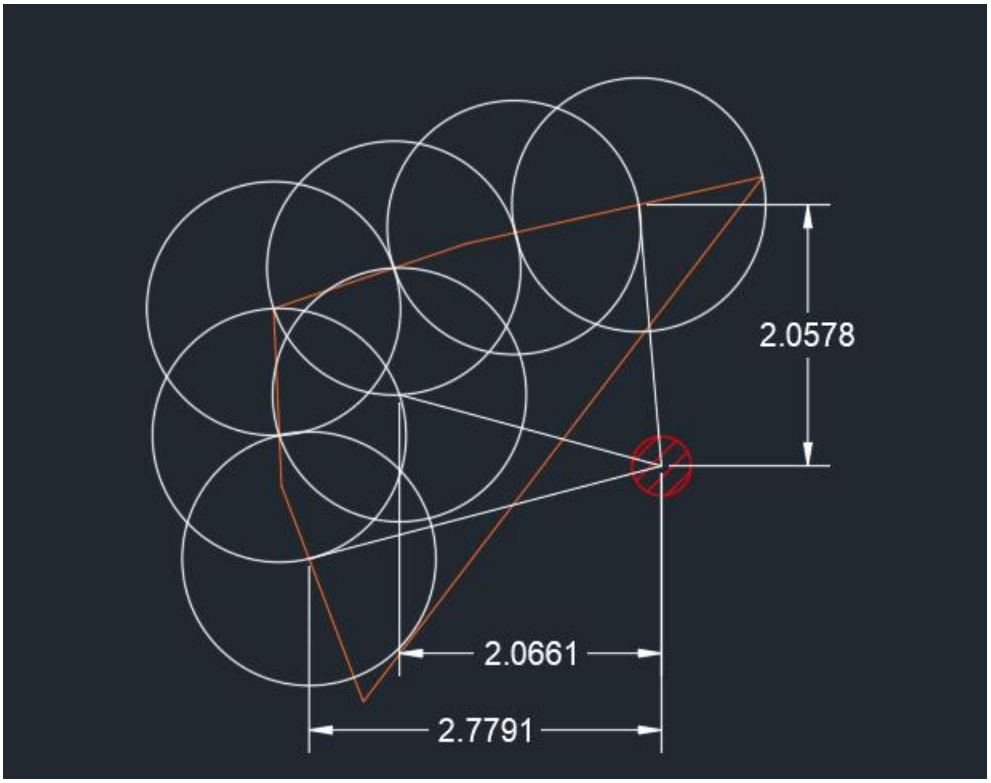


Figure 56 Representation of the turbines near to the palm island natural reserve (red)

Deep waters

The deep waters are the area marked in red which are to be avoided as much as possible since the technology required to operate there is still under development and testing and would be very expensive. It will only be used once every other opportunity for creating energy is used and the goal still has not been reached, and even then will have its requirements. For starters, the deep water technology should not be attempted before 2030 otherwise its cost cannot be estimated, considering it is not absurdly expensive. Moreover, the installation should not compromise sea traffic as it is located near the main maritime trade routes between Eastern European countries, mainly Turkey, and the Tripoli Seaport.

2. Cost Analysis, Returns on Investment and CO2 Emissions

To reiterate what was decided previously, the following table gives an overview of the capacity that this study aims to have within 2050:

Technology	Capacity (MW)	Cost of Installation ($/kW)
Hydraulic	178	N/A
CSP	20	11000
PV	2825	1400
Offshore Wind shallow	250	8000
Offshore Wind deep	0	TBD
Waste to energy	197	15300
Total renewable	**3470**	

Table 40 Summary of the capacity for each renewable technology in Lebanon by 2050

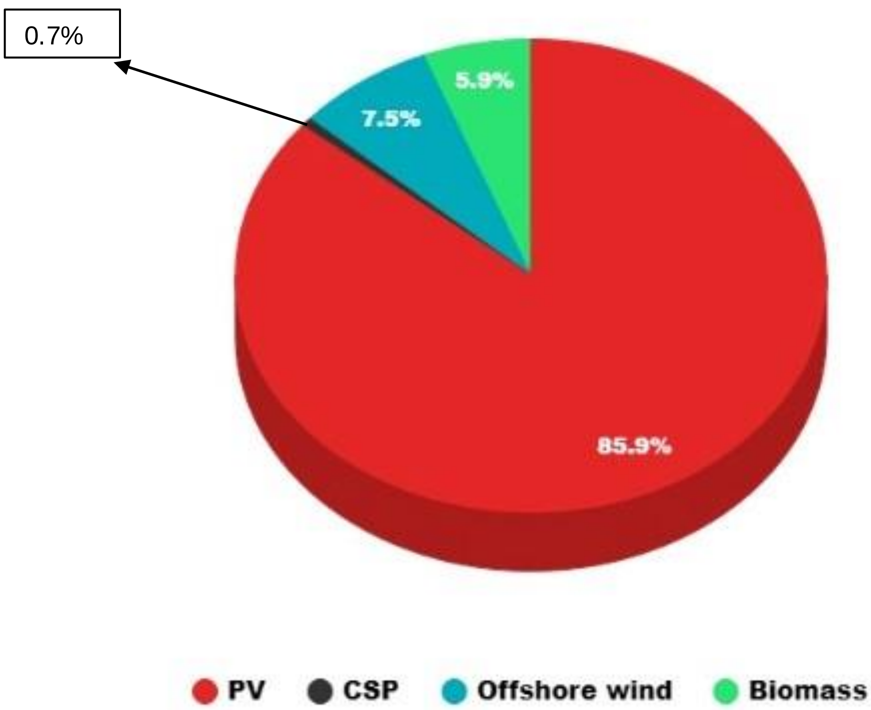


Figure 57 Pie chart showing the capacity of each renewable technology used in this study

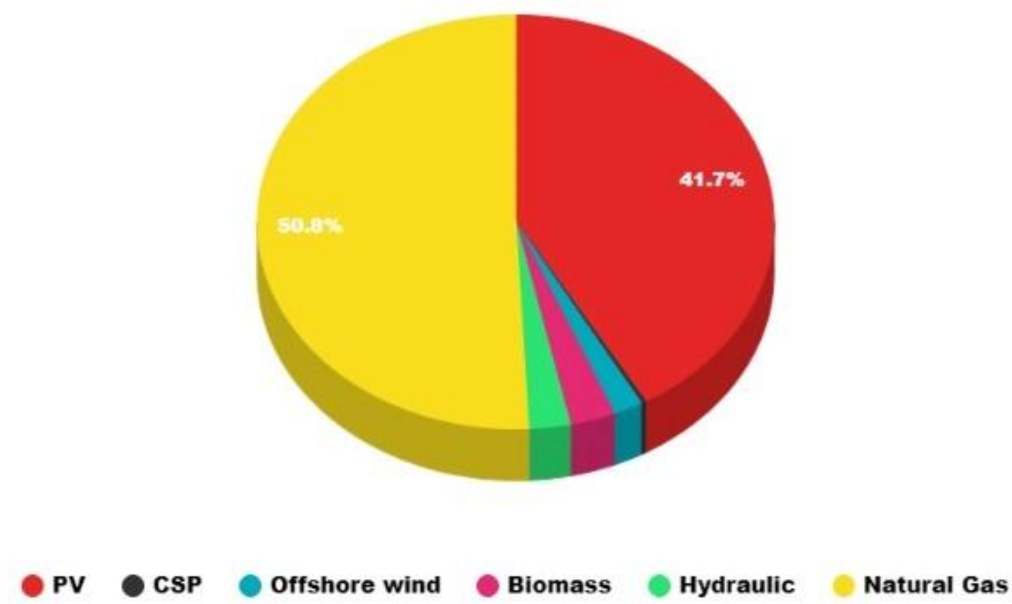


Figure 58 Pie chart showing how the total power capacity was distributed using 50% of Natural Gas and 50% of green energy for Lebanon towards 2050

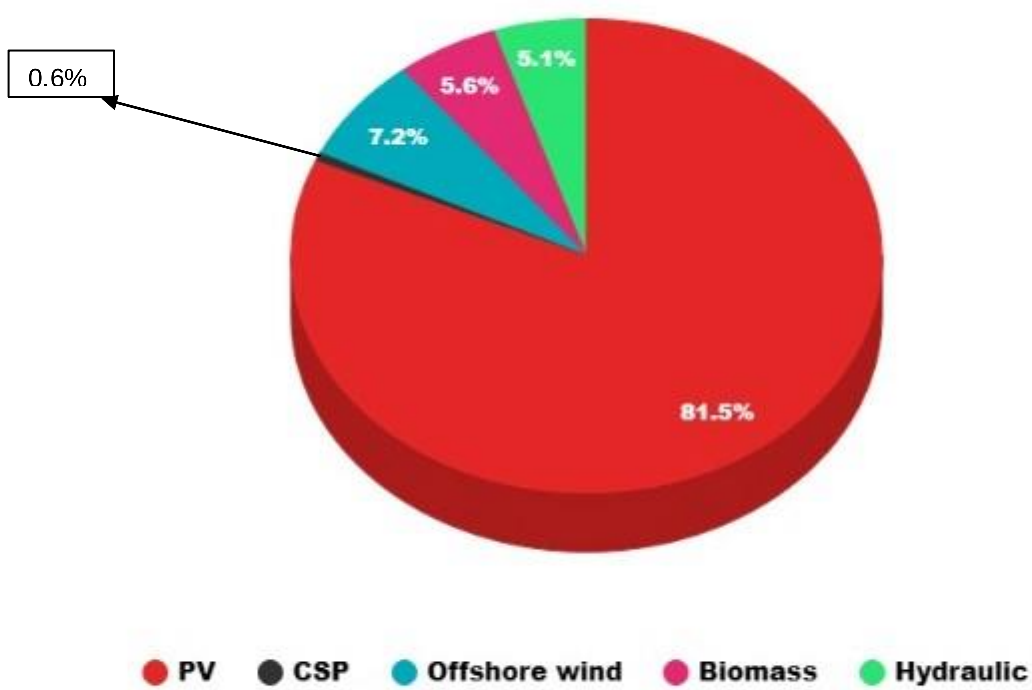


Figure 59 Pie chart showing the capacity of all renewable energy in Lebanon including hydraulic energy

For this project, the calculations show that the total investment required to produce 50% green energy in Lebanon by 2050 is around 9.226 billion dollars. The following table and the following pie chart show the cost in investment for each green technology:

Technology	Investment ($)
CSP	222 000 000
PV	3 990 000 000
Offshore wing	2 000 000 000
Biomass	3 014 000 000

Table 41 Total investment for each renewable technology

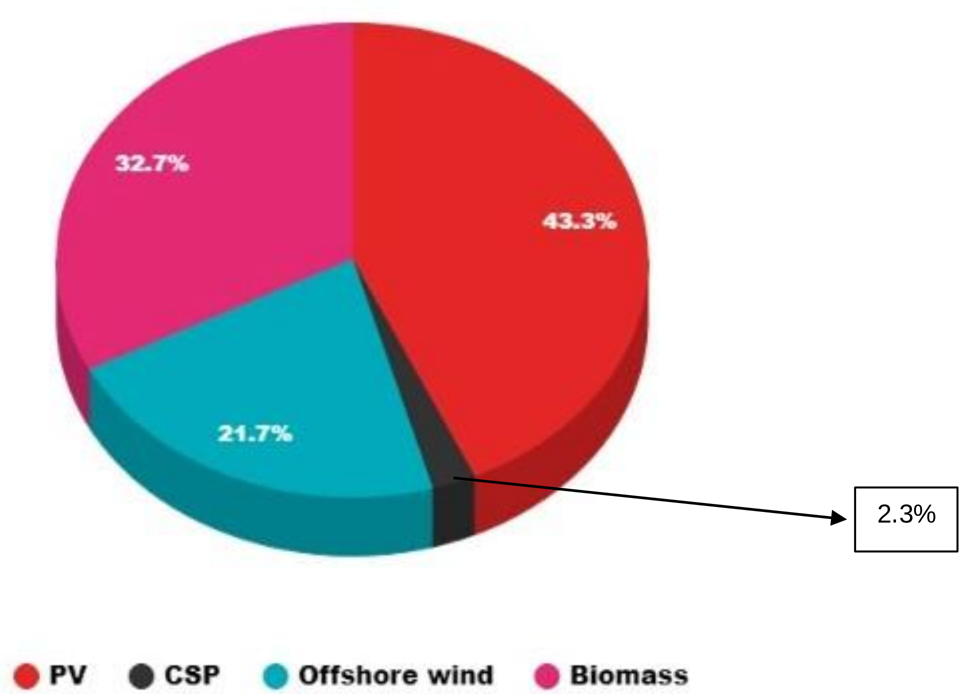


Figure 60 Pie chart showing the total investment of each renewable technology

The developed algorithms then calculate the “cash flow” and leveled values for the cost of producing 1 kWh as well as the benefit that comes with using renewable energies instead of the current combustibles and finally a comparison of the CO2 emissions.

