AMERICAN UNIVERSITY OF BEIRUT

RENEWABLE ENERGY IN LEBANON

by
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AN ABSTRACT OF THE PROJECT OF

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The Lebanese Electricity Sector has been facing technical and financial problems in electricity production. The energy sector suffers from a shortage in power production and is adding to public debt around $1.5 billion per year. In addition, power outages per day reach up to 12 hours in rural areas and 4 hours in cities. Moreover, the energy production depends on oil and natural gas which are expected to deplete over time. For this reason, Lebanon should start searching for alternative renewable sources of energy, in particular solar and wind energy. Many investments on renewable energy have been made in developing nations to tackle their current energy problems, yet Lebanon still lags in developing its green energy. The subject of the project will begin with an overview of Lebanon's electricity sector and its poor management and technical capacity. Chapter 2 will display the current practices in Lebanon's power sector and study its economical and environmental effect. Furthermore, Chapter 3 discusses both current and future solar and wind projects in Lebanon and their implications on the economy. Chapter 4 involves a cost benefit analysis that will be used to compare future renewable energy projects with current energy practices. Finally Chapter 5 will show the results and policy recommendation.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

1.1.1 Overview

The depletion of fossil fuels and the increasing demand over energy has raised global concerns. The world energy is still controlled by non-renewables; 87% dependence on fossil fuels: Oil (33%) is used in transportation, coal (30%) is used in energy production, and natural gas (24%) is used in heat supply and electricity production [1]. The prices of fossil fuels have unpredictable fluctuations and have increased compared to non-renewables. The energy consumption is expected to increase by 70% until 2030, yet by 2030 fossil fuels still represent 88% of total energy. The high demands of energy driven by economic and population growth are causing the world oil supplies to run out faster than expected. There is enough oil reserve to meet the growing demand up until 2030. However after that period, non-renewables may not be enough to support the total demand [2].

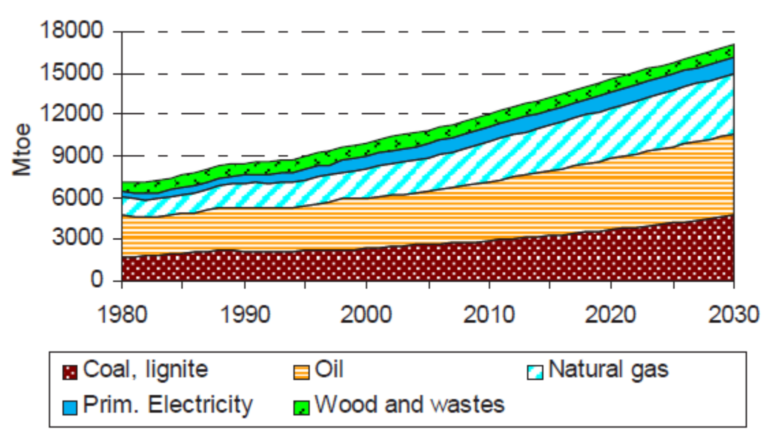

Figure 1: World Energy Consumption [2]

The rest of the world energy is supplied by renewable energy or nuclear energy. The use of fossil fuels in energy generation and transportation accounts for 70% of the greenhouse gases (carbon dioxide, methane and traces of nitrogen oxide) emitted. The dependence on fossil fuels has had a negative impact on the environment, such as global increase in temperature. Since 2000, the CO_2 emissions are increasing by 2.1% yearly [2]. The level of CO_2 emissions in 2030 is projected to be 20% higher than in 1990. The emissions are more than double between 1990 and 2030 [2]. Scarcity of fossil fuels and their destructive environmental effects have raised political and social concerns. An example of the obvious spread of pollution can be found in China, the largest manufacturing country, in which the polluted smog has deteriorated the population's health. Energy produced from solar power, hydroelectric power, wind turbines, geothermal and tidal energy have negligible CO_2 emissions. Switching to renewables can help in decreasing the greenhouse gas emissions and improve the quality of air.

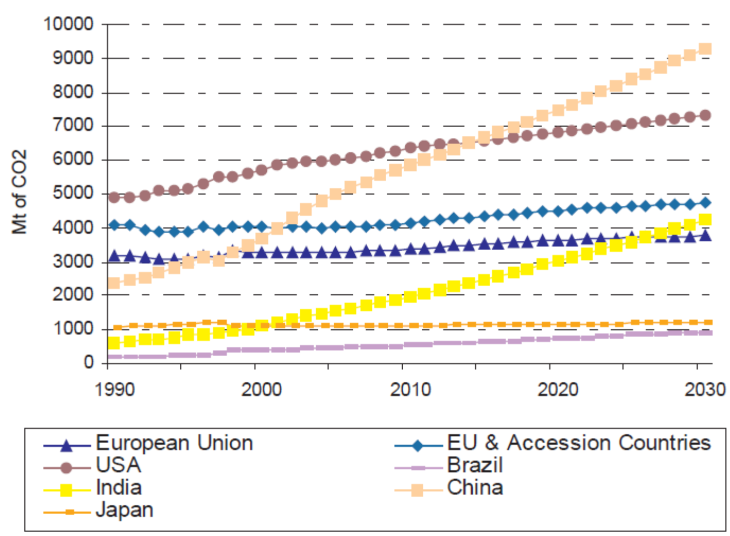

Figure 2: Energy Related CO_2 emissions [2]

For this reason, countries are directed towards renewable energy which can be cost effective and environmental friendly. Solar, wind power, hydroelectric energy, biomass, fuel cells, and geothermal power are types of renewable energy that have been developed and used in many countries to meet the increasing future human demand for energy. The main concentration of renewables was in the electricity sector, followed by transportation and heat supply. Investing in green energy is now even more profitable since their large costs have been decreasing with the advancements in technology. The increased investments in renewable energy can help decrease the level of carbon emissions. When accounting for the negative externalities associated with non-renewables, green energy would become even more competitive [3]. In 2012, 20% of the world global energy was provided using renewable energy. Renewable technologies continue to expand around the world. Investments in renewables have reached 243 billion USD in 2010, compared to 180 billion USD in 2008 [3]. Iceland generates 100% of its country's energy supply by renewables. Following is Norway, with 97% of energy is supplied with renewables [4].

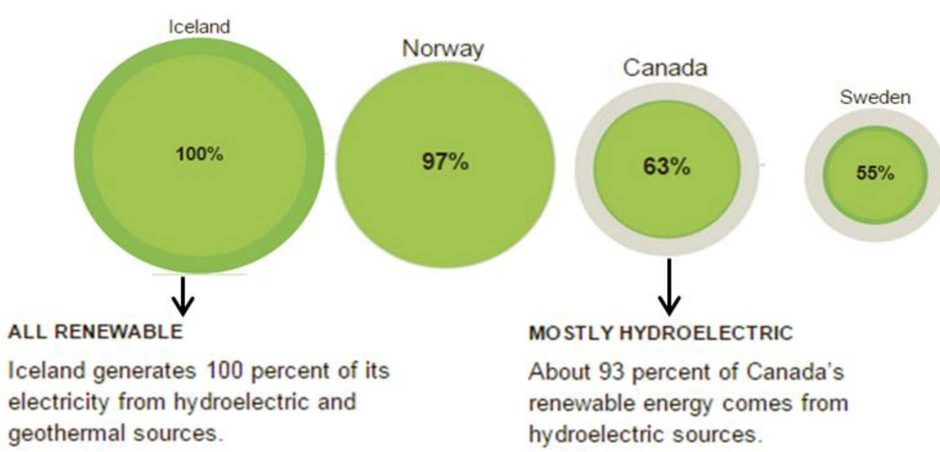

Figure 3: Electricity from Renewables [4]

1.1.2. Research Problem

Lebanon is still behind in green energy. Unlike developed nations that began investing in renewable energy, developing countries are falling behind in their energy renewable technologies and thus their energy supply. After the long years of the Lebanese Civil War that ended in 1990, the economy's infrastructure was destroyed and damaged, including the energy sector. Lebanon doesn't produce coal or oil and thus imports 98% of its energy resources. In addition, power plants are not utilized efficiently and have high technical losses. For this reason, not only is the electricity sector in Lebanon unreliable but also very expensive. Around 60% of the population relies on private generators since they suffer from large hours of blackouts. In order to meet the increasing demand that is estimated at 3,000 MW in 2030, the construction of new plants and investing in renewables is necessary.

The numerous problems EDL (Electricité Du Liban) is facing could be solved with the introduction of renewable energy projects. Lebanon is currently investing in new wind power and solar PV projects, yet renewable energy still constitutes a small portion of the total energy source. Lebanon receives high hours of sunshine per day and around the year. However, this convenient solar flow is not benefited and transformed into energy due to the lack of political union. The discovery and innovation of a new renewable source in Lebanon is vital for the country's energy sustainability. The government plays an important role in encouraging investments in renewable energy. They can provide subsidies and funds, increase R&D and policy support to make renewable energy more attractive. The lack of government aid and policy support can delay renewable energy development.

1.2 Project Objectives and Research Method

In my project, I will discuss the importance of renewable energy in Lebanon. EDL is struggling to improve the electricity sector. Switching to green energy can improve energy efficiency and decrease government deficit. I will move on in Chapter 2 to talk about the current practices in Lebanon's power sector and study their economical and environmental effect. When discussing the current practices, I will highlight the technical and financial problems faced in Lebanon's power sector and identify their causes. These problems include the deficiencies in transmission, distribution, low maintenance and many more. Meanwhile, the environmental effect includes increased level of air pollution, noise pollution from generators and subsequently deterioration in quality of health. Furthermore, Chapter 3 will discuss current renewable energy used in Lebanon, such as solar and wind project, and will then move on to talk about future renewable energy projects. This chapter will also determine the economical and environmental effect of these renewable energies on the economy. The electricity sector in Lebanon set a target rate of 12% of total energy supplied from renewables by 2020. Chapter 4 involves a cost benefit analysis to study in detail the shift from fossil fuel based energy to renewable energy. The cost benefit analysis will test the viability of a 5 MW photovoltaic solar plant in Beirut, Lebanon, using the RETScreen software. RETScreen is a clean energy project analysis software that is used by many investors to evaluate the power production, costs and income, and greenhouse emissions reductions of the proposed project. Finally, Chapter 5 will conclude the project by analyzing the results obtained from the cost benefit and will help us come up with policy implications and suggestions to solve Lebanon's energy problems.

CHAPTER 2

ENERGY SECTOR IN LEBANON

2.1 Background

The main distributor of energy in Lebanon is the Electricité du Liban (EDL). It is a monopoly since it dominates 90% of the energy production in Lebanon. It has been legally established in 1964 to generate, transmit and distribute energy in Lebanon [5]. After the Lebanese civil war, which lasted between 1975 till 1990, many of the country's infrastructures were destroyed including the power sector. Several projects took place to improve the countries energy production and decrease its inefficiency. Yet these steps were not enough to produce the required energy demanded. No major new electricity generation was invested after 1990, despite the 4% annual growth, which forced the country to rely on self-generation to meet their needs. In addition, no plan regarding energy supply has been made for the long term. Total investment in the energy sector was only $1.6 billion since 1992 till 2009; just $50 million from 2002 till 2008 [6]. EDL currently employs around 2000 workers, many of whom are unqualified and do not have any value to the company. EDL is still 100% publically owned even though many economists believe that privatization could solve many of the energy problems encountered [7]. Eventhough the legal framework for privatization exists (law 462), it is still not yet applied. Lebanon imports 95% of energy used which is adding to the yearly annual debt. The yearly deficit has been around 1.5 billion USD since 2010. The supply of electricity in Beirut is 21 hours/day while daily power outages reach 13 hours/day in all other areas [5]. Lebanon's energy demand will keep on increasing and therefore a solution is needed.

