DEPARTMENT OF MECHANICAL & AEROSPACE ENGINEERING

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Energy Strategy to Supply Electric Demands in Politically Unstable Developing Countries (Lebanon Case Study)

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ABSTRACT

The electric power system is a really important pillar in the structure of a country as it provides stability development and wellbeing. New systems are emerging each day to enhance this sector and make it more advanced, less polluting and stable. The electric power system has a big influence on the rate of growth of a country alongside other infrastructure components. Electricity affects people's lives directly and indirectly. Directly through the practical use of the electricity during the daily life and indirectly through the influence on the quality of environment through pollution and the social effect it might have whether it's positive or negative. Modelling a perfect electric power system can be a challenge when trying to have the best system on the practical level and at the same time have positive environmental and social impact. Renewable energy has emerged to the market and has been enhancing the quality of non-polluting and at the same time practical energy. A lot of developing countries today have not took the step forward with renewable energy yet and this kind of move if done properly according to a good plan can help enhance the quality of life on the economic, environmental and social aspect.

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ACRONYMS

CO_2 – Carbon Dioxide

EUR - Euro

GDP – Gross Domestic Product

GNI – Gross National Income

GNP – Gross National Product

GW – Gigawatt

GWh – Gigawatt-hour

HIPC - Heavily Indebted Poor Countries

INDC - Intended Nationally Determined Contributions

IPP - Independent Power Producer

kW – Kilowatt

LCEC - Lebanese Centre for Energy Conservation

LPG – Liquified Petroleum Gas

MEW – Ministry of Energy and Water

MEUR – Million Euro

MUSD – Million United States Dollar

MW – Megawatt

NEEAP – National Energy Efficiency Action Plan

NG – Natural Gas

PP – Power Plant

PPA - Power Purchase Agreements

PV – Photovoltaic

TWh – terawatt-hour

UN – United Nations

UNDP – United Nations Development Centre

WESP - World Economic Situation and Prospects

1 INTRODUCTION

1.1 Background

Third World Countries' Challenges

There are around 200 countries existing in the world today, each country having its own economic, social, political, and environmental characteristics. The combination of these stats for a certain country define its level of development and the quality of life for its citizens. The World Economic Situation and Prospects (WESP) by the United Nations employs country classification which allocates all countries of the world into three broad categories. These categories are as follow; Developed countries, economies in transition and developing countries (Un.org, 2014). These groupings intend to reflect basic economic country conditions. The process of defining which group a country stands is complex and assessed based on economic, social, political and environmental criteria. Some of these factors are per capita income, freedom, education, health, safety quality of housing, access to basic amenities like electricity and safe drinking water.

Several countries in particular the economies in transition have characteristics that could place them in more than one category; However, for purposes of analysis, the groupings have been made mutually exclusive.

Accordingly, countries have been grouped as high-income, upper middle income, lower middle income and low-income. To maintain compatibility with similar classifications used elsewhere, the threshold levels of GNI per capita are those established by the World Bank. Countries with less than $995 GNI per capita are classified as low-income countries, those with between $996 and $3,895 as lower middle-income countries, those with between $3,896 and $12,055 as upper middle-income countries, and those with incomes of more than $12,055 as high-income countries (Databank.com.lb, 2013). The list of the least developed countries (LDCs) is decided upon by the United Nations Economic and Social Council and ultimately by the General Assembly, based on recommendations made by the Committee for Development Policy. The basic criteria for inclusion requires that certain thresholds be met regarding per capita GNI, a human assets index and an economic vulnerability index. As of 29th November 2013, there are 49 LDCs. WESP also refers to the group of heavily indebted poor countries (HIPCs), which are considered by the World Bank and IMF as part of their debt-relief initiative (the Enhanced HIPC Initiative). In September 2013, there were 39 HIPCs. (New country classifications by income level: 2018-2019).

[https://blogs.worldbank.org/opendata/new-country-classifications-income-level-2018-2019]

Less than 20% of the world's population live in developed countries (Globalissues.org., 2018). The rest of the population are in economies in transition and developing countries. Although there are a lot of factors that define the human development, the main focus of this study is going to be on infrastructure and in particular electricity in developing countries.