These numbers are calculated using the following equations:

Cost of kWh:

$$\text{Cost of kWh}\left(\frac{\$}{\text{kWh}}\right)=\frac{\text{Cost of kW}\,(\frac{\$}{\text{kW}})}{(24\,\left(\frac{\text{h}}{\text{day}}\right)\times 365\,(\frac{\text{days}}{\text{year}})\times \text{Economic Lifetime (years)}\times \text{load factor}}$$

Leveled Cost of kWh:

$$\text{Leveled Cost of kWh}\left(\frac{\$}{\text{kWh}}\right)=\text{Investment}*\frac{\frac{Discount\ rate*(1+Discount\ rate)^{Economic\ Lifetime}}{(1+Discount\ rate)^{Economic\ Lifetime}-1}+\frac{Annual\ maintenance}{Investment}}{Functional\ hours\ per\ year}$$

Gain:

$$\text{Gain}=\ \text{Price of combustible kWh}-\text{Price of [energy] kWh}$$

Net Present Value:

$$\text{Net Present Value}=\text{Gain}-\text{Investment}$$

Leveled Net Present Value:

$$\text{Net Present Value (\$)}\ =\text{Gain}*\left(\frac{1\ -\ \frac{1}{(1+\ discount\ rate)^{Economic\ Lifetime}}}{discount\ rate}\right)-\text{Investment (\$)}$$

Carbon footprint:

$$CF(ton)=footprint\left(\frac{ton}{MWh}\right)*energy(MWh)$$

Time of Return on Investment:

$$\text{TR}=\frac{\text{Investment}}{\text{Gain}}$$

Leveled Time of Return on Investment:

$$Leveled\ TR = \frac{ln(1 - \frac{investment}{yearly\ benefit} * (\frac{discount\ rate}{1 + discount\ rate}))}{ln(\frac{1}{1 + discount\ rate})}$$

	Cost of kWh (c$)	Levelized Cost of kWh (c$)	Time of Return in Investment (years)	Levelized Time of Return in Investment (years)	Actual Net Value ($)	Carbon Footprint (tons / MWh)
PV	3.76	11.7	4.6	5.7	4257358526	0.032
CSP	5.581	24.72	9.2	18.9	7179788	0.032
Biomass	15.525	29.23	22.8	N/A	-1762603623	0.23
Wind offshore	10.744	25.97	13.7	N/A	-619523920	0.001
Fuel	24	N/A	N/A	N/A	N/A	0.778
Natural gas	15	N/A	N/A	N/A	N/A	0.443

Table 42 Algorithm results for each technology

Looking at the algorithm results (Table 41), they can be interpreted in order to explain the chosen capacities and explain the benefits of each of these technologies:

- In terms of cost of kWh, PV and CSP are by far the cheapest due to how suitable these technologies are for Lebanon. While biomass and offshore wind are more expensive, their presence has a purpose which will be elaborated a bit later. Finally, fuel and natural gas, the non-renewable sources here are also very expensive due to the cost of the combustibles themselves, but new installations do not need to be implemented for their usage. Furthermore, natural gas was put in because not only is it cheaper than fuel, it will also become, in the near future, the subject of local extraction, ending Lebanon's dependence on importations for this matter. The levelized cost of kWh is equals to the cost when it is multiplied by a factor that depends on the market discount rate.
- The Levelized Time of Return on Investment and the Actual Net Value (ANV) are somewhat related. The higher the latter is, the shorter will the former be. Also, when the ANV is negative, there is no return on investment, which means that the project will come at a financial loss. However, this does not mean that the energy should not be used at all. In the case of offshore wind farms, using those would pave the way for more efficient installations in the future. That financial loss can also be excused thanks to the extremely low carbon footprint of wind farms, even when compared to other installations. For the biomass energy production however, the loss, in terms of electricity, is much bigger than that of the wind farms at 1.76 Billion USD but this is because this installation not only produces electricity, it also solves one of Lebanon's biggest issues: the trash crisis. This two-bird-one-stone approach has not been taken into account, and

the benefit from it is actually much greater than the numbers show. However, a financial analysis of this purpose would go much beyond the scope of the project and require many documents that are unfortunately not available.

Overall, photovoltaic panel installations could be all Lebanon needs to generate electricity, being by far the most profitable and it is why the chosen solution consists of around 70% PV. However, the other sources have their reasons to be. Wind and CSP production are expected to see a drop in prices as the technologies are developed, which means that if implemented in a few years, they might become rentable and pave the way for the next generation of installations of this type. Meanwhile, the biomass plants would have their place in solving Lebanon's trash crisis while not wasting anything and putting out electricity. Finally, a perfect scenario would also include replacing all fuel power plants with natural gas power plants, as it is expected to be locally sourced in the near future while also being cleaner than the currently used combustibles. This means that even the remaining 50% non-renewable portion of the demand will be more efficient than what is currently available.

3. Implementation model

Public Private partnership is when the government collaborates with a private-sector company to finance and implement projects such as public transportation networks, hospitals, infrastructure, roads and bridges. The project can then be done within a budget, faster and completed sooner.

To install around 3500 MW of renewable energy in Lebanon towards 2050, using PV, CSP, Wind offshore and waste to energy technologies, big investments are needed. Throughout this study and by doing all the calculations needed using the algorithms, the amounts are very large and cannot be supported by the Lebanese government alone. Lebanon is severely indebted and unable to finance a project of 3500 MW capacity of renewable energy by 2050. The public sector cannot match the massive investment required to meet the growing demand for power on its own. A private company might be interested in supporting, designing, implementing and funding the project and getting in return profits once the project is completely done.

When you start a renewable energy initiative, funding is your top priority. In this study, a lot of problems arose such as the low wind speed for offshore wind turbines and the lack of large and empty lands to place CSP and PV plants, but financing the project was the reel and the biggest obstacle. The PPP technic must be used in the power sector by signing a long term contract between the Lebanese government and a private party to carry out such a project having big and heavy investments. The government should partner with a private company that will be in charge of the project's investment and management.

What is build, own and operate strategy?

BOO (build own and operate) is a PPP project model in which the government sells the right to a private sector party to finance, build and operate a project over a specified period of time. The BOO is popular in the electricity sector and especially renewable energy projects because this model is best suited for high-cost projects. The product or the service is sold by the private company to the users or the beneficiaries of this project.

What is build operate and transfer strategy?

BOT (build operate transfer), also known as BOOT (build own operate transfer) is also a PPP project model usually for large scale infrastructure projects in which the government grants a concession to a private entity to fund, build and operate a project. The company operates the project for a certain period of time, perhaps 2 or 3 decades, in order to return its investment and all maintenance expenses and then transfers control of the project to the government.

BOT or BOOT presents multiple advantages such as minimizing the public cost for infrastructure development and as a result of that the total public debts will be reduced and the public sector can now maintain a balanced budget so he can now focus on funding other projects where investments are most needed. This project also encourages innovation and development and provides a lot of chances to bring in expertise.

On the other hand, BOT only works for large projects and is not suitable for small projects and requires a lot of fund-raising to start the planning phase of the project. One of the most common reasons for a BOT model to fail is the lack of communication between the public sector and the private entity, the government must be involved with the supervision of the project during the ownership phase.

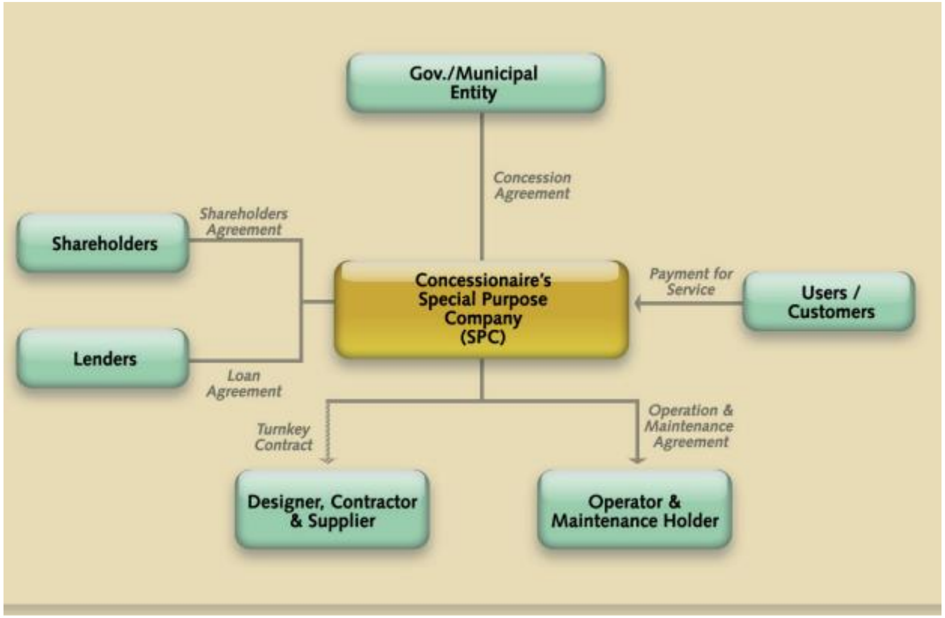


Figure 61 typical BOOT project structure

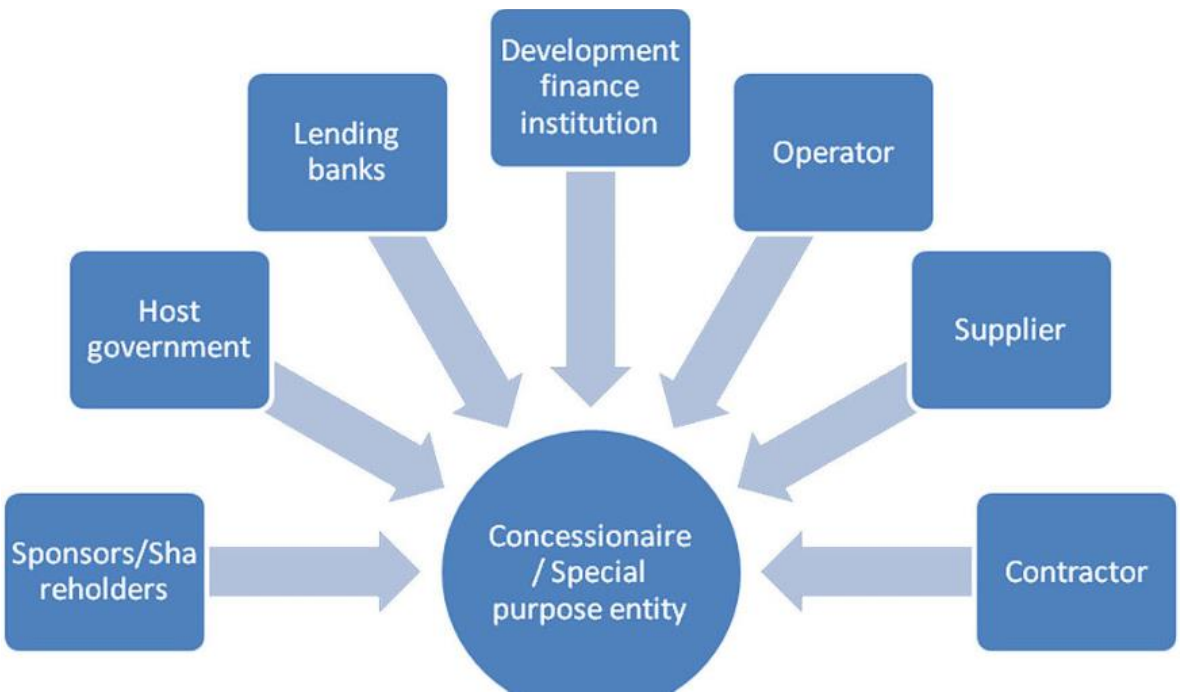


Figure 62 BOT project structure

BOO and BOT are two strategies that can be or must be used to finance the “50% green electricity towards 2050” project, because Lebanon has no other choice.