2.2. Literature Review

A report by the European Union describes the Lebanese electricity sector and its impediments. The CCGT power plant in Zahrani and Beddawi should be operated using natural gas. Since natural gas is unavailable in Lebanon, the plant is operating on diesel fuel which is more expensive and polluting. A lower cost can be attained when switching from diesel fuel to natural gas. The power sector faces shortages and is operating on very old generating units. The capacity demanded in Lebanon 2,300 MW but the EDL only supplies 1,685 MW. The EDL supplies 15 hours per day in the country. In addition, the technical losses in the transmission distribution are 15%, while the non-technical losses are 25%. Lebanon does not have any laws concerning renewable energy. If investments in renewable energy increased, a proper law for green energy should be written. For instance, pricing electricity from renewable energy is still not defined. The government is trying to promote green projects by financing them with a 0% interest rate [8].

Another report by the World Bank describes the expenditure of the electricity public sector. Electricity in Lebanon is using up many of the governments public resources, around 5% each year since the past 5 years. High operating and maintenance costs, inefficient production and high technical losses all add up to the high production costs. The electricity sector is in a crisis and is unable to supply electricity needed to locals. Lebanon has several options to increase electricity generation. One is rehabilitation of old power plants in Zouk and Jieh. The new power plants however should operate on natural gas and not diesel fuel to be efficient and more economically attractive. Another way to improve electricity generation is reducing technical losses to improve the financial performance of EDL [9].

The paper “Renewable and Sustainable Energy Reviews” by E. Kinab and M.El Khoury, discusses how renewable energy can be improved in Lebanon. The energy sector in Lebanon runs a $1.5 billion deficit annually due to the low quality transportation in electricity, lack of maintenance and wrong tariff implementation. The article suggests that this energy crisis should be tackled by investing in both the generation and transmission sector. Electricity loss is estimated at 55% which is high compared to developing countries [10]. New investments could be directed towards renewable energy. Lebanon is rich in solar energy with an annual average irradiance of 5.01 kWh/ m^2/ day. Solar water heating is being used due to its low cost, yet photovoltaic electricity power is still expensive and not being used as much.

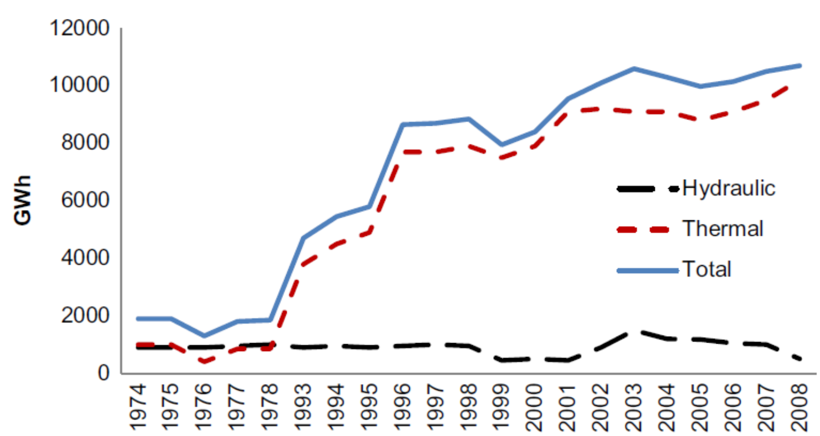

Figure 4: Evolution of Renewable Electricity Production in Lebanon [10]

Moreover, the paper tackles the main barriers that are preventing the use of green energy in Lebanon. The first reason is the absence of reliable data on wind and solar resources; this prevents the country from the proper implementation of renewable technologies and inefficient projects. The second reason is the monopolization of EDL and the absence of proper certified institution to clearly plan the use of renewable. Furthermore, the high price of solar energy compared to current practices also discourages locals to invest in solar or other green power. Finally, the society is unaware of the huge disastrous effects on their surroundings and health that is being caused by current energy practices. The suggestions imposed to tackle these barriers are developing a plan for the renewable energy in Lebanon in accordance in the global principles for sustainable energy. Next, the government should fund research at universities to develop green energy projects in Lebanon. A third solution is the creation of a proper data base to accurately study the cost benefit analysis of such projects. Final solution is reconstructing the tariff system on electricity consumption [10].

Another article by Oussama Ibrahim and Farouk Fardoun discusses the barriers on conventional and renewable energy in Lebanon and the proposed solutions. The development of an efficient and renewable energy department in the Ministry is a must to be able to develop and invest in the sector. The conventional energy sources are mainly concentrated on coal and oil [5]. Some recommendations to improve non-renewables that were suggested are the exploitation of crude oil and gas that were detected both on shore and land. Another approach is the renovation of the two old refineries: Zahrani and Beddawi. The paper then moves to talk about the different types of renewable energies in Lebanon and their potential. The first is wave and tidal energy; however Lebanon's shore and sea does not meet the requirements so this type of renewable cannot be used. Wind power energy cannot be properly measured due to the absence of data. Third is Lebanon's hydropower which is important in a country whose annual rain and snow reaches 8600 MCM. Nevertheless, only 20% of this water is being taken advantage of. The generation of electricity using hydropower only reaches 4.5% and this should be increased and improved. Fourth is biomass since solid wastes are found at a rate of 4300 ton/day. However, since there is an absence of emission control, this type of renewable would cause more harm than benefit the society. The final and most practical solution is solar energy. Solar energy is either used as solar photovoltaic (PV) or solar thermal. Solar energy in Lebanon is growing at a rate faster than other renewables and has shown great advancements in the past years. However, solar PV still remains limited due to its high start-up cost.

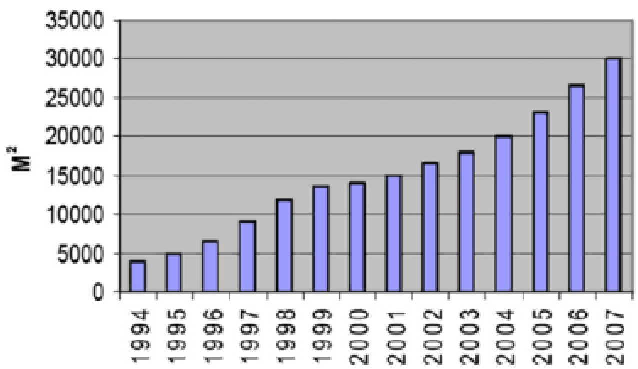

Figure 5: Evolution of annual installed solar thermal system areas in Lebanon [5]

A paper by Elizabeth Harder and Jacqueline MacDonald Gibson study the potential of renewable energy in the United Arab Emirates using the RETScreen software. The country shows that a potential 10MW solar power plant is viable in Abu Dhabi. The first step in their analysis consists of estimating the energy production and its financial feasibility. The second step is calculating the reductions in the GHG emissions. The final step is assessing the social benefits of this project. GHG emissions of their projects are obtained from measuring the emissions of 1550-MW Umm Al Nar plant. The large scale solar power plant seems not profitable at first in Abu Dhabi with a -50 million USD since cost of fuel is low in their country. However, when environmental effects are taken into account, the construction of the 10MW power plant becomes profitable. The solar PV would save 10,000 tons of CO_2 yearly which a have a financial value of 50million USD. This improves the social living of citizens and promotes a cleaner environment [10].

Another paper written by Eyad S. Hrayshat, discusses the viability of a solar power plant in Jordan. Since Jordan witnesses high hours of sunshine throughout the day (9 hours on average), the paper proposes a 5MW grid-connected solar photovoltaic power plant. The plant shows that 7,000 tons of CO_2 can be saved yearly. Using the RETScreen software, the most favorable site was Tafila and Karak which witness 3311 hours of sunshine per year. The equipment and feasibility study in this report can be a guideline for future solar projects in Lebanon since the two countries share same demographic characteristics (same hours of daily sunshine). The main initial costs include the feasibility study, required engineering and installation of energy equipment. The largest portion of the fund (70.6%) accounts for the energy equipment, followed by the balance of the plant cost (26.8%). The internal rate of return of the PV project is calculated to be 6.2%. The net present value varied from a minimum of 4 million USD to 40 million USD. The paper concluded that a 5MW solar plant is profitable and should be installed in each of these areas [11].

In addition, many studies have shown that Lebanon may have oil and gas on its shore. A report by bank med discusses in details the oil and gas potentials and their exploitation. The Levant Basin, territorial waters of Lebanon, Israel, Syria and Cyprus, has been assessed as the new hydrocarbon area. The Ministry of Energy and Water said that oil reserves can reach 850 million barrels of oil. Oil is estimated at $108/barrel; the value of resources would be around $80 billion [13].

2.3. Infrastructure

2.3.1 Generation

Lebanon relies on fuel imports to produce its energy. Imports of fuel and diesel (oil products) are 120,000 barrels per day. Imports are worth $500 million per year [12]. The three main inputs of plants used in Lebanon are heavy fuel, diesel and hydropower. Energy produced from heavy fuel and diesel represents around 87% and energy from hydropower 13% of total energy. The power generating plants are divided into two categories: Thermal and Hydroelectric.

2.3.1.1 Thermal Power Plants:

The installed capacity for thermal factories is 2038 MW but the actual usage is 1685 MW. The demand is estimated at 2,500MW. Thermal plants consist of steam turbine, two combined cycle gas turbine and open cycle gas turbine plants.

Steam turbine plants that rely on heavy fuel oil (HFO) are located in Zouk, Jieh and Hrieche [13]. Heavy fuel oil is among the most polluting energy sources. Due to the lack of environmental control and absence of equipment need, this pollution has many several consequences ranging from air, soil and water pollution.

Furthermore, power plants that depend on oil/diesel fuel (LFO) are Zahrani, Deir Ammar, Baalbeck and Tyre. The power plants are either combined cycle gas turbine (CCGT) such as those found in Deir-Ammar and Zahrani; or open cycle gas turbine (GT) such as Baalbek and Tyr. Initially, these plants were designed to be fueled with natural gas. However, they are fueled with diesel oil since no natural gas is available. This makes energy generation very expensive; is cost would be decreased when switching to natural gas. Due to the low quality of diesel fuel imported and used in Lebanon, it has increased the level of pollution [5].