Underdevelopment is not the absence of development, as every nation has developed in one way or another to a greater or lesser extent. Underdevelopment only makes sense as a means of comparing levels of development. It is very much tied to the fact that human social development has been uneven and from a strictly economic view-point some human groups have advanced further by producing more and becoming wealthier (Rodney, 1972:21)

Our main pre-occupation this time around is with the disparity in wealth between Europe and North America on the one hand and Africa, Asia and Latin America on the other. The latter group can be said to be backward or underdeveloped in relation to the former. The idea behind underdevelopment can therefore be established as a purely comparative one. Underdevelopment can also be explained in terms of relationship of exploitation of one country by another or by internal governmental corruption (Rodney, 1972:22).

Developing countries might have some characteristics usually seen in developed countries but the lack of development in other characteristics still prevent them from reaching developed status. For example, Lebanon, the country of this case study might be seen by many of its own occupants as a developed country but when it comes to number it is still far from becoming developed. Although the country is classified as an upper middle income ($3,896-$12,055) (worldbank.org/country/Lebanon) (Income Group Classification – World Bank), high life expectancy (79.5 according to Human

Development Report 2016) (Index, H. D., Development, et, al., 2014) and high number of physicians (32 per 1,000 people) alongside other figures that would suggest the country might be a developed country, the country is still a developing country. The main reason for that is the inequality in development between different areas in the country and the high disparity in income between the wealthy and the poor. In addition, Lebanon was heavily depended in terms of tourism before 1975 as it contributed up to 20% of the country's gross national product (GNP) (Teker, S., & Akcay, M. B., 2008), which has dropped drastically post-civil war in 1990. As a result of the destruction the country witnessed during the war, the country had never had the opportunity to complete its recovery and rebuild the infrastructure. Without a suitable infrastructure, Lebanon would not be able to cope with the continuous increase of population alongside the economic and social needs. Lebanon has always been a service-oriented economy mainly based on tourism, trading and banking with the composition of the GDP being services (73.3%), industry (21%) and agriculture (5.7%) in 2017(Indexmundi.com, 2018). This in addition to the high-income difference and week infrastructure (transportation, electricity and water) are some of the attributes that put the country in the developing countries category.

1.2 Importance of Infrastructure to the development of countries

One of the main factors that play a big role in the transition of countries' development is the infrastructure. Better quantity and quality of infrastructure can directly raise the productivity of human and physical capital and hence growth. For example, providing access, roads can improve education and markets for farmers' outputs and others by cutting costs, facilitate private investment, improve jobs and income levels for many, etc. [paraphrase] (The impact of infrastructure on growth)

Infrastructure is a main contributor to the advancement of human development on many levels. This could be seen in its relation to poverty reduction, economic growth and health and safety enhancement. It was concluded (Estache, Garsous, 2012) that the less developed the country, the more likely infrastructure to matter in terms of development rate. The more developed a country is, the more other dimensions such as bottlenecks, or technological lags tend to matter more than the aggregate infrastructure stock (Yilmaz, & Cetin, 2012).

The adequacy of infrastructure helps determine one country's success and another's failure in diversifying production, expanding trade, coping population growth, reducing poverty, or improving environmental conditions. If these facilities and services are not available in that place development will be very difficult, it will cause negative effect on the production activities of the economy, which means lower levels of production always leads to the underutilization of the resources, security goods and services. People will spend more money obtaining basic needs and facilities (Teker, S., & Akcay, M. B., 2008).

A well-functioning infrastructure including electric power, road and rail, connectivity, telecommunications, air transport and efficient ports required for rapid growth. Without any of these either economic production will suffer, or the quality of life will deteriorate. In this respect, adequate and efficient infrastructure is crucial because of its impact on the welfare of the society. Apart from growth linkages, infrastructure has a direct relationship with environment, health, poverty, equity and the general quality of life. The higher affluence of the developed countries with advanced infrastructure bears testimony to this relationship. (Teker S., & Akcay M. B., 2008)

The challenges facing developing countries goes beyond lack of infrastructure assets. In many instances, the benefits of past investments in infrastructure have not been fully realized due to policy deficiencies and poor institutional arrangements. This reinforced the shift in project design that was already underway in most developing regions, from a focus on the physical and economic merits of proposed investments to much greater involvement with the political authorities to promote efficiency, establish sound and consistent sector policies, and supportive institutional arrangements for their execution.