In Lebanon, to install a 2825 MW capacity using PV technology, around 4 billion dollars are needed. To install a 20 MW capacity using the central receiver with 15 hours of storage, around 222 million dollars are also needed. In addition to that, the investment in 3 plants delivering a capacity of 197 MW electric combined is around 3 billion dollars. And finally, 2 billion dollars are required to install 250 MW using the offshore wind technology. In total, to install 3500 MW using 4 different renewable energy technologies, more than 9 billion dollars are needed.

As mentioned above, these are big numbers that cannot be supported by the Lebanese government alone and private entities should do the job.

Lebanon’s electricity sector has been suffering for decades and is now facing a serious risk of collapse due the economic crisis and after Beirut Blast on August 4. The national debt of Lebanon amounted to around 96 billion dollars and 46% of its debt is due to the power sector (bank Audi 2021). EDL is unable to meet the growing electricity demand. Diesel generators, which are spread practically all over the country, covered the gap between electricity supply and demand. Such generators are expensive, noisy and polluting the environment and that’s why the gap should be filled with renewable technologies and green energy generation.

Concerning the dirty energy part, EDL has already signed a long term contract with three private companies; BUS (BUTEC), KVA (joint venture between Arabian Construction company and Khatib & Alami) and NEUC (Debbas), later joined by MRAD for the southern governorate. The contracts were extended first until 2018 and then until December 2021 in order to reach the target and install 1.1 million smart meters all over Lebanon.

However, the 2017 auction was based on a BOO model in order to make it more attractive for companies on the long run, as well as reduce immediate costs for the state which lacks funding.

IPP (independent power producers) contracts are where an entity that is not a public utility, but owns facilities to generate electric power for sale to utilities and end-users. IPP and BOT contracts are not allowed because of the laws and regulations of EDL, no one is allowed to generate or sell electricity except EDL. This issue has been legalized through Law number 129 from 2019. IPP and BOT (build operate and transfer) strategies must be used in Lebanon to meet the demands in electricity of the Lebanese population. The BOT strategy must be used to generate the 3500 MW of electricity using renewable energy technologies.

4. Private Sector and Smart Grid Optimization

As mentioned before, private installations of solar panels are greatly on the rise in Lebanon, especially in 2022 due to people not wanting to rely on private generator owners and EDL during the crisis, which amount to a total of 1 MW across Lebanon as of early 2022. However, these installations are not big enough to sustain all the regular appliances in a household and in most cases, only provide electricity for lighting and basic needs such as refrigerators. This is due to the fact that a large majority of the Lebanese population lives in apartment buildings in cities with limited areas to exploit using PV panels which usually end up being the rooftops of said buildings. There is also the issue that batteries are the most expensive part of the installation and power might be lost during the day if the apartment is vacant while the batteries are full and the sun is still up. For these reasons, as well as a maximum economy of energy, it is crucial to implement a smart grid with a feed in/feed out system.

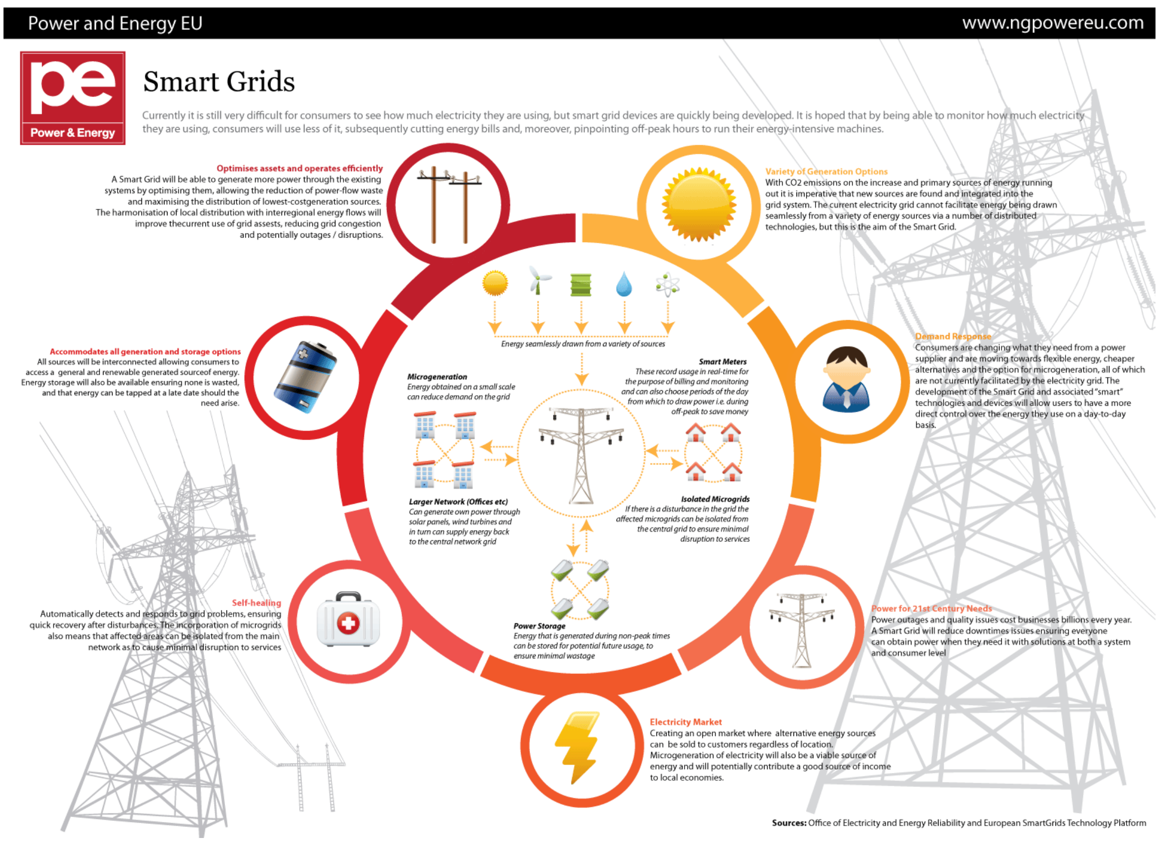


Figure 63 components of a smart grid

This figure displays the components of a smart grid in order to make it viable. It contains two ideas that are already mentioned in the project: multiple types of generation and micro generation of electricity which comes from household installations such as small generators, small PV installations and small wind turbines.

The grid must be fit for all generation options, whether small or large scale, and incorporate storage units in order to minimize energy losses outside of peak hours. On the customer's end, smart counters must be installed to track the consumption and create a distribution that fulfills the demand at all times. In Lebanon, these smart counters are already being installed in most regions, they will allow to optimize the system and crack down on bill evasion.

Other than optimizing the demand during and out of peak hours, the smart grid should be designed for quick recovery when an outage occurs, by switching from one generation to another in the swiftest possible manner.

Finally, the core of the smart grid is a decentralization of the grid itself. Instead of a single connection from every receiver to the central, the smart grid incorporates micro grids, themselves connected to the central, that relay the power to the receivers. Micro grids allow better optimization, especially considering the decentralized production and the multiple installations that will be put into the network.

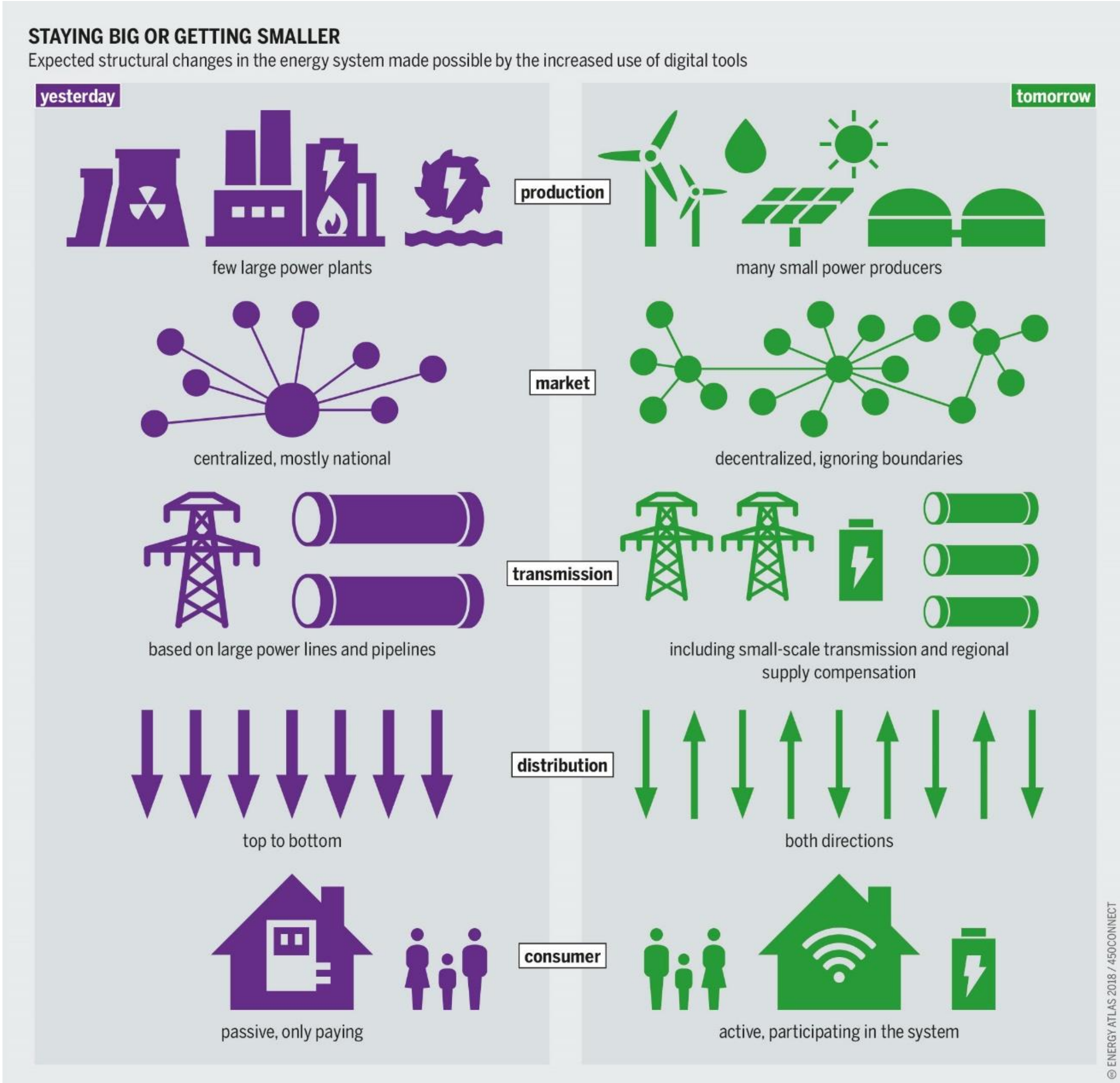


Figure 64 current grid on the left and the expected implementation on the right

The figure above allows to elaborate a bit more. The sketch on the left is a good representation of the Lebanese electricity network as of today, where production in a single area comes entirely from one source that distributes electricity (considering the EDL generation only). If the renewable production is achieved, this will no longer be efficient since electricity will come from multiple sources. For example, each PV farm will be a single small producer. This means that micro grids with connections between them will be the most viable solution. Moreover, these allow to manage micro production is which, as seen on the bottom right, consumers will be able to produce power for themselves and even distribute the excess to the grid itself.