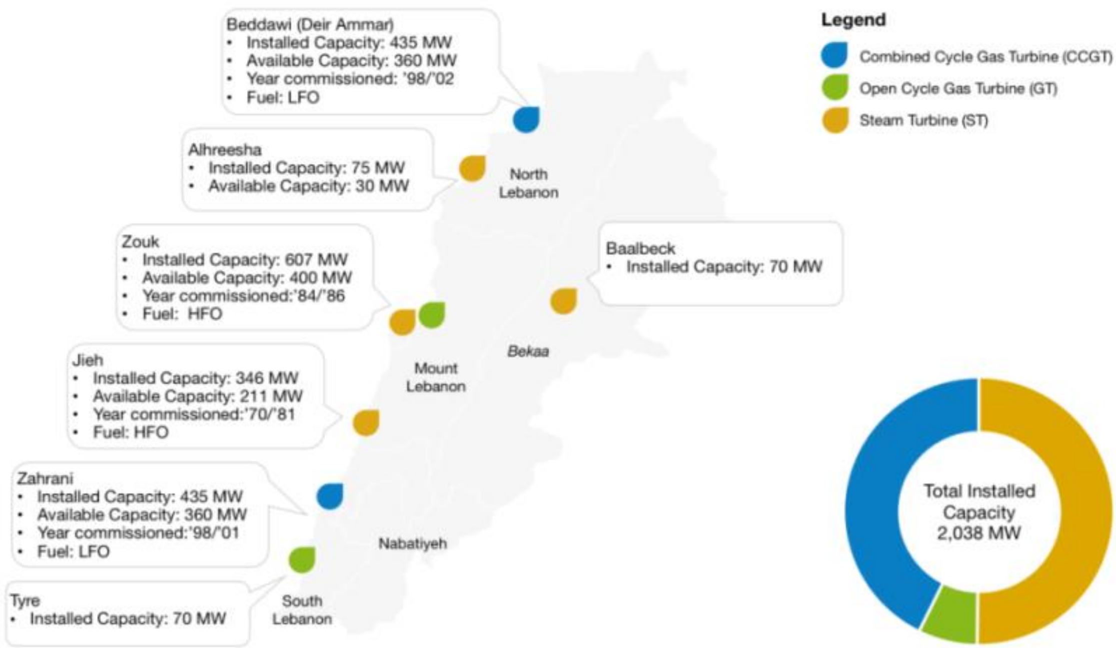

Figure 6: Types of Thermal Power Plants [6]

2.3.1.2 Hydroelectric Power Plants

Lebanon is also known for its water resources and stands out among all other MENA countries. However, the country has not yet utilized this water source properly to generate power. Hydraulic power plants have installed capacity is for 274 MW but the actual usage is190 MW. Kadisha, Nahr Ibrahim, Nahr El Bared, Richmaya and Litani Plants all compose a small section of total energy production from hydropower stations. Hydropower produces 3% to 7% of total energy generated depending on yearly rainfall [12].

The generation sector, both thermal and hydraulic, suffers from problems which are the following:

- Insufficient generating capacity
- Lack of maintenance and updating infrastructure
- Both the combined cycle gas turbine (CCGT) and open cycle gas turbine (GT) are built to operate on natural gas. Until now generation in these plants are dependent on diesel rather than natural gas as required.

Plant	**Number and Types of Units**				**Total Capacity (MW) Installed**
	Thermal	**Steam**	**Gas**	**Hydro**	
Zouk	4				607
Jieh	4				346
Zahrani		1	2		435
Deir Ammar		1	2		435
Baalbeck			2		70
Tyre			2		70
Hreiche	1				75
Kadish, Nahr Ibrahim, Nahr El Bared, Richmaya, Litani				15	221
Total					2,334

Table 1: Type and Quantity of Power Plants in Lebanon [14]

2.3.2 Transmission

The power transmission is delivering the electricity from generating plants to electric substations found near businesses, homes and factories (high demand). The EDL transmission system of high voltage line has a total distance of 1427 km. It consists of 4 power lines: 66, 150, 220 and 400 kV. In addition, EDL has 58 power stations to convert high power voltage to medium power voltage. The transmission lost rate (% of output) was

11.4% in 2011 according to the World Bank. The following points contribute to the problems caused in transmission and lack of efficiency in 220kv and 400kV:

220 kV Network: The 220kV networks are incomplete which does not allow for optimal transmission. The incomplete 220kV causes the energy transmission to be switched to 150 and 66kV power lines. This causes overloading and loss of power [15]. Overloading is faced the most during summer when heavy use of air conditioning takes places.

400 kV Network: This line is used to connect the 400kV station in Ksara with the 400kV in station in Syria. However, until now this transmission line in not operational because it has not yet finished construction. This results in the inability to exchange power with Syria's station (7-Nation EIJLLST grid) when needed at times of emergency.

Other problems that are found among all transmission lines are:

- 15% technical loss in all transmission lines due to resistance and iron core losses in metallic lines that connect power plants to end-users, lack of restoration and aging of power lines, and incomplete infrastructure that reduce efficiency. They cause large losses in transmission and distribution.
- 11% of the transmission lines are outdated and which causes disturbances and ineffectiveness in transmission.
- Lack of maintenance for HV lines that are both decreasing power capacity and causing a negative effect on the environment.
- No clear budget allocated to the transmission directory to improve its production.
- Absence of control party to organize and maintenance facilities [5].

2.3.3 Distribution

Electricity distribution is the final in the 3 stage process. It delivers the electricity from the transmission phase to its subscribers. Distribution stations lower the transmission voltage from medium power to low power. Lebanon's distribution network consists of 18,000 transformers which delivers energy to the customers. The two distribution directorates are the "Beirut and Mount Lebanon Directorate" and "Regions Directorate", each responsible for administering the network within its region [16]. The distribution directorates are also responsible for billing and collecting what is charged to every customer at a monthly basis. The distribution networks found in Lebanon are 11 kV, 15 kV and 20 kV, with some additional networks at 5.5 kV and 33 kV [5]. The distribution system is divided accordingly:

- Low-voltage distribution: 45%, allocated to commercial enterprises and households.

- Medium and high voltage distribution: 23% for industry and 12% for administrative buildings

- Technical Losses: 20%

Not only does the transmission network suffer from inefficiencies, but also the distribution network. Below is a list of problems found in our distribution network:

- 5% are non-technical such as losses from the unaccounted bills of private sector energy ($97.5million) and the uncollected bills of the public sector ($32.5milion). The distribution system suffers from high overloads, thefts, and absence of management. There is no metering system to provide the estimation of the total transmission and distribution losses. It also makes electricity theft almost impossible to control. [6] Only until 2010, the EDL was able to monitor more the electricity network and was able to decrease the number of technical losses and facilitate the detection of non-technical losses (theft), consequently increasing the share of electricity produced that is actually delivered to customers.

- Poor maintenance on substations converting medium voltage to low voltage. In addition 37% of the transformers used in these stations have passed their average life time. [5]
- Due to the low number of distribution networks, Beirut's medium voltage network is faced with overload.
- No financial aid given to improve the poor and inadequate supplies

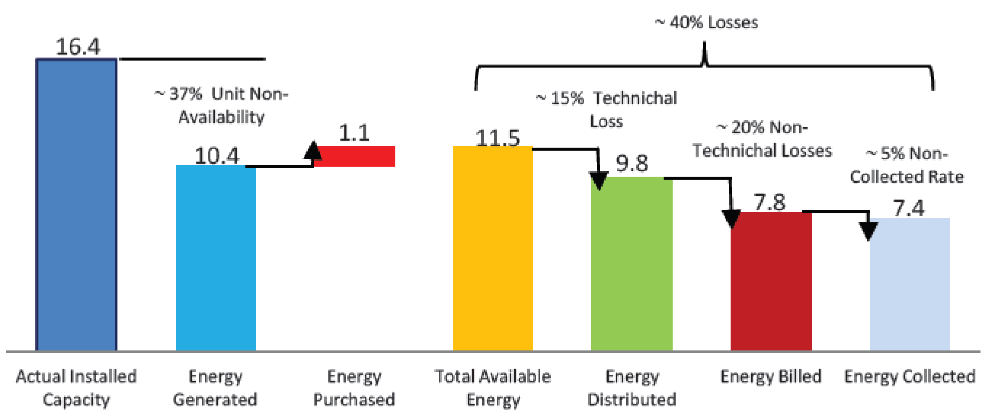

Figure 7: Lebanon's electricity sector: Generation, transmission, distribution [17]

2.4. Supply

The EDL suffers from supply deficit and does not meet the required load due to the high prices of fuel, technical losses listed above and inaccurate collection of bills. In 2011, the energy supply was 11,500GWh while the average demand exceeded 15,330GWh [18]. To compensate for EDL's power shortages, 60% of people depend on private generators which cost more than twice the price of public electricity. Both the industrial sector and residential depend on the back-up supply. Lebanon's generating system is unable to serve the current demand and is in need for huge investments to meet future demand. The deficit in supply is increasing yearly. In 2010, the deficit was 800MW (33%) which translates into 8hrs/day of blackout. In 2013, the deficit was 1330MW (47%) and 11.3 hrs/day of blackout. The forecast of power shortage for 2016 is 1909 MW (58%) and 14 hrs/day [5]. EDL's fuel imports constitute 35% of total national imports. 96% of the total primary energy supply depends on imported energy sources and 4% depends on local sources. In 2011, the losses due to transmission is 12%, compared to average world loses which is at 7%. The commercial loses is 18% due to unaccounted bills and illegal energy supply which translates into 150 million USD lost revenue for the government. Both add up to 35% of electricity loss which is considered a high percentage [19]. The energy produced from each sector is divided accordingly:

- Hydroelectric power: 60 ktoe – 2% of total supply
- Combustible renewables and waste: 127 ktoe – 4 % of total supply
- Solar and Wind power: 18 ktoe – very small percentage of total supply
- Petroleum Products: 4.3 million toe – 91.4% of total supply
- Coal and Peat Products: 142 ktoe – 4.5% of total supply [19]

As shown in the figure 3, the total supply of energy was low between 1970 and 1990 due to the civil war in Lebanon. After the civil war ended in 1990, energy supply increased at a high rate up until 2006 when the war with Israel took place, which had destroyed many of the electric infrastructure. Moreover, after the oil shock in 2006, fuel imports dropped by 20% and debt increased due to higher energy prices. EDL's fuel imports in 2006 were 900million USD compared to 2004 which was 475million USD [19].

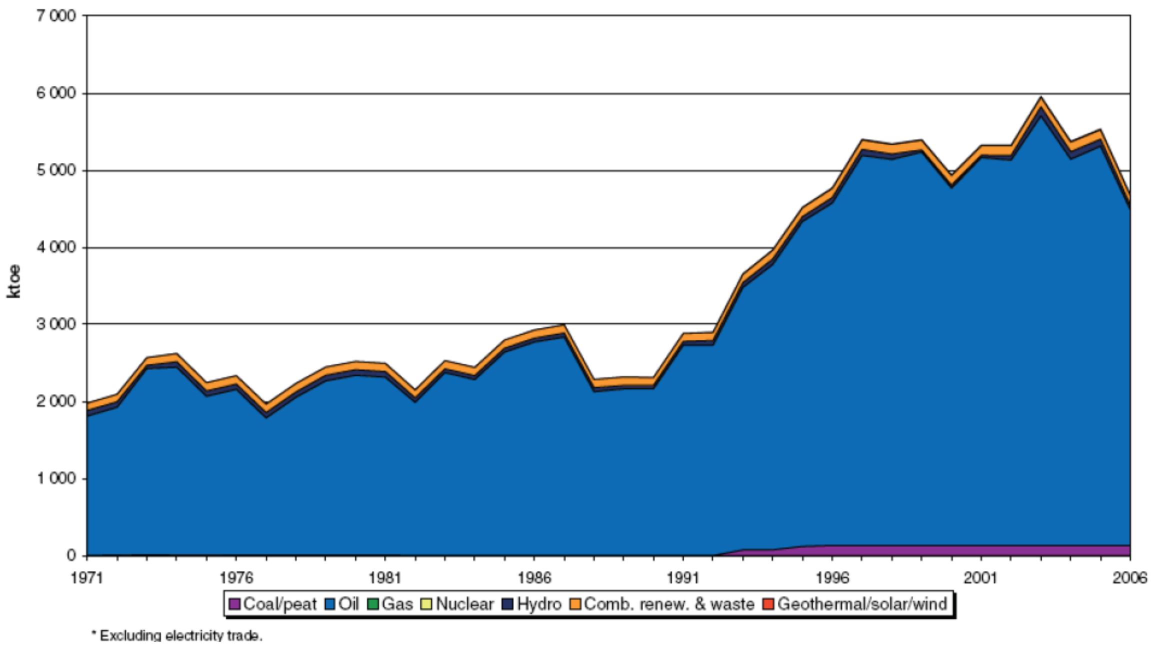

Figure 8: Total Primary Energy Supply [19]

2.5. Demand

In 2011, the energy consumption per capita was 1.44 toe per capita. Oil covers 91% of total consumption while coal, hydroelectric and biomass each contributes to 3% [20]. Lebanon's peak demand is 2600MW and EDL operates at a capacity between 400 and 650MW [21]. As any other developing country, this capacity should upgrade to 3000MW to meet the increasing demand in the future. EDL's energy demand increases during the summer (June) because of air conditioning, and winter (January) because of heating appliances and lighting. In addition, during the day the peak loads are in the evening, from 5pm till 7pm, mainly due to lighting in buildings and residents. Low-voltage consumers, such as households and small businesses, represent more than half of the energy demand (53%).