1.3 The role of Electricity

The significance of access to electricity to human development has been well documented particularly in cross-country econometric studies across regions. It has been shown though that these studies that invest in the energy sector may be the safest bet to achieve a high social rate of return. This is understandable as energy is an input to any of the other infrastructure subsectors. (Teker, S., & Akcay, M. B., 2008)

1.4 Brief history of Lebanon (Energy)

Before the Lebanese civil war (pre-1975), 41.5% of the produced power was hydroelectric. After 1990, the electricity sector infrastructure was damaged and disregarded. A rehabilitation plan took place between 1992 and 2003 to enhance the transmission, distribution and generating capacity. After implementation, the demand still exceeded the supply and heavy oil & diesel became the primary resources of electric power generation. This left the Lebanese community in some cities facing up to 13 hours of blackouts, which eventually was covered locally by self-generated electricity using primarily diesel generators covering up to 30% of the demand (F. Fardoun et al. 2012, p.311). The hydroelectric generation formed less than 5% of the total power generated in 2011. This can be attributed to the deterioration of hydroelectric plants that need rehabilitation (MECOMeter - Macro Economy Meter, 2018).

Electricity in present Lebanon is one of the weak governmental sectors that is always facing a lot of problems and burdens accumulating each year. This is caused by the inefficient power plants, weak grid connections, high increase in population leading to increase in demand and the economic problems that leaves the government unable to implement solutions.
The outcome of all these problems can be witnessed by the high level of pollution caused by the inefficient and deteriorating power plants. In addition to that, there are daily electric cut-outs in different districts to balance the national demand to the capacity of the of the power plants.

Looking on the continuously increasing deficit in the electric power supply and the problems faced by the energy sector, many solutions can be proposed. These solution plans would target the use of more renewable resources and energy efficiency enhancements.

1.5 Objective

The main objective of this dissertation is to study up closely the key problems of the electric energy generation in Lebanon. This report would recommend an electric power plan that would meet the electric generation capacity needed for the country by balancing the supply and demand. The plan(s) recommended will consider the long-term adoptability to the growth of the country to ensure its sustainability with minimizing the needs of external exports of electricity.

2 LITERATURE REVIEW

2.1 Electricity System in Lebanon

2.1.1 Power Outlook in Lebanon

Demand:

The demand is distributed on the different sectors as follows: 40% residential, 29% industrial, 18% tertiary, 15% for technical losses and 5% for concessions. Although Lebanon is known as active tertiary sector, contributing to 70% of the country's GDP, the tertiary sector comes third in terms of electricity behind the industrial sector (29%) which contributes to 25% of the GDP. Sector (Berjawi, et al., 2017)

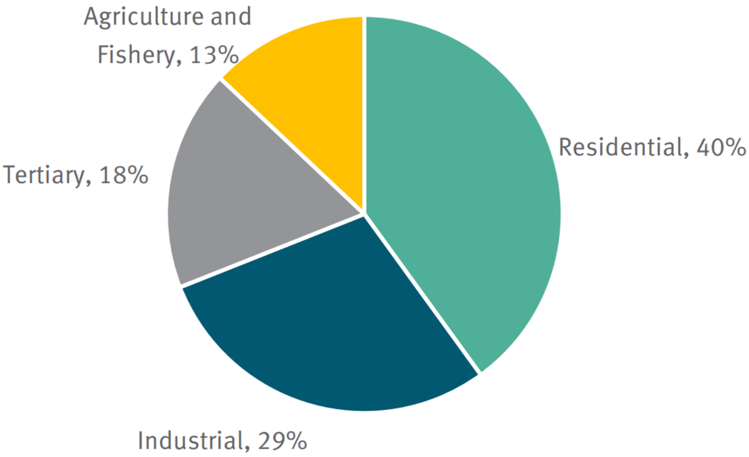

Figure 2.1: Distribution of Electric Power Demand by Sector (Berjawi, et al., 2017)

Supply:

There are currently seven thermal power plants, six hydroelectric plants and two power ships operating in Lebanon. The total power generated is still far from reaching 70% of the demand. This deficit is covered by private owned diesel generators all around the country, which provide local power distribution in towns and cities.