Micro grids will also allow to isolate and resolve issues quicker by immediately initiating a self-repair protocol or at least pinpoint the area that is subject to a malfunction and notify the technical team responsible for this part of the grid.

Finally, since every area has different operation and demand patterns, a decentralized smart grid makes the distribution more efficient by harmonizing the energy flow between regions at different times.

7 Impact of the Solution

Implementing a large scale renewable energy source in Lebanon to replace a part of the fossil fuel-based production is crucial and will lead to a cleaner air in a country where the pollution fog is clearly visible over the capital. It will reduce combustion and thus “dirty” particles in the atmosphere.

This change could also make Lebanon closer to self-sufficiency when it comes to electricity distribution as it relies for now on importation of fuel and a shortage of it would, as experienced in 2021, have disastrous consequences on the living standards of the Lebanese people. It will also help end or limit the effects of the electricity crisis which has been crippling Lebanon since the 1975 civil war and only got worse in the past years, maybe allowing the Lebanese people to have 24 hours of electricity for the first time in a generation and ending the monopoly of privately owned generators.

Financially speaking, a return on investment is expected later in the future for both the Lebanese State and the companies involved in the execution of the project which will be calculated later on using the financial algorithm put in place. The smart distribution network will also allow to crack down on bill evasion, fixing a major issue in the country.

Switching to renewable energy which is a consistent power source will, as mentioned before, start making private generator owners obsolete which will result in a slight loss of jobs. However, the project itself and later on the maintenance of the farms will, if executed correctly, create a massive demand for jobs in a country with increasing unemployment [12]as prices soar higher every month. This will also allow industries and startups to invest in Lebanon as electricity will be more readily available at affordable prices.

The downsides of this change come in the shape of higher taxes and fees on the Lebanese people to pay for and maintain the installations. In the long run, it will always be worth it and one can see it as a sacrifice for future generations but not everyone might. Solar and wind farms also take large areas which could be used alternatively for agriculture or any other purpose, maybe more efficiently. Their presence is however indispensable to make this leap for a more sustainable Lebanon.

8 Conclusion

In conclusion, the project's main goal was to provide 50% green electricity for Lebanon by 2050. The first step was to determine the expected economic and demographic growth rate in Lebanon based on our estimation and specialist's surveys. Afterwards, an elaborative background research on solar panels, concentrated solar power, waste to energy and offshore wind turbines has been done to determine the best sources for Lebanon. Afterwards, based on the algorithms we have developed (cost of the KWh, return on investment, emission of CO2 and cumulative discounted profit) we have determined that 70% of Lebanon's green electricity should come from solar panels and the rest will be distributed equally among the other technologies. Finally, a smart grid system should be developed to create a synergy between the private production of electricity and the main network.

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10 Appendix

الطاقة المنتجة والمشتراة (جيغا وات ساعة)			اسم المعمل أو جهة الاستجرار
2018	**2019**	**2020**	
184.407	758.816	822.514	الليطاني
64.236	108.278	89.781	نهر ابراهيم
29.386	55.335	49.755	البارد
278.029	**922.429**	**962.050**	**مجموع المائي المشترى**
9.106	1.745	0.000	الصفا(مؤسسة)
58.203	45.865	45.559	القاديشا
345.338	**970.039**	**1,007.609**	**مجموع المائي العام**
1,706.656	2,072.376	1,388.077	الذوق
828.320	846.995	613.627	الجية
2,534.976	**2,919.371**	**2,001.704**	**مجموع البخاري**
1,496.736	994.525	562.161	الذوق (مولدات عكسية)
595.728	407.292	266.660	الجية (مولدات عكسية)
2,092.464	**1,401.817**	**828.820**	**مجموع المولدات العكسية**
3,409.573	2,923.740	2,972.176	الزهراني
2,764.644	3,507.695	3,240.212	دير عمار
6,174.217	**6,431.435**	**6,212.388**	**مجموع الدائرة المختلطة**
190.947	104.570	40.924	بعلبك
229.054	160.969	47.412	صور
420.001	**265.539**	**88.336**	**مجموع الغازي**
6,594.218	**6,696.974**	**6,300.724**	**مجموع الغازي+ دائرة مختلطة**
11,221.658	**11,018.162**	**9,131.248**	**مجموع الحراري(مؤسسة)**
194.527	169.825	0.000	الحريشة
11,416.185	**11,187.987**	**9,131.248**	**مجموع الحراري العام**
22.340	34.612	22.969	طاقة من النفايات - الناعمة
22.340	**34.612**	**22.969**	**مجموع الطاقة من النفايات**
11.627	90.779	0.000	استجرار من سوريا
0.000	0.000	0.000	استجرار من مصر
3,288.314	2,700.747	2,190.672	البواخر التركية
11,253.104	**11,054.519**	**9,154.217**	**مجموع المؤسسة حراري + مائي**
252.730	**215.690**	**45.559**	**مجموع القاديشا حراري + مائي**
3,577.970	**3,713.955**	**3,152.721**	**مجموع الشراء: (مائي+سوريا+مصر+الباخرتين)**
15,083.804	**14,984.164**	**12,352.497**	**المجموع العام السنوي**