The consumption of the Lebanese electricity sector is divided into the following: 30% by residential sector, 26% commerce and industry sector, 18% by government sector and the remaining are lost due to technical inefficiencies.

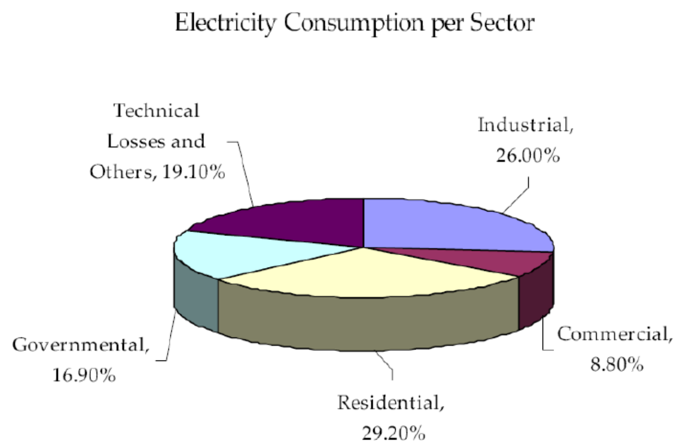

Figure 9: Electrical Consumption per Sector [19]

Consumption per Capita

The following table shows the consumption of energy per capita from year 2000 till 2011 and is measured both in toe and kWh.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Toe	1.517	1.566	1.485	1.415	1.368	1.26	1.17	1.016	1.296	1.566	1.47	1.449
kWh	2,691	2,166	2,350	1,996	1,969.7	2,245	2,754	2,427	2,054.6	2,032	2,374	2,364

Table 2: Consumption per Capita [18]

CHAPTER 3

RENEWABLE ENERGY AND ITS IMPLICATIONS

3.1 Overview of Green Energy

Renewable energy can be replenished infinitely. They are generated from natural resources such as sunlight, wind, tidal power, hydropower, geothermal heat and biomass. Hydro-power is the most widely used form of renewable electricity in the world. Solar and wind energy are considered new forms of renewable energy. More than 2.7 billion people around, usually poor class, rely on biomass for heating and cooking. Overall, all renewable energy still contribute to a small portion of the world's total energy.

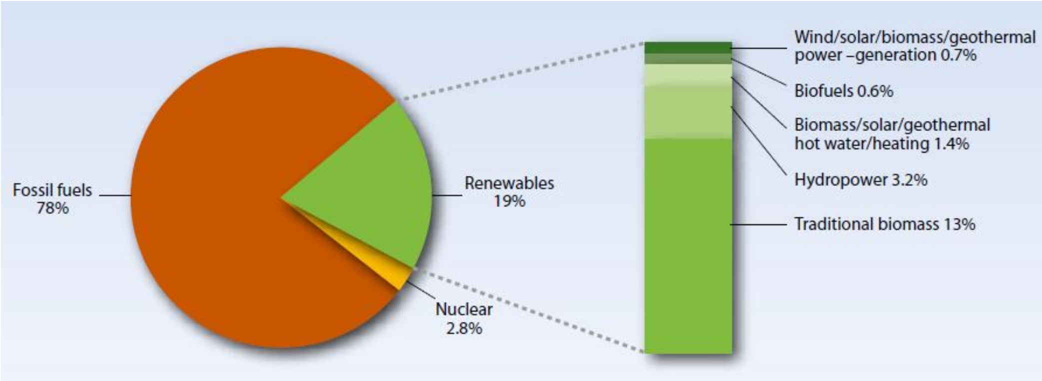

Figure 10: Renewable energy share of global final energy consumption, 2008 [3]

The challenges that the world faces with the energy sector are increasing energy demand due to rapid increase in population and industrialization, climate change due to greenhouse gases and deteriorating public health due to fossil fuel emissions. Switching to renewable energy can help solve many of these problems but is still not sufficient alone [3].

Their main common characteristic is large fixed costs and low maintenance and fuel costs (variable costs). In contrast, fuel power plants have significant ongoing fuel costs. Renewables have increasing advantages, but are still slowed down by their high initial costs [22]. However, when this high initial cost is distributed over the renewable power station's life, which is above 50 years, its costs becomes less than those fossil fuel power stations. Renewable energy has many advantages. It is stable and independent and is not volatile unlike the energy market. The oil prices are fluctuating and mainly increasing in prices due to its inelastic demand. Investments in green power have been made due to the fast depletion in the quantity of fossil fuels and its negative impact on the environment. Renewable energy has unlimited supply and can help reduce the dependency on energy imports. Another advantage of renewables is that they may decrease the rate of poverty; non-renewable energy is expensive which leaves 2.7 billion people without access to proper electricity. Switching to green energy can help decrease expenses paid to electricity. Moreover, the combustion of fossil fuels has negative impact on the environment as well as human health. If these negative externalities are taken into account, renewable energy would be more competitive and beneficial [3].

Lebanon's dependence on energy import is expected to increase if no alternative renewable energy solutions are found. Green energy is the main factor in solving Lebanon's energy crisis. Daily power outages for 12 hours in rural areas and 3-4 hours in cities should be an alert for the Lebanese to start investing in renewable electricity. Switching to renewables can help improve the standards of living in the country by reducing energy costs and power cuts. The increase in oil prices has increased the government's fuel subsidies, which in turn has increased government deficit. The heavy dependence on fossil fuels also has deteriorated the air quality due to the rapid increase of CO_2 emissions.

In the past couple of years, Lebanon slowly began turning to green power, but this transition is not enough to meet the growing energy and therefore should be expanded. Lebanon, as a growing developing country, has inefficient energy generation which also has many environmental impacts. The country has an effective location for the growth of renewable energy, specifically solar power. Currently, the Lebanese Central Bank offers loans for renewable energy at 0 % interest. Water heaters powered by the sun are also increasing rapidly. The following renewable energy in Lebanon would help increase energy efficiency and reduce negative environmental impacts. These energy productions have zero or negligible emissions [23]. Lebanon aims to produce 12% of its energy using renewables by 2020.

3.2 Renewable Energy in Lebanon

3.2.1 Hydropower

Hydropower is renewable energy that is created from floating water. The most common type of hydroelectric plant use dams to store the water in a reservoir; then it releases this water to drive turbines which consequently produce electricity. Hydropower has been producing energy efficiently for the past decade. It is the most used renewable source of energy; it represents 15.3% of total energy production while the rest of the renewables represent only 5% of total production. Hydropower does not require burning fuel and therefore does not pollute the air or water. The high initial cost should be offset by its long term use and low maintenance cost. China is the largest producer of hydroelectricity, followed by Canada, Brazil, and the United States.

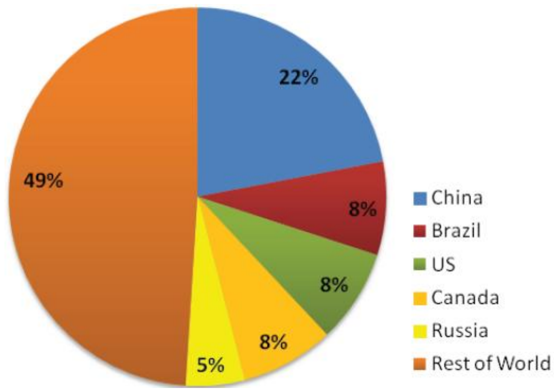

Figure 11: Distribution of existing hydropower capacity globally [24]

The highest production of renewable electricity in Lebanon comes from hydropower. Lebanon is ranked as the 127th country in terms of the total electric production produced by hydro stations [23]. Unlike the desert countries that surround the country, Lebanon is known for its moderate climate and yearly precipitation. Lebanon's high levels of rain throughout the year provide natural resources that are not being exploited fully. The total installed capacity of hydropower plants is 282MW, but the actual usage is 190MW. The production of hydroelectricity has dropped by 33% from 1975 till 2006 [12]. Over the last 20 years, electricity generation from hydropower ranges from 273 to1204GWh with an average of 722GWh [12]. Several reasons account for these drops which are the destructive civil war years and an increase in water consumption both household level and agriculture sector.

Litani power plant is the main hydro plant which is situated at the Litani River in the south of Lebanon. The Litani River is the longest river in Lebanon and is a major water source for southern Lebanon. It is 140 meters extending from the Bekaa Valley and empties into the Mediterranean Sea. The Qaraoun dam is created by the Litani river and has a storing capacity of 220 million m^3 [25]. The production of electricity from the Litani River depends on the annual amount of rainfall which is around 920 million cubic meters and a thus making it good source of hydropower. The electricity production from the Litani plan is not constant over the years due to the variation in rainfall. The maximum production was 1352 MWh in 2003 and the minimum production was 373 MWh in 2008 [23]. The plant was originally constructed in 1959 in order to produce electricity and water irrigation across the south and Bekaa [23]. Ever since the power plant became active, the production increased from 21 million kilowatts/hour in 1962 to 1029 million kilowatts/ hour in 2003, which was a year of abundant precipitations [25]. Other plants are smaller than the Litani hydro plant and contribute in total to 30% of the remaining electricity produced by hydropower.

Table 3: Current Hydroelectric Capacity Installed [24]

Location	No. of Units	Year of Installation	MW installed capacity
Litani	7	1955, 1964, 1967	199
Nahr Ibrahim	8	1961, 1955,1951	32
Kadisha Valley	11	1924, 1957,1932	21
Nahr Al Bared	5	1936	17
Safa Spring	3	1931	13
Total Installed Capacity in MW			282

The policy paper for the electricity sector in Lebanon discusses increase of electricity production from hydraulic plants by improving their maintenance and replacement of old plants. It also proposes the implementation of additional capacity by increasing the number of dams. This improvement in hydraulic power is a project that could take up to 5 years and would increase capacity by 120MW [6].

Lebanon is not fully optimizing the electricity produced by hydro stations. These stations have been installed over 60 years and no new plants have been constructed since. The construction of new hydro plants is would add up to 250 MW [27]. The first step the government should do is improve the efficiencies of the old generators to increase energy efficiency from 75% to 90%. This process would increase electricity production by 150GWh with no additional plants installed [14]. Furthermore, the rehabilitation of the Kadisha Hydro plant by updating all civil works (water intake, channels, and storage basins) would increase its production by 7%. Moreover, the irrigation of lands in the Bekaa region is not optimized. Instead of having this water lost, it should be used efficiently in the Qaraoun hydropower plant. Last, micro-hydro power should be studied in Lebanon. Micro-hydro systems can produce a large amount of energy from a small current or water flow. It does not require high initial costs, it is environmentally safe and it can increase energy production [6].

3.2.2 Wind Energy

The second most worldwide source of renewables is wind power. It is produced by using wind turbines that capture the kinetic energy of the wind and transfer it to electricity. It is a power sector that is booming in the entire world year after year because of its low cost and cleanliness to the environment. The leading countries in wind power are Germany, Spain, the United States (USA) and China. According to figure 2, Europe captures 54% of the worldwide wind capacity followed by North America that captures 21%. Asia (excluding the Middle East) comes next with 19.4%, followed by the remaining countries, all together adding up to 4.7%. This would highlight how the Middle East countries are still lagging in wind energy. Wind power, unlike solar energy, in the Middle East still remains low.

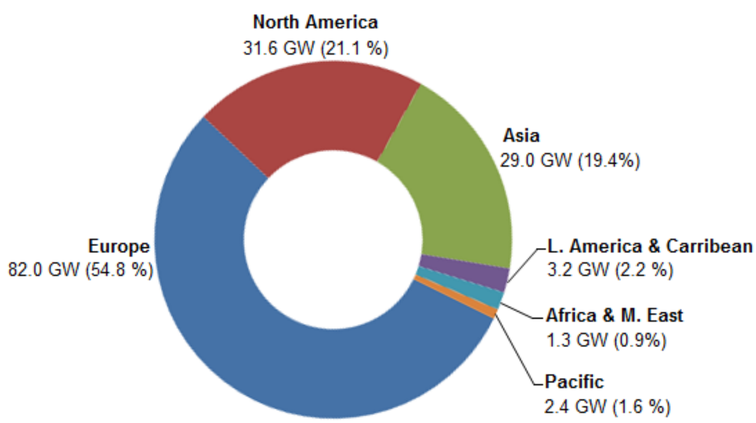

Figure 12: Total Wind Power Capacity **[28]**

The MENA region (Middle East and North Africa) have starting developing their wind energy capacity. In North Africa, Egypt had the largest capacity addition in 2010 of 120MW and currently has a total of 550MW of wind power. In the Middle East, Iran has always been ahead of all other countries in wind power electricity. Due to the limitation of their natural resources, they quickly developed wind power [28]. In comparison to the MENA region, Lebanon is still behind on its wind energy. Investments in wind power can help reach the country's goal which is having 12% of total energy from renewables [29].

There is still no efficient wind production in Lebanon. All researchers state that there is no sufficient and accurate wind information for a trustworthy wind energy study [27]. Some small size wind turbines can be found and are used for several household electricity generation. The Ministry of Energy and Water with the support of the United Nations Development Program (UNDP) published the national wind atlas. The wind atlas considers that there is uncertainty in wind mapping due to absence of monthly data, lack of detail information on each station. In addition, clear policies by the government on wind power are still not made. However, the wind atlas indicates that Lebanon does have the potential for wind energy projects. It estimates wind potential for at least 1500MW [29].

The geological structure of the country, its mountains and its wind energy potential make it a good site in wind power harvesting. Yet Lebanon does not exploit the benefits of this renewable energy. In the paper by El Khoury, a study was made calculating the yearly wind speeds on several key locations and testing for wind power production in these areas. Data on the yearly wind speed in different areas are represented in table 2 below.

Table 4: Yearly average wind speed **[30]**

Station	Airport	Arz	Ryak	Ksara	Khaldeh	Marjaayoun	Qlaiaat	Tripoli	Daher el Baydar
Wind Speed (m/s)	4.5	3.7	3.9	4.3	2.8	4.5	4.4	3.9	4.3

The paper concludes that Zahle and Beirut are both good candidates for wind power generation due to their yearly high wind speeds. However, the wind speed is not enough to be an independent source of electricity. This problem could be overcome by supplementing the energy deficiency during peak hours [30].

Another report by Z. Nakad studies wind farm optimization in many regions in Lebanon, mainly Zahle, which aims to maximize electricity production with the lowest turbine costs. The study proves that Lebanon is a good candidate for wind energy however proper data collection is needed to ensure better results [31].

A new wind project has been launches in Akkar, Northern Lebanon, called “Hawa Akkar”. The location has a remarkable wind speed and atmosphere. The electricity supplied by this wind farm has enough energy for 60,000 households a year, around 60MW. In addition the wind farm will provide electricity in a low price. This project requires government officials to pass on the required laws to be able to start project construction. There also several other projects taking place that would allow people not to depend on polluting fuel source of electricity [32]. Regardless of the small quantity of electricity produced, this project is an important step in helping daily power outages and reducing harmful emissions.

3.2.3 Solar Energy

Solar Energy is an important type of renewable energy and is the most abundant fuel source. It works by converting the sun’s energy into electricity through photovoltaic cells. Photovoltaic cells are also called solar cells or PV. The advancements in solar power have decreased its costs yet its efficiency in energy conversion still lies between 15-20%. Solar energy produces no emissions and helps keep the environment clean. This type of energy can be found in areas where the sun is abundant. The efficiency of solar panels depends on the quality of photovoltaic cells used. There are 3 types of solar panels: amorphous, monocrystalline, and polycrystalline. Higher efficiency and quality of the panels would mean a higher price. Monocrystalline has the highest efficiency; it converts 18% of sunlight [33]. Another factor that determines the efficiency of the solar panels is the weather. Throughout the year, energy absorbed from the sun is high during the summer and less during the winter when the amount of sunlight is limited. Germany is the leader in solar power followed by Italy, Belgium and Czech Republic.

Table 5: Total Solar By Country **[34]**

Country	Total Solar Power Capacity Per Million People	Total Solar Power Capacity (MW)
Germany	398.63	32411
Italy	267.07	16361
Belgium	253.87	2650
Czech Rep.	203.59	2072
Greece	142.65	1536
Bulgaria	129.02	908
Spain	109.81	5166
Australia	109.56	2412
Solvenia	99.17	198
Denmark	71.07	523

Lebanon is considered to be rich in solar radiation which is 300 days/year and produces a daily radiation of 4.8 kW h/m^2 [27]. The graph below shows the daily solar insulation throughout the year. As stated before, winter shows the least amount of radiation.

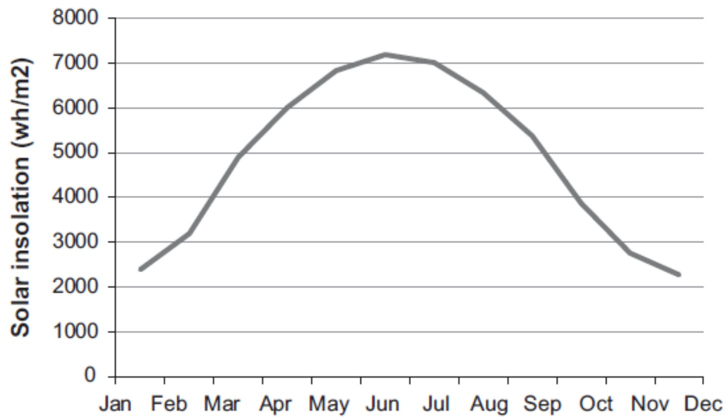

Figure 13: Average daily solar insolation in Beirut throughout the year **[27]**

Solar energy in Lebanon has increased over the years. The government's national efficiency plan aims at installing 200MW of solar farms by 2020. Solar Photovoltaic transfers the solar radiation into electricity using the PV cells. The three types of solar photovoltaic systems that can be implemented in Lebanon are:

- Off-Grid System: they are able to operate alone without any electricity and can replace diesel generators
- On-Grid System: Able to operate only when the National Grid (EDL) is on.
- Grid-Interactive System: It the most developed and the most expensive. Grid Interactive system combines Off-Grid and On-Grid systems [35].

The largest PV installation was organized in 2008 at the Monastery of Saints Sarkis and Backos with a total power capacity of 15 kW. Despite the drop in PV prices from $6 to $3, this new technology is still lagging behind. It is still not implemented fully due its high initial costs, low efficiency and lack of development in PV market in Lebanon [27]. The current installed capacity is 85 kW and is expected to increase in the future. It could be a solution to rural areas that experience high solar radiation throughout the day and large hours of electricity blackout.

Solar Thermal uses the sun’s energy to heat water. Solar thermal collectors are usually placed on rooftops of buildings to absorb solar energy. Solar water heaters in Lebanon represent only 3% of total installed water heaters; the rest are operated using fossil fuels. This percentage is relatively low in a country having the ideal climate for using thermal energy. Switching from electric water heaters to solar water heaters can help relieve the burden on the Lebanese Electricity Sector. The LCEC states that the return of investment from solar heaters is in 2-3 years while its lifetime exceeds 20 years [27]. Recently, financial institutions became more aware of this renewable and starting giving water heater loans and funding to develop and motivate the solar market. In 2005 solar water heaters were 250,000 m^2 and they increased to 700,000 m^2 in 2010 [10]. Solar thermal uses are mainly found in households, 61%, followed by residential buildings 24% [10].

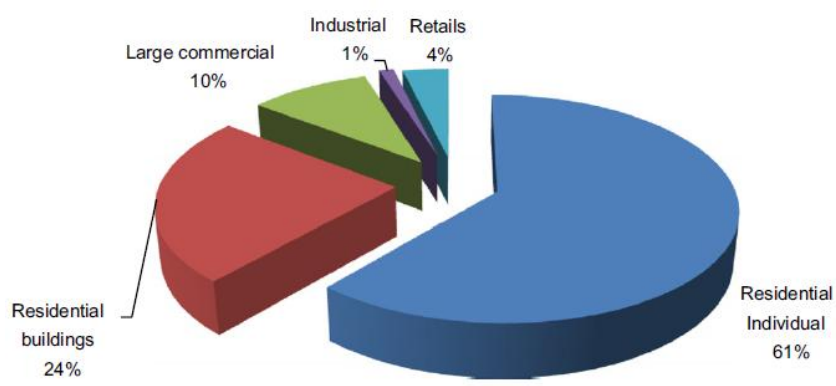

Figure 14: Breakdown of the Lebanese solar thermal applications **[10]**

The Italian government subsidized 1 million euros to train energy experts to properly install water solar heaters, raise awareness on the importance of renewables from solar and installed 66 solar water heaters in buildings [36]. In 2003, the Chinese government donated 500 solar water heating systems in Marjeyoun, South Lebanon. Its annual energy production was 1,018 MWh. In addition annual savings for consumers was $71,000 and annual energy saving for the EDL was $362,000 [37]. However, as a result of the war in June 2006, 200 of the solar heaters were destroyed.

Table 6: Installed Solar Water Heaters and their status after 2006 War **[38]**

Location	Installed	Destroyed	Remaining
Bint Jbeil	156	114	42
Jezzine	40	1	39
Hasbaya	89	0	89
Sour	75	30	45
Marjeyoun	110	45	65
Nabatiye	18	0	18
Total	488	190	298

The success of the initial project encouraged the Chinese to donate anther 600 solar panels, 200 of which are used to replace the destroyed ones and 400 new panels. Their annual energy production is 1221 MWh [37].

Another solar thermal project is being installed on the Beirut River and it is called “Beirut River Solar Snake (BRSS)” project. It is the first solar farm constructed in Lebanon and is estimated to cost around 3.5 million USD. In 2015, it will place photovoltaic cells 325 meters across the Beirut River. The project will use 3,600 polycrystalline panels that will generate 1,655 Mega Watt Hour per year [39].

3.2.4 Biomass Energy

Biomass is another type of renewable energy that uses biomass to produce electricity. Biomass is organic material found in living matter, plants or animals. It can be burned and transformed into electrical energy. Usually, wood biomass has been used for fuel. Lebanon does not have high areas of forests, they cover only 13% of Lebanon's land, therefore fuel using wood is not recommended. However, the country can still produce energy from waste of biomass. The higher the amount of organic wastes, the higher the energy that can be produced. Lebanon's organic wastes constitute 63% of total sold wastes, which is a high amount [10]. Residential wastes are estimated to be 4300 tons/day and industrial wastes are estimated at 600 tons/day [10]. However due to the lack of proper controlled, this source of energy can produce high emissions and therefore is still not implemented. In addition to wastes, biofuel can be produced using biogas and biodiesel. Several studies in Bourj Hammoud, Quarantinah and Naameh indicate high biogas storage in these areas which could generate 850GWm of electricity. Lebanon does not benefit from this renewable resource that has the potential of producing 30% of the country's electricity needs [27].