Figure 65 Electricity production report in Lebanon from 2018 to 2020

Figure 66 navigation page

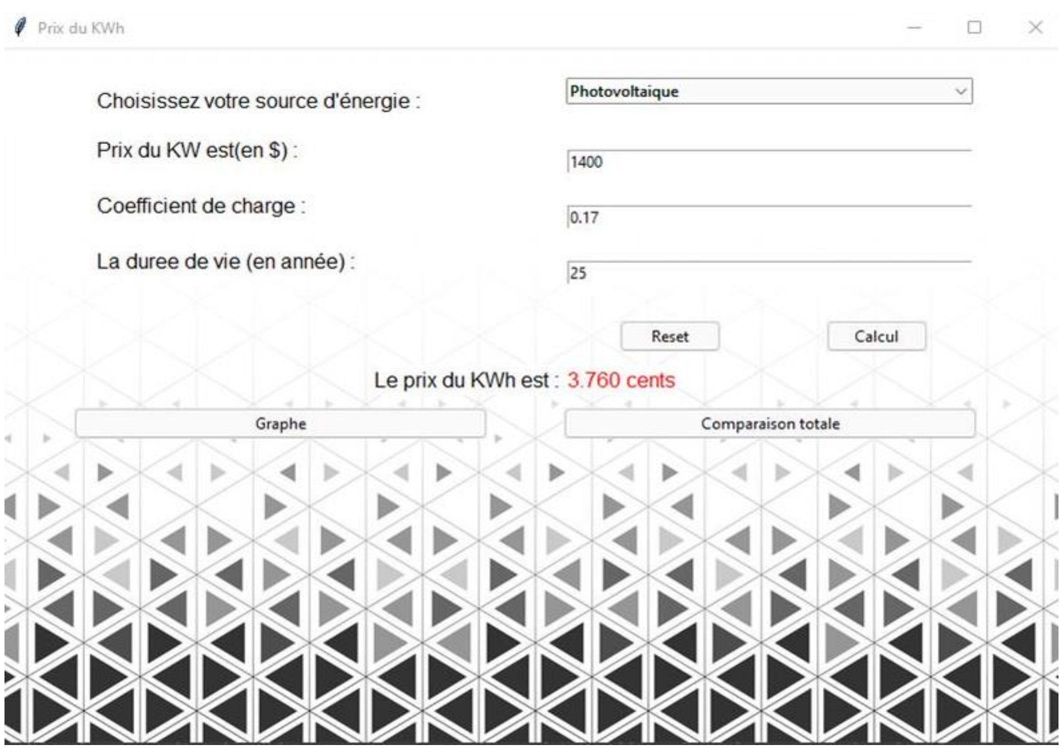

Figure 67 PV cost of kWh

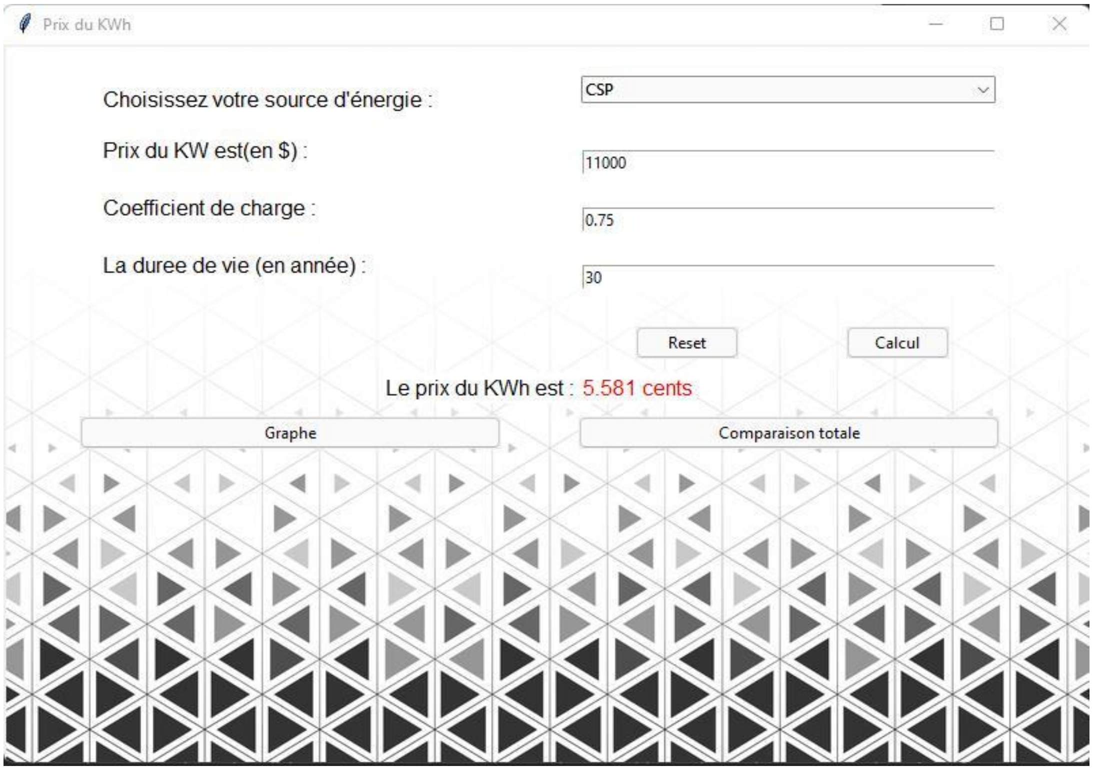

Figure 68 CSP cost of kWh

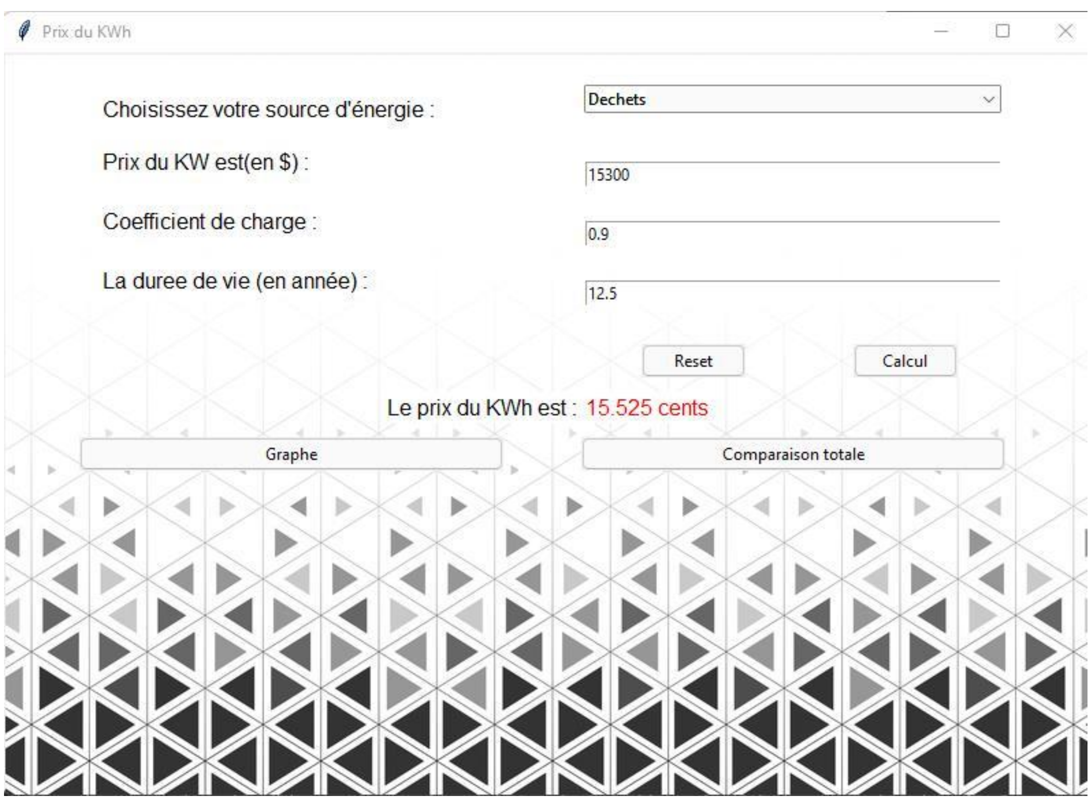

Figure 69 Biomass cost of kWh

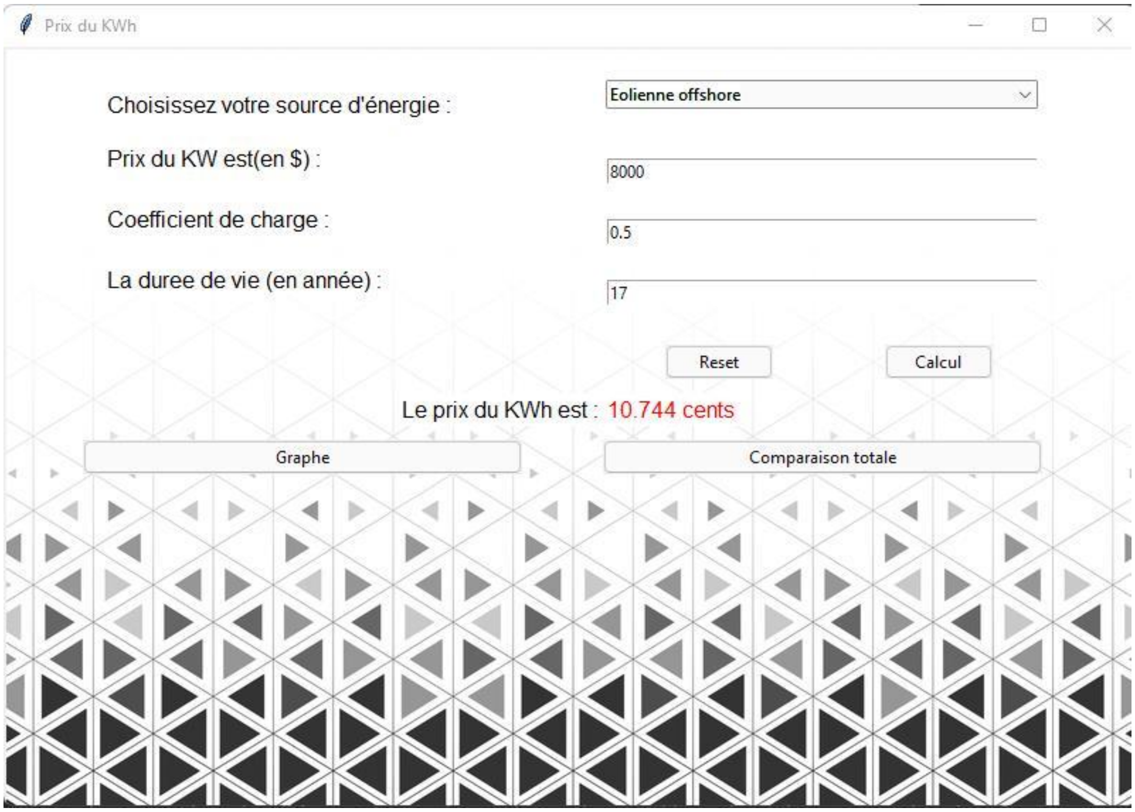

Figure 70 Wind offshore cost of kWh

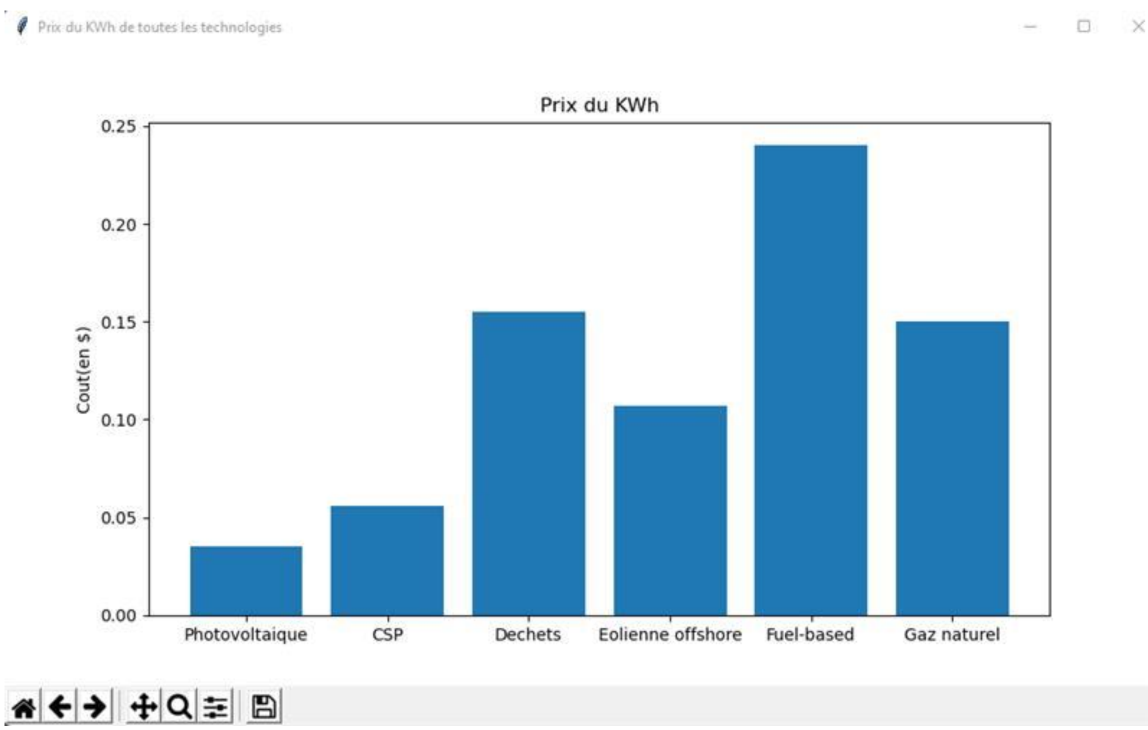