3.2.5 Geothermal Energy

Geothermal energy is thermal energy from the Earth. Geothermal energy has a low cost and is environmental friendly. The geothermal energy of the Earth originates from the shallow ground to hot waters found miles under the surface. Sources with 200-300 degrees Celsius can be used for electricity production. Electricity from geothermal energy has been used in only 26 countries so far. Previous research has shown that hot geothermal waters have been found in Lebanon, specifically Sammaqiye, Akkar and Tyre [27]. This thermal energy can be used to for water heating. However, the geothermal fluids do not reach high temperatures enough for steam turbines and to generate electricity.

CHAPTER 4

COST BENEFIT ANALYSIS

4.1 Introduction to RETScreen

Lebanon has begun investing in renewable, clean and sustainable energy to meet the increase electricity demand. Photovoltaic solar energy uses solar panels to supply solar energy. It is an important source of energy in countries, such as Lebanon, that exhibit high hours of sunshine throughout the day. This section will examine the costs and benefits of implementing a 5MW photovoltaic power plant in Beirut. In order to study the financial feasibility and energy production of this 5MW project, a cost benefit analysis will be made using the RETScreen software.

RETScreen software is a clean energy program developed by the Canadian government. It can be used to measure the efficiency of the different types of renewable projects. The software can be used to calculate the energy production, savings, costs and emission reduction of these clean energy projects. RETScreen allows investors and decision makers to assess the financial viability of the project and determines whether the project is feasible or not. The RETScreen analysis is divided into 5 parts: energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis [40].

In this chapter, the RETScreen software will estimate the performance of hypothetical solar PV installations in Lebanon. Previous reports have used the RETscreen software on Arab countries to study the feasibility of PV-grid connected power plant. A report by Rehman, studies the solar radiation in Saudi Arabia and discusses the potentials of installing a 5MW photovoltaic grid to produce electricity [41]. Another study in Egypt by El-Shimy, investigates the feasibility of a 10MW photovoltaic grid power plant [42]. Hrayshat tests for photovoltaic power generation in Jordan using a 5MW plant [12]. A fourth study using RETScreen software is testing for energy production by installing a 10 MW photovoltaic power plant in Abu Dhabi [11].

Table 7: Results from four studies of PV power potential in the Middle East

Country	Saudi Arabia	Egypt	Jordan	Abu Dhabi
Capacity	5 MW	10MW	5MW	10MW
Location	Bishah	Wahat Kharga	Talifa	close to AD airport
Daily sunshine duration	9.2 h	12.1 h	9.6 h	11.2 h
Module type	BP 90 W	Sanyo 205 W	BP 90 W	BP 90 W
Internal rate of return	16.70%	24.90%	20.10%	0.50%
Net Present Value	74 million (US)	144.3 million (US)	40.5 million (US)	50.8 million (US)
Cost of Energy	20 cents/kWh	20 cents/kWh	123 cents/kWh	16.18 cents/kWh
GHG Reduction	10,007 tons/year	14,538 tons/year	9317 tons/year	10,000 tons/year
Annual generation	12.4 GWh	29.5 GWh	11.9 GWh	24 GWh

In our project, the specifications of the PV plants are taken similar to the hypothetical solar PV plants in the projects listed above (Abu Dhabi, Saudi Arabia, Jordan and Egypt) since they are neighboring countries with similar solar radiation and environments. The cost benefit analysis will be taking Beirut, Lebanon as the location for installation. The RETScreen CBA will be divided into three main parts: PV specifications, financial feasibility of the hypothetical power plant, and the estimation of the amount of air pollutants (GHC emissions) reduced.

4.2 PV Specifications

There are many different PV-modules each with different specifications. The PV-module selected in this project will have characteristics most suitable for Lebanon's environment and budget. Using RETScreen, we will consider this project's type as "power" and the technology type used is photovoltaic with central grid. The project will be located in a country with high average hours of sunshine per day; therefore the project type used is higher heating value. There are four axis options that can be selected from RETScreen: ''Fixed'', ''One-axis'', ''Two-axis'', and ''Azimuth''. For our project we will select a "Fixed" solar tracking mode.

Table 8: Start-up Project Information

Project Type	Power
Technology	Photovoltaic
Grid type	Central Grid
Analysis Type	Method 2
Heating Value Reference	Higher heating value (HHV)

There are different forms of solar cells. The monocrystalline modules have the highest conversion efficiencies but are the most costly. The PV-module will have a capacity of 5MW and will be using mono-silicon BP 590F model manufactured by BP solar. The number of module units used is 55,556 and the capacity of each module is 90W (a total of 5MW). The total area of the PV plant is 34,990m^2. The miscellaneous losses account for the losses in the PV not accounted in the model, such as mismatching in wiring or dirt on modules [12].

Table 9: PV module specifications **[12]**

Type	Mono-silicon
Power Capacity	5,000 kW
Manufacturer	BP Solar
Model	mono-Si - BP 590F
Efficiency	14.30%
Nominal Operating Cell Temperature	45° C
Solar Collector area	34,990m^2
Miscellaneous losses	1%

The percentage efficiency of the inverter is the percentage of electricity the inverter successfully converts from DC to AC. Since the PV-module used is a modern inverter, its efficiency should range between 95-97%. For this model, we will assume an efficiency of 95%. The inverter capacity, which is based on the converter's efficiency, is the total output in kW and is calculated by RETScreen as 4,750MW. The miscellaneous losses are taken as 0% for the inverter. The capacity factor found by RETScreen is 21.5% and the total electricity exported to the grid 9,433.5 MWh.

Table 10: Inverter Characteristics

Efficiency	95%
Capacity	4750 kW
Miscellaneous Losses	0%
Capacity Factor	21.40%
Electricity Exported to grid	9,381.5 MWh

4.5 RETScreen Results

4.5.1 Financial Analysis

This section will be estimating the costs and revenues based on similar PV projects in neighboring countries such as Jordan and Syria. Our financial analysis section will determine the viability of the project by looking at the yearly cash flows and studying the financial indicators such as net present value, IRR and equity payback. RETScreen calculates the cash flow by subtracting the cash outflow from the cash inflow. Cash inflow include: Fuel saving, O&M saving, periodic saving and GHG reduction. Cash outflow include: Equity investment, annual debt payments, O&M payments and periodic costs.

We will begin by entering the initial costs, annual costs and periodic costs of the project found in the "Cost Analysis" worksheet. RETScreen will display each cost in USD (first column) and its percentage from the total cost (second column). The initial costs include the feasibility study of the project, cost of development and engineering, PV equipment and balance of system & miscellaneous. The feasibility study is estimated at $80,000 and the development cost is $70,000. Engineering costs includes civil, electrical and mechanical design and is $62,500. The module market price is averaged at 5.5USD/Watt and since the total power production is 5,000 kW, the total power system's equipment costs $27,750,000. These components, energy equipment, account for 70% of total costs. Furthermore, the balance of system costs include the inverter, transmission, spare parts, transportation, building construction, contingencies and interest during construction, and they represent 27.8% of total initial costs. After the initial costs, we have the annual costs which include the operation and maintenance costs (O&M). They are estimated at to be $334,500 annually. Finally, our last component in our "Cost Analysis" worksheet is the periodic costs. The periodic costs include the inverter replacement costs. It is calculated as 1 million USD every 5 years. Therefore, the total costs in this section are USD 39,862,630 [41].

Table 11: Initial Costs **[41]**

Initial Cost Elements	Unit USD	Relative Cost (%)
Feasibility Study	$80,000	0.2
Development	$70,000	0.2
Engineering	$62,500	0.2
Photovoltaic Equipment	$27,750,000	71.6
Miscellaneous	$806,130	2
Balance of System	$11,094,000	27.8

Table 12: Annual and Periodic Costs **[41]**

Annual Costs	$334,500 annually
Inverter Replacement Costs	$1,000,000 every 5 Years

We will then move to the "Financial Analysis" worksheet which includes the financial parameters, annual income, yearly cash flows and financial viability indicators. To begin, the financial parameters of the project include the fuel cost escalation rate, inflation rate, discount rate, project life and debt financing. All these factors are needed to adjust the annual and periodic costs entered in the cost analysis worksheet. The first section of the financial parameters is the general parameters. The photovoltaic project is considered to have a lifetime of 25 years. The annual inflation rate is at 2.5% and the discount rate is 5.0%. The annual assumed escalation in electricity prices during the project's life time is 4.0% [12].

Table 13: General Parameters **[12]**

Fuel cost escalation rate	4.0%
Inflation rate	2.5%
Discount rate	5.0%
Project life	25 years

The second section of the financial parameters is the finance section. It indicates how much of our project is paid with debt and how much is paid with equity. The debt ratio is the percentage of the PV project financed with debt. In our case 60% is paid by debt (23,917,578) and 40% by equity. Annual debt payments of 3,645,223 USD are paid over the projects lifetime which is 15years. The debt interest rate is taken to be 8.5%.

Table 14: General Financial Parameters

Incentives and grants	$0
Debt ratio	60%
Debt	$23,917,578
Equity	$15,945,052
Debt interest rate	$8.5
Debt term	10 years
Debt payments	$3,645,223/year

After discussing the different types of costs in this project, we will move to the income generated. The annual income depends on two factors: the electricity export income and the GHG reduction income. In the electricity export income section, it is important to define the electricity export rate. In our case, the energy export rate is 480 USD/MWh [42]. RETScreen calculates the annual income by multiplying the total energy produced from the solar PV (9,381MWh) by the electricity exported rate (480 USD/MWh) which will generate a total income of $4,503,044.

Table 15: Electricity Export Income **[42]**

Electricity exported to grid	9,381 MWh
Electricity export rate	$480.00/MWh
Electricity export income	$4,503,044

The other part of the income generated is the GHG reduction income. This section calculates the total GHG reduction per year in tons of carbon dioxide (tCO_2). It then assigns a monetary value to GHG emission reduction in terms of USD/tCO_2. We will then be able to calculate the total amount of dollars saved from using the PV plant.

Net GHG reduction (tCO_2) x GHG reduction credit rate ($/$CO_2$) = GHG reduction income ($)

Table 16: GHG Reduction Income

Net GHG reduction	3,707 tCO_2/yr
Net GHG reduction - 25 yrs	92,685 tCO_2
GHG reduction credit rate	$26/$tCO_2$
GHG reduction income	$96,392
GHG reduction credit duration	25 yr
Net GHG reduction - 25 yrs	92,685 tCO_2
GHG reduction credit escalation rate	0.05 %

After finding the costs and income of the project, RETScreen calculates the yearly cash flows and represents them both in a table (numerically) and in a graph. Looking at the cumulative cash flow graph in USD, after 13 years the project starts having positive returns. This positive cash flow increases and therefore seems attractive.

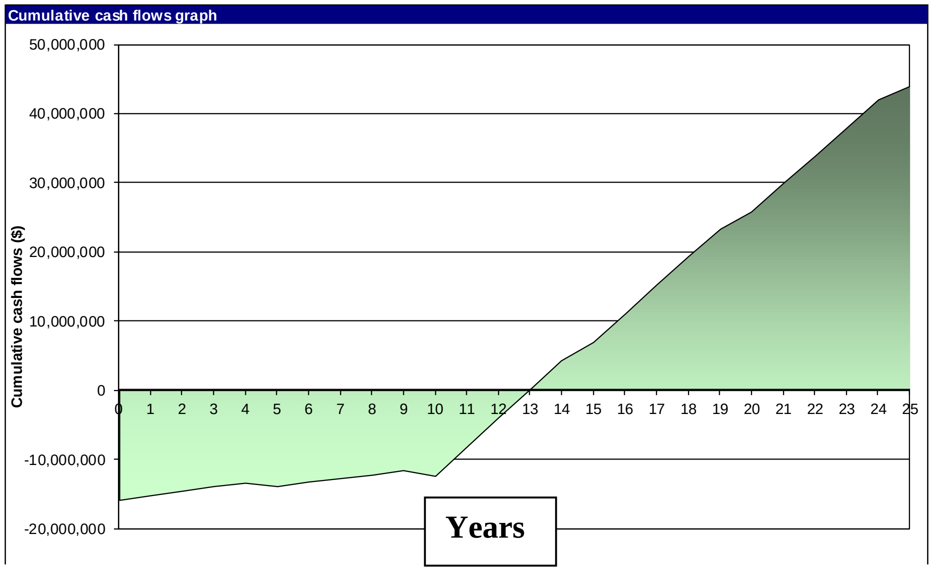

Figure 15: Yearly Cash Flows

In the last section of the “Financial Analysis” worksheet, we will analyze the financial viability of the project by looking at the financial indicators. RETScreen software can calculate many financial parameters which are: After-tax IRR - equity, After-tax IRR - assets, equity payback, net present value and benefit cost ratio [42].

4.5.1.1 IRR

The IRR is the rate at which the net present value of all cash flows is equal to 0, and it is also called the discounted cash flow rate of return [43]. IRR represents the true interest yield provided by the project equity over its life. It is used in projects to measure the desirability of the investment; the higher the IRR the more attractive the project would be. To study the project’s profitability, the IRR is compared with the required rate of return [42]. If the IRR is higher than the required rate, the PV project is considered feasible and profitable. If IRR is lower than required rate, the project will incur losses and hence will be rejected. The IRR-equity is also known as return on investment, while IRR-assets are also known as the return on assets. On average, an IRR of 8.8 % can be found when investing in solar PV in Lebanon.

4.5.1.2 Equity Payback

The RETScreen calculates the equity payback which is the number of years it will take to recoup its own initial investment (equity) out of the project cash flows generated [40]. However, the equity payback can be misleading. Therefore, the benefit-cost ratio, IRR and NVP are better indicators to use due to two factors. First the equity payback ignored all the fuel savings following the payback period. Second, it only accounts for the investments paid by equity and does not consider the investments paid by debt [40]. The equity payback in our scenario is 9.3 years which seems attractive, yet it is not sufficient alone to test for profitability.

4.5.1.3 Benefit-Cost Ratio

The model also calculates the cost-benefit ratio which is the ratio of benefits to costs of the PV plant. The benefits are calculated by the total income generated annually minus the annual costs. The costs are defined as the initial equity of the project. If the ratio is greater than 1, benefits are greater than the costs, the project is a good investment. The PV project has a B-C ratio of 1.7 which means the benefits are greater than costs.

4.5.1.4 Net Present Value

Another financial viability calculated by RETScreen is the Net Present Value (NPV). The present value of all cash inflows is compared with the present value of all cash outflows of the solar project [12]. The NPV is the net cash inflow from the project minus the initial investment. The project is accepted only when the NPV is greater than zero. If NPV is negative, the project is not feasible. The NPV is 10,998,655 USD which seems very attractive.

Table 17: Summary of financial indicators for the PV power plant

Pre-tax IRR - equity	8.8 %
Pre-tax IRR - assets	2.4 %
After-tax IRR - equity	8.8 %
After-tax IRR - assets	2.4 %
Simple payback	9.3 year
Equity payback	13 year
Net Present Value (NPV)	$10,998,655
Annual life cycle savings	$780,382/year
Benefit-Cost (B-C) ratio	1.69
Debt service coverage	0.85
Energy production cost	$396.82 /MWh
GHG reduction cost	-$210/t$CO_2$

4.5.1.5 Sensitivity and Risk Analysis

The sensitivity analysis is used if we are not sure of the exact amount of our initial cost, debt interest rate or debt ratio and they might vary from -20% to +20%. This section allows us to estimate for these uncertainties in our input variables and check whether the project is still profitable [40].

Sensitivity Analysis

The sensitivity analysis shows how the viability of the project is affected by changed in two of the parameters together. RETScreen calculates the sensitivity of the internal rate of return, Net Present Value (NPV) and equity payback to simultaneous changes in the initial costs, the debt interest rate & debt term. The changes are -20%, -10%, 0, +10% and +20% [40].

Table 18: Sensitivity Analysis

		Initial costs USD				
Electricity export rate		31,890,104	35,876,367	39,862,630	43,848,893	47,835,156
$/MWh		-20%	-10%	0%	10%	20%
384	-20%	7,124,025	2,714,775	-1,694,475	-6,103,725	-10,512,975
432	-10%	13,470,590	9,061,340	4,652,090	242,840	-4,166,410
480	0%	19,817,155	15,407,905	**10,998,655**	6,589,405	2,180,155
528	10%	26,163,720	21,754,470	17,345,220	12,935,970	8,526,720
576	20%	32,510,285	28,101,035	23,691,785	19,282,535	14,873,285

		Debt interest rate %				
Electricity export rate		6.80%	7.65%	8.50%	9.35%	10.20%
$/MWh		-20%	-10%	0%	10%	20%
384	-20%	400,525	-637,637	-1,694,475	-2,769,550	-3,862,414
432	-10%	6,747,090	5,708,928	4,652,090	3,577,015	2,484,151
480	0%	13,093,655	12,055,493	**10,998,655**	9,923,580	8,830,716
528	10%	19,440,220	18,402,058	17,345,220	16,270,145	15,177,280
576	20%	25,786,785	24,748,623	23,691,785	22,616,710	21,523,845

		Debt ratio				
Electricity export rate		48%	54%	60%	66%	72%
$/MWh		-20%	-10%	0%	10%	20%
384	-20%	-848,501	-1,271,488	-1,694,475	-2,117,462	-2,540,449
432	-10%	5,498,064	5,075,077	4,652,090	4,229,103	3,806,116
480	0%	11,844,629	11,421,642	**10,998,655**	10,575,668	10,152,681
528	10%	18,191,194	17,768,207	17,345,220	16,922,233	16,499,246
576	20%	24,537,759	24,114,772	23,691,785	23,268,798	22,845,811

In this case we are studying the variations in the NPV when the initial costs, debt interest rate, debt ratio and export electricity rate are changed between -20% and +20%. We can analyze the change in our financial variables by looking at the table. When we do not have any changes (0%) the NPV is our original value that we had calculated, 10,998,655 USD. When we have initial costs higher by 20% and our electricity export rate is lower by 20%, then our NPV will give a negative value of 10,512,975. In addition, when our debt interest rate might be higher by 20% and our electricity export rate is lower by 20%, then our NPV will give a negative value of -3,862,414. Also if our export rate is lower by -20%, it is $384 instead of $480, for all values of debt ration our NPV will give us a negative result. Therefore, if we are uncertain about our initial costs and they have a tendency to be 20% higher, or we might expect that the electricity export rate might be lower by 20%, then the solar photovoltaic project might not be considered as viable.

Risk Analysis

In this analysis, the user is uncertain of the variation of many parameters. The user can estimate the percentage of how the parameters might change from their original values [40]. The risk analysis runs several Montecarlo simulations. It reruns its analysis 500 times, letting each key input simultaneously vary within the limits specified by the user. For instance, if our IRR is 7% we can allow it to vary between - 20% and +20%. The parameters that can change include the initial costs, electricity export rate, debt ratio, debt interest rate and debt term. The parameters that are affected include the net present value, the equity payback, after-tax IRR – equity, and after-tax IRR – assets.

Table 19: Risk Analysis

Parameter	Value	Range (+/-)	Minimum	Maximum
Initial costs	$39,862,630	20%	$31,890,104	$47,835,156
O&M	$334,500	5%	$317,775	$351,225
Electricity export rate	$480/MWh	10%	$432/MWh	$528/MWh
GHG reduction credit rate	$26/t$CO_2$	5%	$24.7/t$CO_2$	$27.3/t$CO_2$
Net GHG reduction - credit duration	92,685 tCO_2	5%	88,050 tCO_2	97,319 tCO_2
Debt ratio	60%	10%	54%	66%
Debt interest rate	8.50%	2%	8.33%	8.67%
Debt term	10 years	1%	9.9 years	10.1 years

In this table, the parameters that are varying are shown to the right. Each parameter is assigned a % range in which it can vary. When the percentage range is inserted, RETScreen will calculate the maximum and minimum values the parameter will take. After calculating these parameters, we performed an analysis on the equity payback.

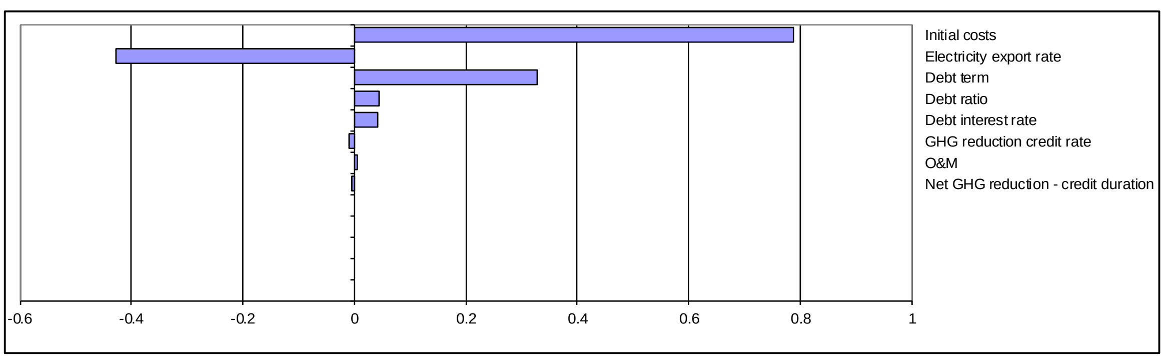

Figure 16: Impact of Parameters on Equity Payback

As shown in the table, the variations in the initial costs have the highest impact on equity, followed by electricity export rate and then debt term. The rest of the parameters do not have much of an effect on equity payback.

4.4 Emissions Analysis

4.4.1 GHG Emission Analysis

As the population increased, the usage of fossil fuels has increased accordingly. Therefore, the emission of harmful gases has risen in our atmosphere. These greenhouse gases absorb the sun's radiation and traps the heat in the atmosphere. This in turn causes the Earth's temperature to rise and leads to global warming. Contrary to non-renewable energy currently used in Lebanon, PV plants are known for their 0 emissions. Renewable energy can be more competitive and attractive if the negative externalities associated with fossil fuels plants are taken into account [44]. For this reason, RETScreen assigns monetary value to the greenhouse gases, unlike other clean energy software. It estimates the amount of GHG emissions that can be avoided if we switch to renewable energy. Then RETScreen compares the GHG emissions, when a portion of the energy is supplied by PV, to the GHG emissions when all of the energy is supplied by non-renewables. The data required are the carbon dioxide (CO_2), methane (CH_4) and nitrogen oxide (NO_2) emissions which contribute to global warming[1]. The amount of emissions reduced per year is presented in tones of CO_2 per year, regardless of the type of emission. For this reason, methane and nitrogen oxide emissions are converted to the equivalent carbon dioxide emissions in terms of their global warming potential [45]. The GHG emissions are important in our cost-benefit projects to estimate the real value of the project. If we do not account for these GHG emissions, our project might appear as unprofitable. Figure 3, shows the cost of air pollutants and climate change (USD) in Germany, due to CO_2 emissions [46].