Figure 71 Bar chart comparing cost of kWh for each technology

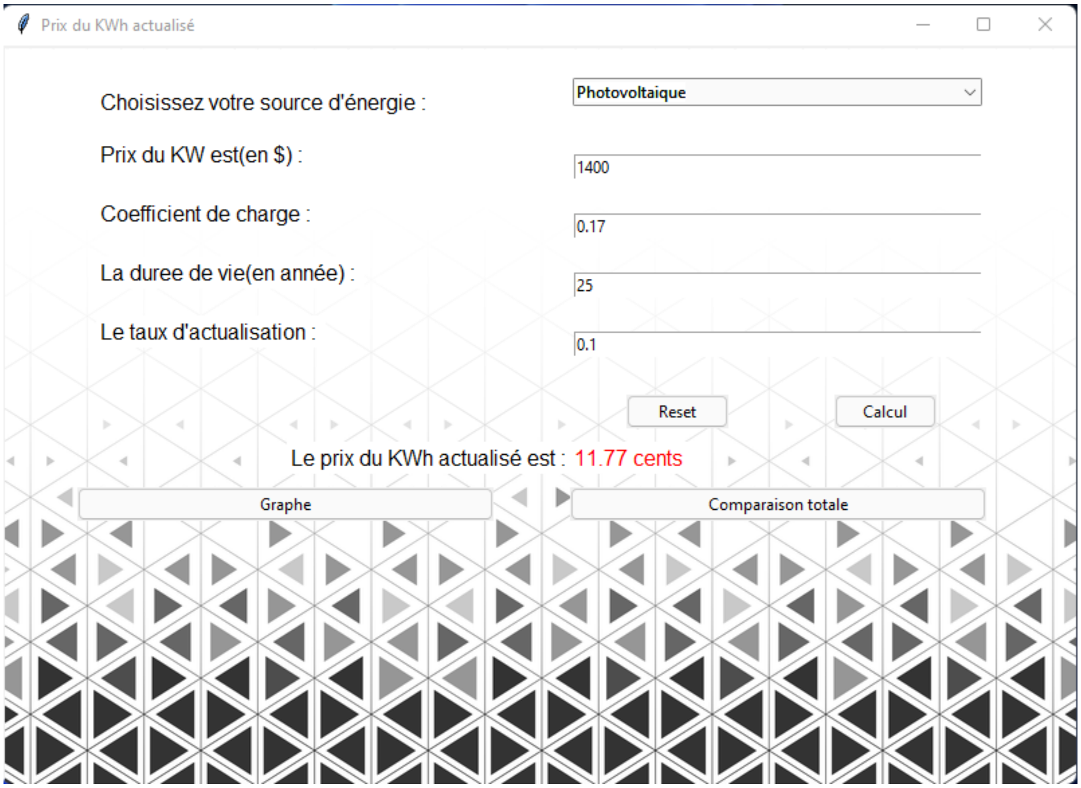

Figure 72 PV cost of levelised kWh

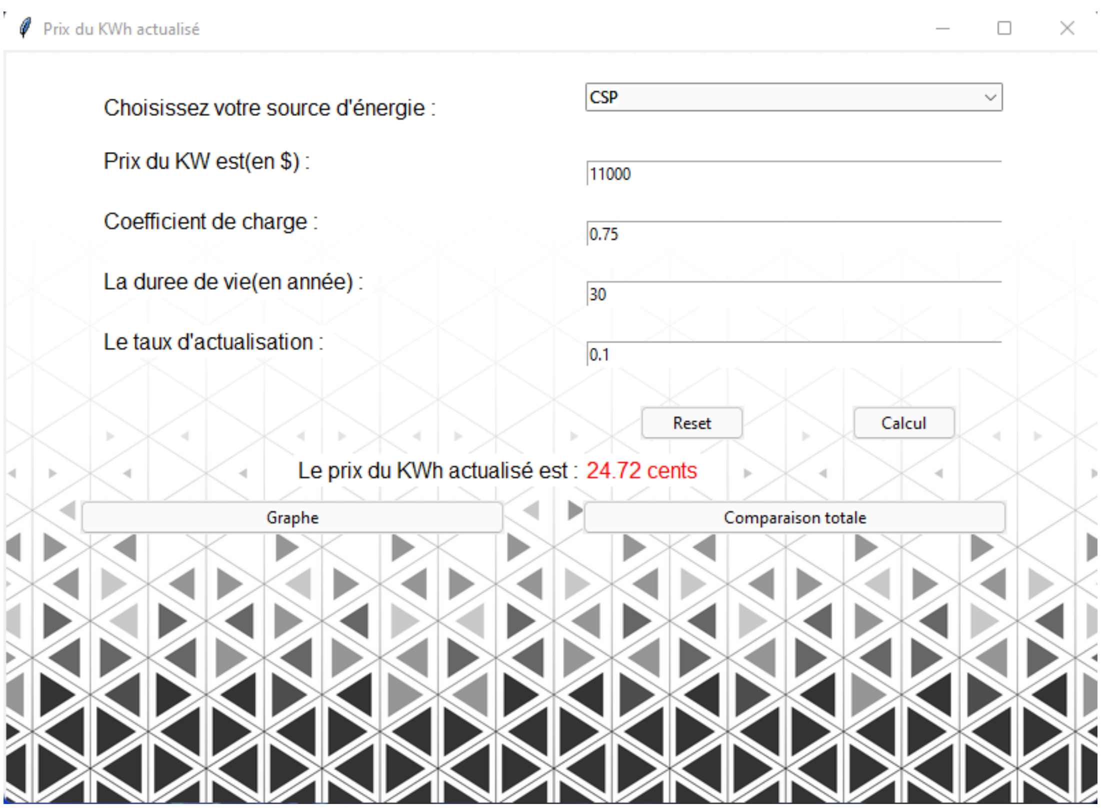

Figure 73 CSP cost of levelised kWh

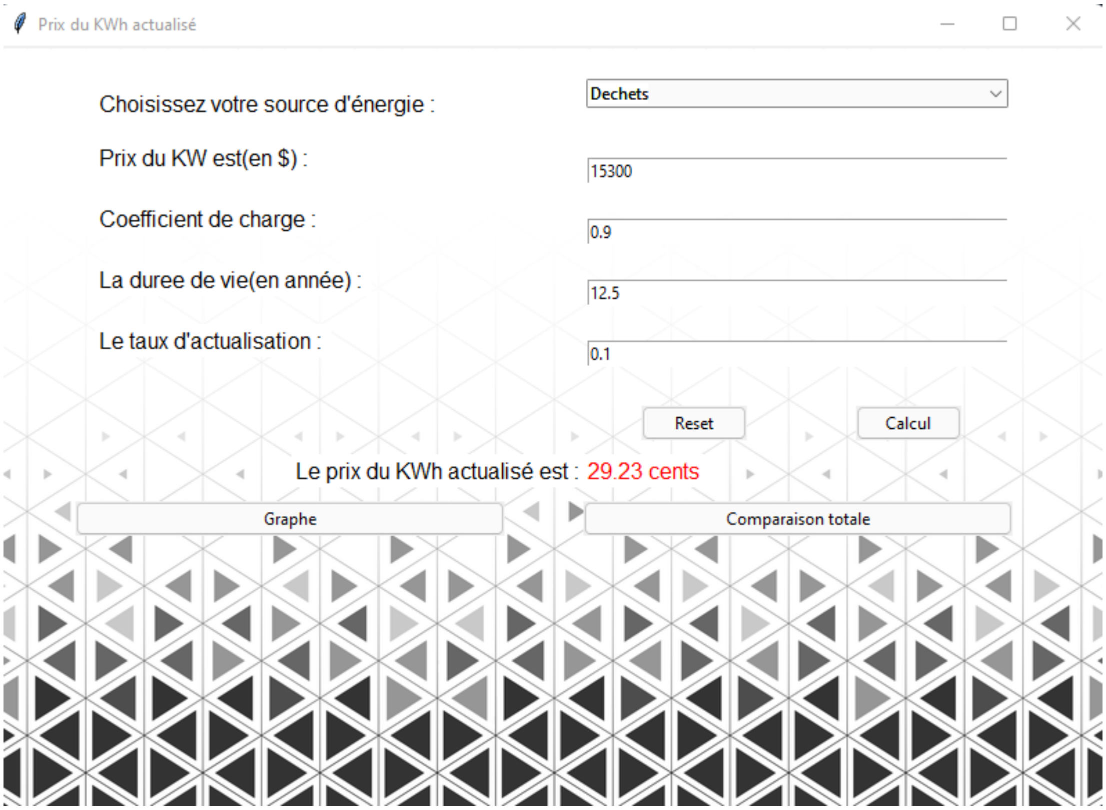

Figure 74 Biomass cost of levelised kWh

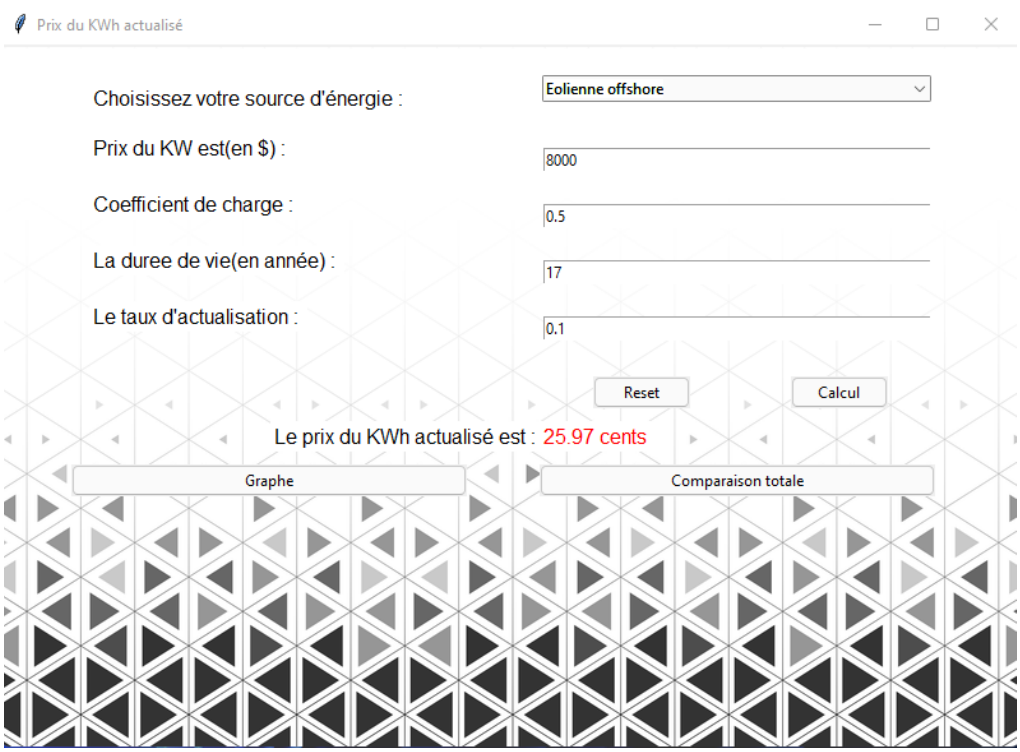

Figure 75 Wind offshore cost of levelised kWh

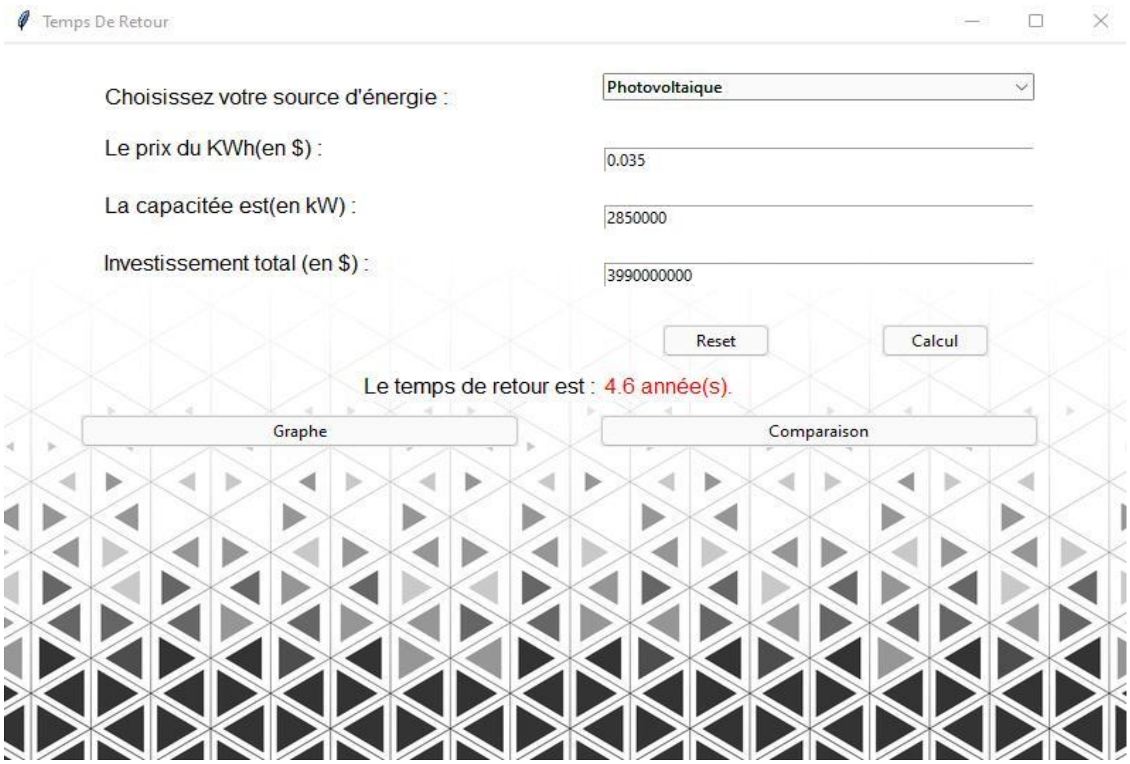