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[1] The composition of emission has been taken from the Umm Al Nahr power plant in Abu Dhabi.

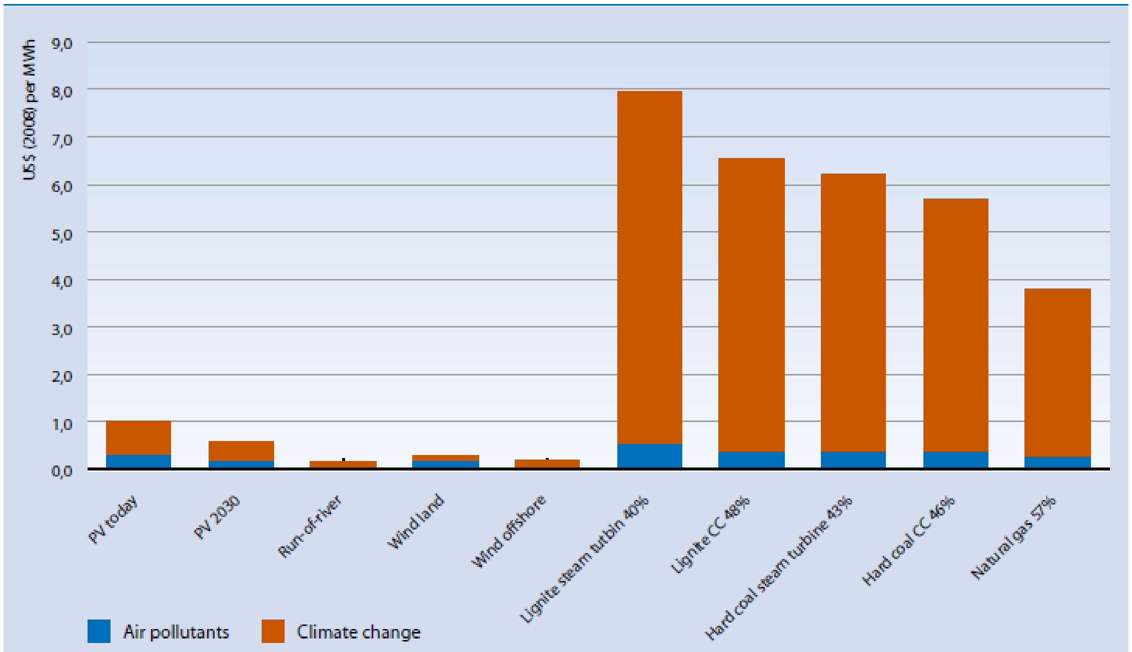

Figure 17: External costs of electricity production in Germany **[46]**

The calculation of the GHG emissions was performed on our 5MW photovoltaic plant. RETScreen measures the annual greenhouse gas emission reduction for the proposed PV power plant compared to the fuel power plants base case. The difference in the GHG emissions per unit of energy delivered is multiplied by the end-use annual energy delivered. Below is the formula representing GHG emission calculation:

[(Base case GHG emissions $_{ton/MWh}$) – (Proposed case GHG emissions $_{tons/MWh}$)] x end use annual energy delivered $_{MWh}$

Looking at table 17, the PV project will reduce around 3,700 tons of GHG emissions annually. The model estimated GHG emission factor to be 0.493 tCO_2/MWh. RETScreen accounts for transmission and distribution losses (T&D) as well, which is taken as 15% since Lebanon is a developing country [42].

Table 20: Base Case Electricity System **[11]**

Fuel Type	% of fuel consumed	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel conversion efficiency (%)	GHG emission factor (tCO_2/MWh)
Natural gas	99.93%	56.1	0.003	0.001	45%	0.439
Crude oil	0.057%	77.4	0.003	0.002	30%	0.897
Gas Oil	0.001%	63.1	0.001	0.001	45%	0
Fuel Oil	0.012%	74.1	0.002	0.002	30%	0

Table 21: Base Case System GHG Summary **[11]**

Fuel Type	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel consumption MWh	GHG emission factor (tCO_2/MWh)	GHG emission (tCO_2)
Electricity	121.086	0.0089	0.0022	9,381	0.439	4,119.3
Total	121.086	0.0089	0.0022	9,381	0.439	4,119.3

Table 22: Proposed Case System GHG Summary **[11]**

Fuel Type	CO_2 emission factor (kg/GJ)	CH_4 emission factor (kg/GJ)	N_2O emission factor (kg/GJ)	Fuel consumption MWh	GHG emission factor (tCO_2/MWh)	GHG emission (tCO_2)
Solar	0	0	0	9,381	0	0
Total	0	0	0	9,381	0	0

Table 23: GHG Emission Reduction Summary [11]

Base Case GHG Emissions (tCO_2)	Proposed Case GHG Emissions (tCO_2)	Gross Annual Emission Reduction (tCO_2)	GHG credit transaction fee (%)	Net Annual GHG emission reduction tCO_2
4,119.3	411.9	3,707.4	0.0	3,707.4

According to the above tables, a significant amount of GHG emissions will be reduced annually when the PV plant is installed. Therefore including the emission analysis in our PV project highlighted further that our project is feasible and profitable.

4.4.2 Air Pollutant Emission Analysis

Another air pollutant cost benefit analysis will be made to count other air pollutants (tons/year) such as NO_x, SO_2 and PM_{10}. The difference between the two emission analyses is the following: these air pollutants deteriorate the air quality while the previous GHG emissions contribute to global warming. The rate of air pollutant emissions is calculated by dividing the total amount of air pollutants by the total electricity produced in the Abu Dhabi power plant (Umm Al Nahr plant in 2003) [11].

Many studies have quantified the social costs of air pollution. They assign monetary values for each pollutant to quantify the benefits of avoided air pollutant emissions [11]. The mean of the air pollutants: NO_x, SO_2 and PM_{10} are as the following $345/ton, 314/ton and $1491/ton.

Table 24: Additional GHG emissions **[11]**

Pollutant	Annual emissions (tons/year)	Emissions rate (g/kWh)
NOx	86,483.40	15.26
SO2	34.16	0.01

CHAPTER 5

CONCLUSION

5.1 Summary of Research Findings

In the past 20 years, the Lebanese government has failed to provide a secure power supply to its people. The electricity company, Electricité du Liban (EDL), suffers from many problems including shortage in energy production, inefficient energy transmission, corruption and lack of government union. Lebanon's energy sector mainly depends on oil imports despite the evidence of existence of oil, natural gas and abundant natural resources within the country. Electricity supply has been a major issue in Lebanon yet no main reform plan has been provided since 1990. The Lebanese government pays 2 billion USD per year to cover for electricity losses which leads to the debt. Lebanon has paid 30 billion USD to the electricity company Electricité du Liban (EDL) in the past 20 years yet still suffers from power shortages. Power supply has been causing financial, social and environmental issues.

It is important for the Lebanese government to find alternative energy resources to meet the country's increasing demand. The renewable energy market in Lebanon can help solve many of the problems facing the electricity sector. A comprehensive study of renewable energy projects in Lebanon is provided in this paper. The study shows that Lebanon's geographical characteristics are ideal for solar and wind power. The country expects that by 2020, 12% of the total electricity will be provided by renewables. The renewable energy market may not seem competitive at first. However, with the decrease of non-renewable resources in the future, the fuel prices are expected to increase due to their low availability. In addition, when taking into account the environmental damages caused by non-renewables, green energy becomes more attractive. Greenhouse gases from fossil fuels are adding pressure to economies to switch to green energy and provide a better environment for its citizens.

Furthermore, a detailed cost benefit analysis has been made to test for the financial viability of a 5MW solar photovoltaic plant in Beirut. The first step was the selection of the PV module which is taken similar to Lebanon's neighboring countries since they share similar geographical characteristics. The second step was gathering all the required financial data for the project, such as fuel costs and inflation rates. The third step was the gathering the quantity and type of greenhouse gas emissions generated from the electricity sector. All these inputs are then entered into the RETScreen software to study the energy production, saving, costs, emission reduction and financial viability of the project [47]. The results show that the cost of electricity production from the photovoltaic grid is $480/MWh compared to $0.094/kWh from the non-renewables. Therefore, project shows that either a feed-in tarrif or accounting for the social benefits is needed to make the project profitable. The construction of the PV plant would save around 4000 tons of CO_2 per year. Therefore the greenhouse gases reduction is valued at $100,000 per year. All the results of the financial analysis support the 5MW solar plant in Beirut. This was concluded after viewing the internal rate of return (IRR), equity payback, net present value and other financial projects. This plant can be a step forward in solving the shortage in electricity supply.

5.2 Research Significance

The significance and contributions of this research study are as follows:

- This study shows that Lebanon has a high potential in producing electricity from renewables. Investing in renewable energy is necessary and can help meet the country's growing energy demand. In addition, it can reduce energy pollution and improve energy efficiency.
- The study shows the problems in the electricity's generation, transmission and distribution. It also provides different recommendations for these inefficiencies which will increase energy production by 25%.
- This research highlighted that that solar, wind and hydro energy can be further optimized by improving their locations and construction. Renewable energy currently represents only 4% of the total energy production in Lebanon.
- This study uses RETScreen software, which has been rarely used in the Arab region, and can be a useful tool to evaluate the green energy production accurately. Not only does it account for financial parameters but it also gives monetary value for pollutants and greenhouse gas emissions. The power plants in Lebanon produce huge amounts of CO_2 that also have an economical value which should be accounted for. This can help investors asses the true financial viability of the project.
- In this paper, studying a photovoltaic plant in Beirut area using the RETScreen software, can help serve as a guide to model different renewable projects such as hydro and wind in different Lebanese regions using this software.

5.3 Research Limitations and Policy Recommendations

Some limitations of the current study need to be further examined and addressed in future research works. They include the following:

- Lack of reliable wind, solar and hydro power can cause inaccurate results and uncertainty in our conclusions. Poor monthly data is provided and no detailed information on these renewable energies is found. The creation of a national energy data base, such has national wind atlas and solar atlas, is needed to improve the studies and investments in green power.
- Not accounting for air pollutants and GHG emissions causes renewable energy to be of a high cost compared to nonrenewable energy leading to less investment in the green sector. Moreover, the society is unaware of the huge environmental impact of the current fossil fuel plants
- The lack of a proper and complete energy institution has hindered the expansion of renewable energy in Lebanon.
- Controlling electricity theft is necessary and will help decrease the state's debt.
- The government has a major role in creating investment opportunities in renewable energy, yet the Lebanese government is still not encouraging this sector. The state can first implement a grid connection to distribute future renewable power. Second, it can transfer government subsidies from thermal energy to renewable energy.
- There is no tariff system for electricity produced by renewables. Therefore, further research should be examined for installing PV plants with both a feed-in tariff and measurement of the social costs.

The high initial cost of renewable energy remains the main barrier for investing in this sector. However, with the rise in energy demand in Lebanon electricity from renewable energy could help supply part of this growing demand. Both the financial and social costs should be taken into account when studying the viability of a renewable energy project. The government plays a major role in in promoting investment in green energy technology. The paper supports a proposed 5MW plant in Beirut and ensures a good profitability rate. However, a proper solution for the limitations listed above is needed to ensure an accurate cost benefit analysis using the RETScreen software. Additional studies and efforts should be made to establish profitable green energy which will help reduce the country's debt, meet the growing energy demand and decrease environmental pollution.

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