Figure 76 PV time of return in investment

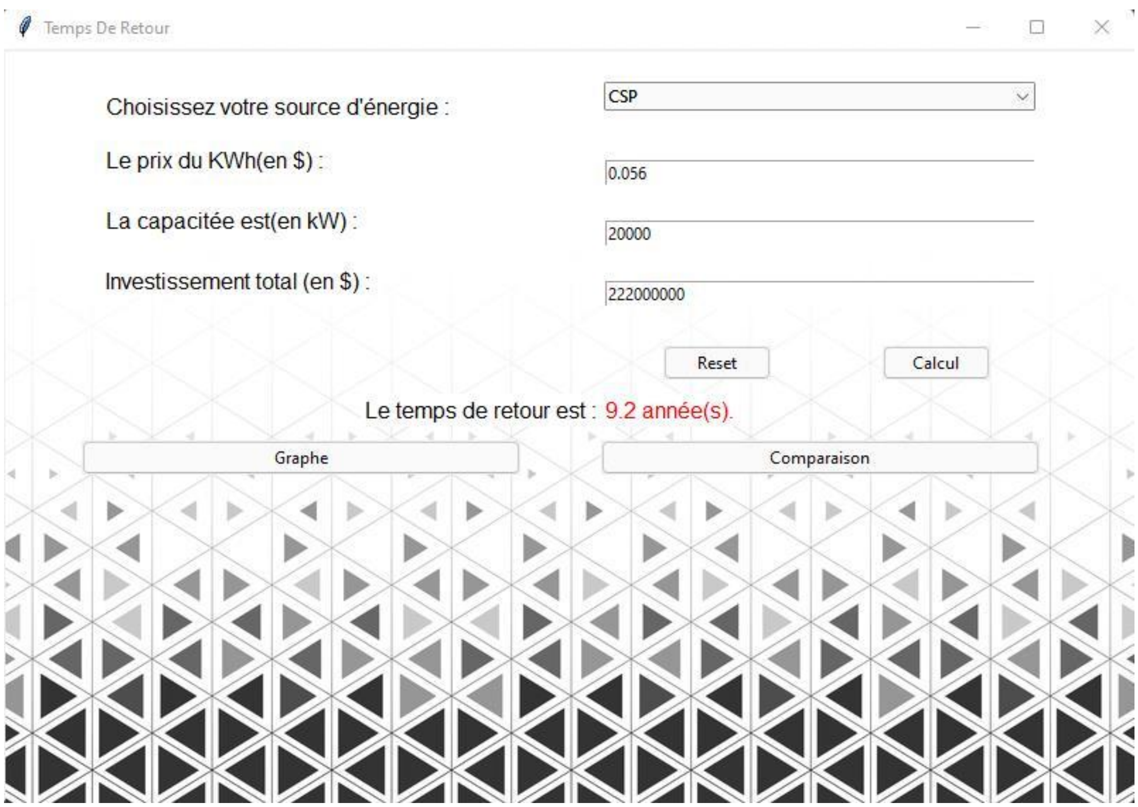

Figure 77 CSP time of return in investment

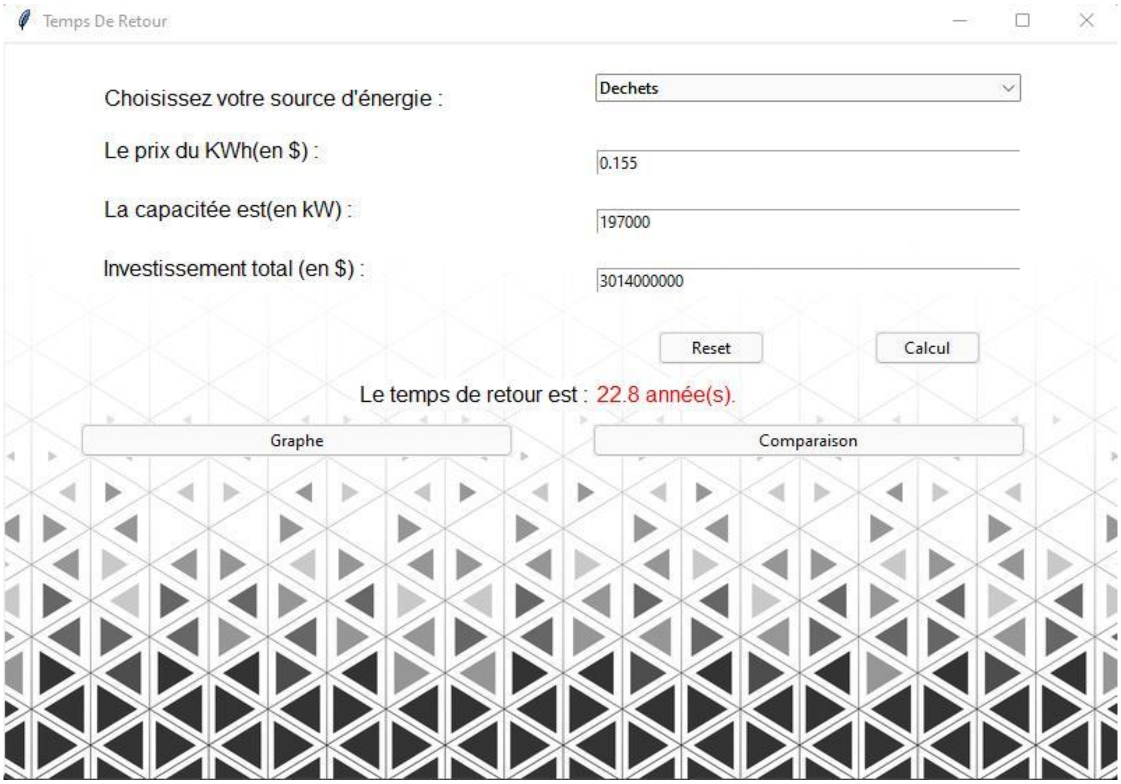

Figure 78 Biomass time of return in investment

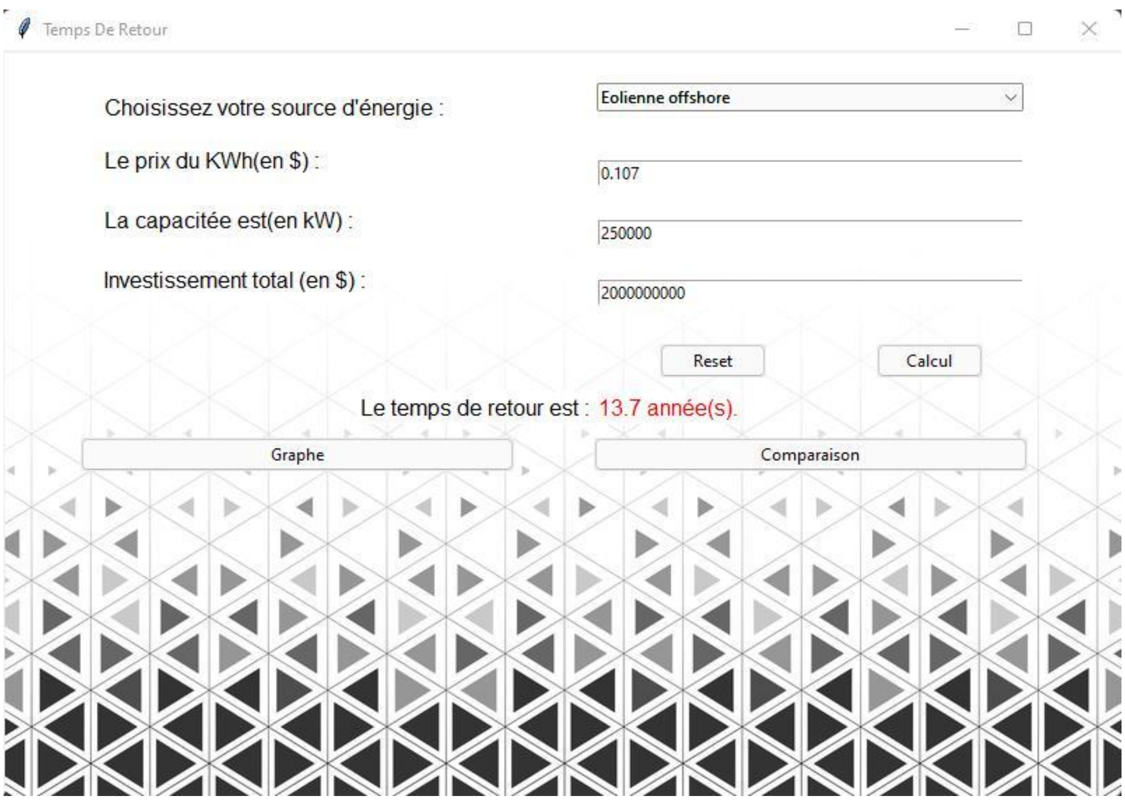

Figure 79 Wind offshore time of return in investment

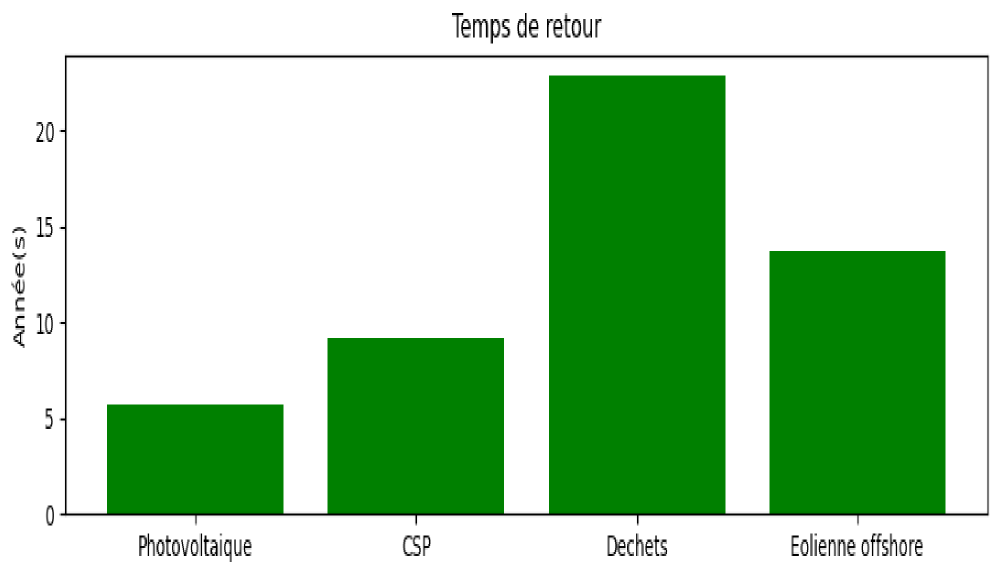

Figure 80 Bar chart comparing the time of return in investment for every technology

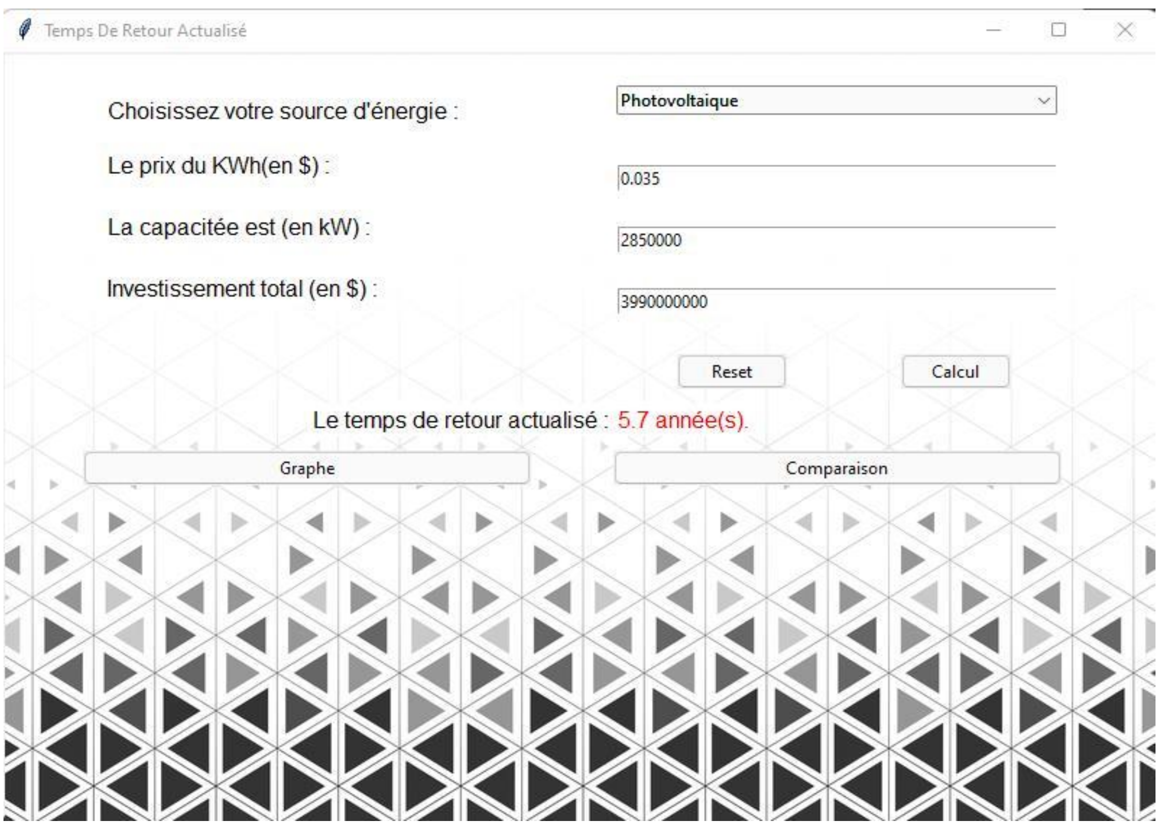

Figure 81 PV leveled time of return in investment

Figure 82 CSP leveled time of return in investment

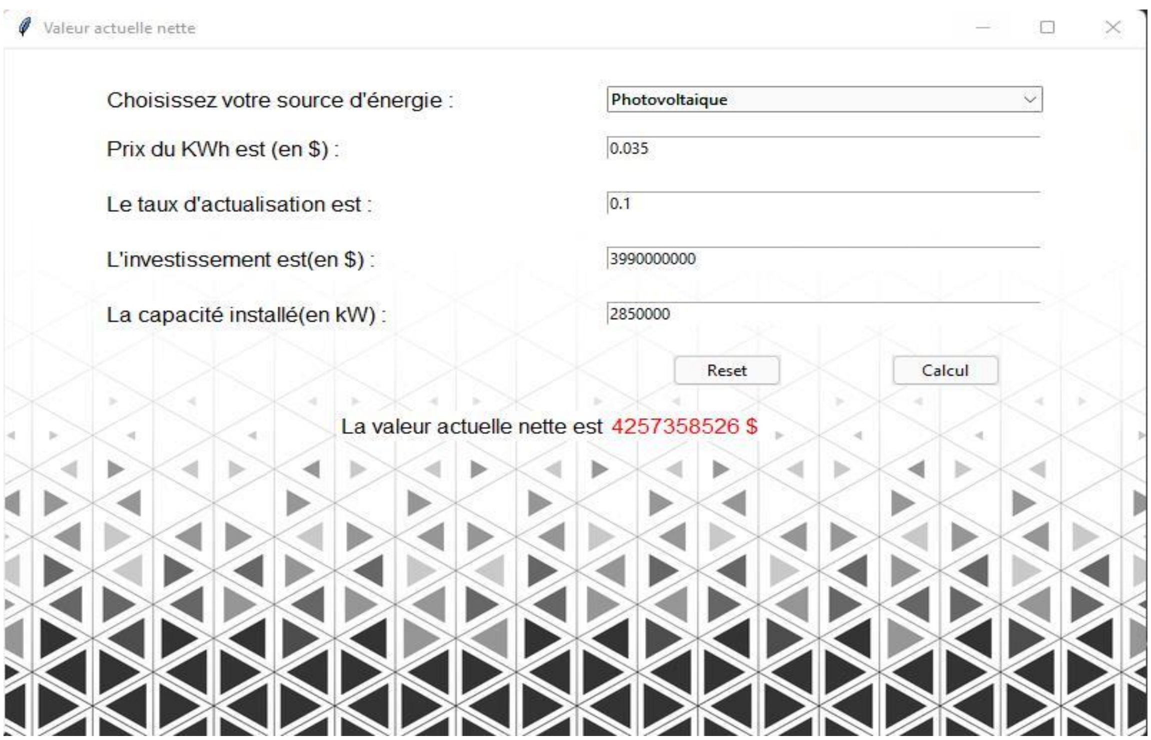

Figure 83 PV actual net value

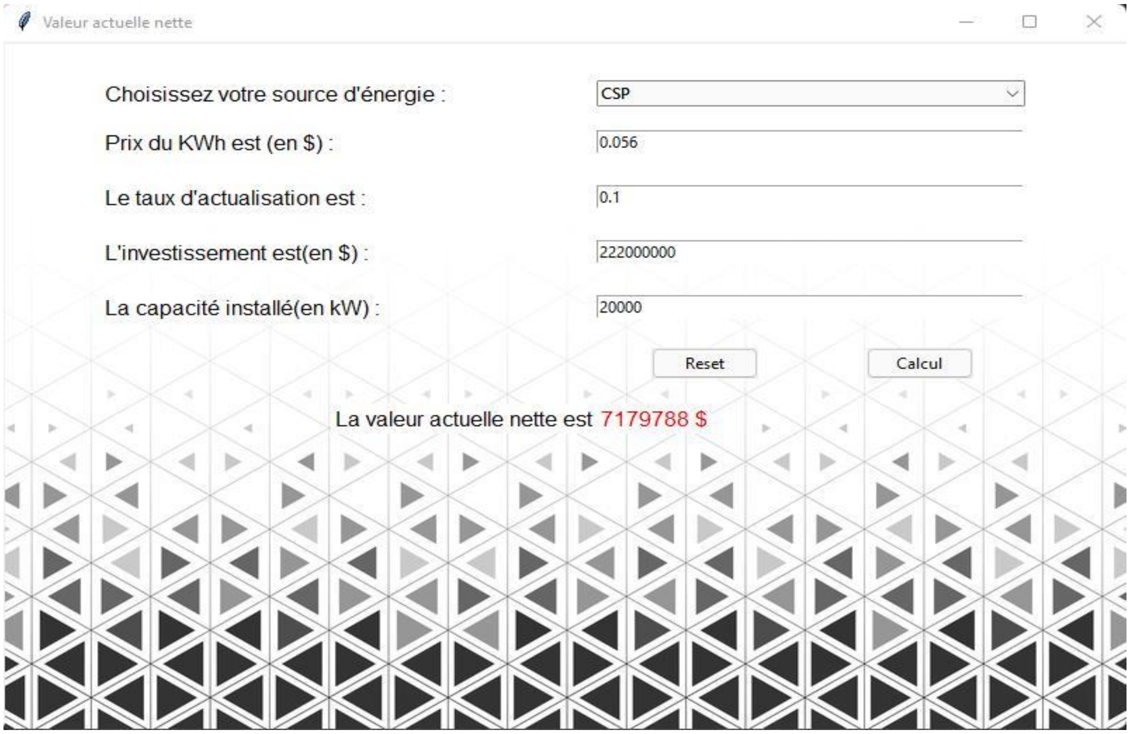

Figure 84 CSP actual net value

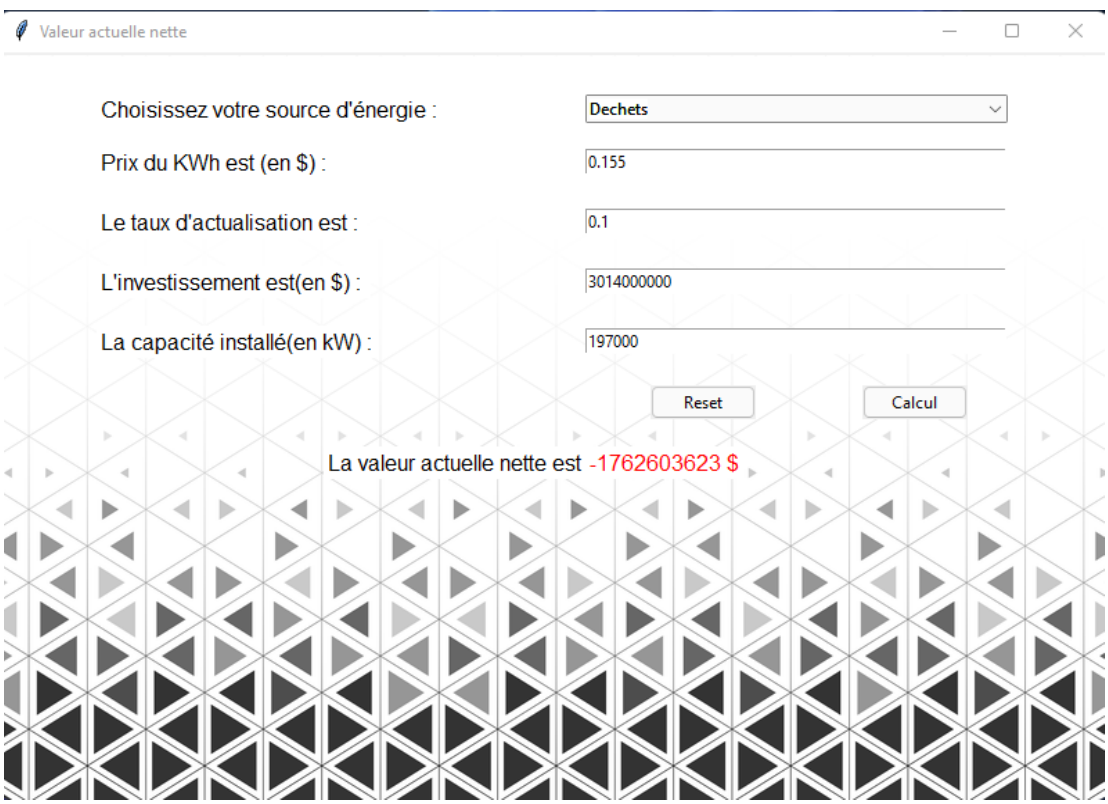

Figure 85 Biomass actual net value

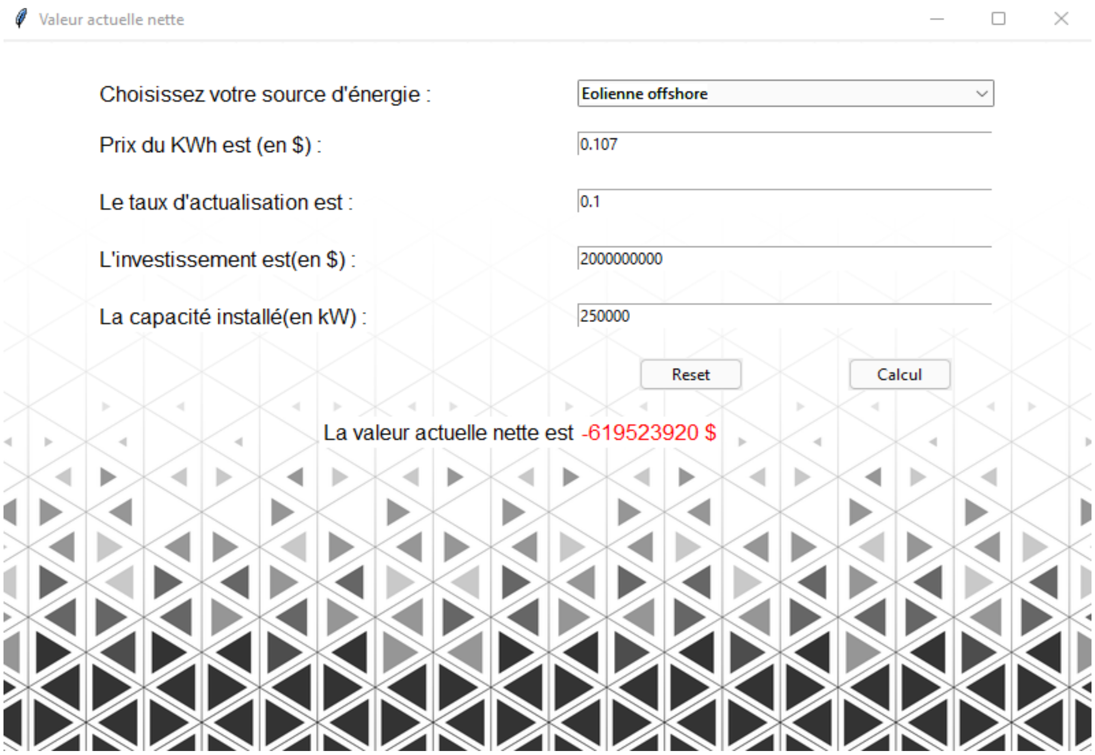

Figure 86 Wind offshore actual net value

Figure 87 Error message for the actual net value of the waste to energy

Figure 88 Error message for the actual net value of the wind offshore

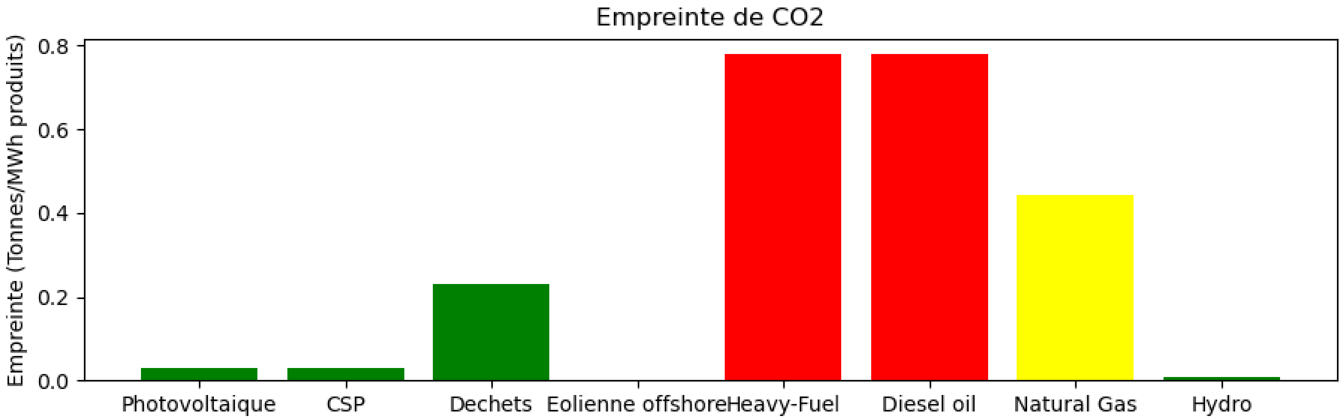

Figure 89 Bar chart comparing the carbon footprint of different technologies