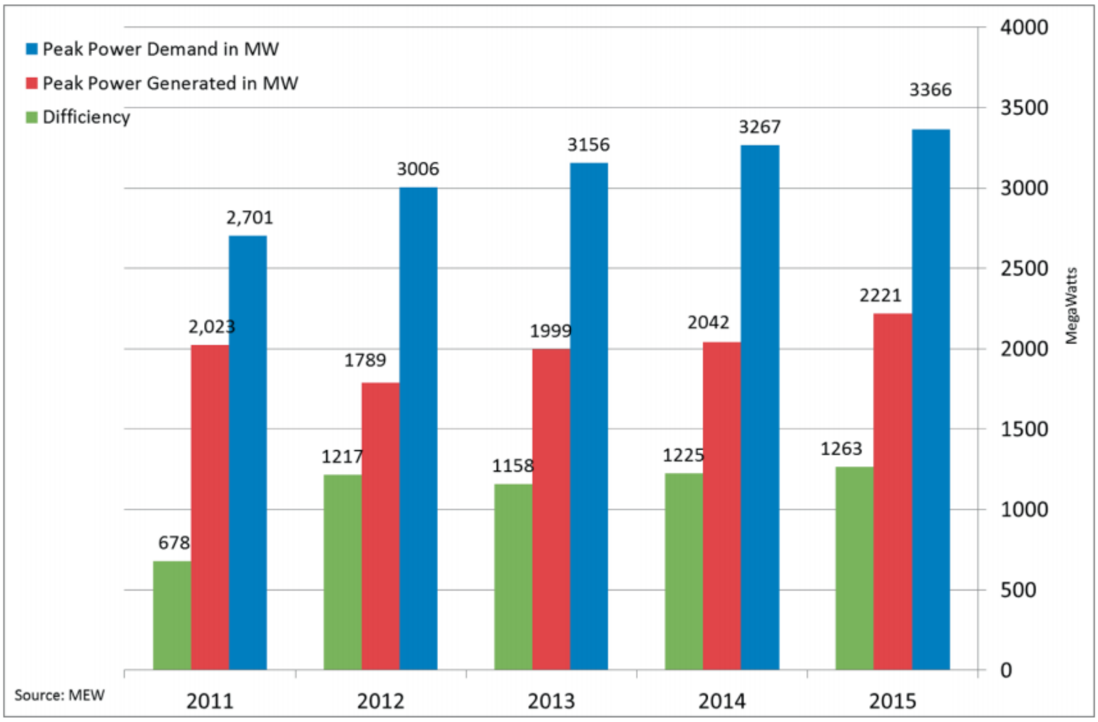

Figure 2.2: Annual Power, Demand, and Deficiency (Council for Development and Reconstruction, 2016)

According to J. Arbid (Executive Magazine,2017) the peak demand reached in the summer of 2016 is 3,100 MW. The total generating capacity in Lebanon at the end of 2016 was 1,873 MW. This figure is generated by the country's powerplants in addition to two Turkish barges that were used to cover the peak demands during the summer. It also included new reciprocating generators that were installed in Jiyeh and Zouk power plants.

In summer 2017, the maximum generation capacity was 2,000 MW, far less than the peak demand of 3,400 MW (Energy-lebanon.com).

This shows that the deficit has only been increasing more and more over the years and even though the rehabilitation and upgrading of some of the powerplants is taking place, the rate of increase of the generating capacity is far less than the rate of increase of the demand. Between 2009 and 2016 Zouk and Jiiyeh power plants were upgraded by adding 272 MW, 63 MW in Dier Ammar and Zahrani. In addition to that power barges with a generating capacity of 370 MW were rented from Turkey Ational, (L. E. N., & Lne, E. N.,2017).

Most of the demand is located in urban areas, which contains about 88% of the population with the majority of the big cities being along the coast. This is the main reason most of the thermal power plants are seen on the Lebanese-Mediterranean coast today with.

2.1.2 Main resources used for electricity generation

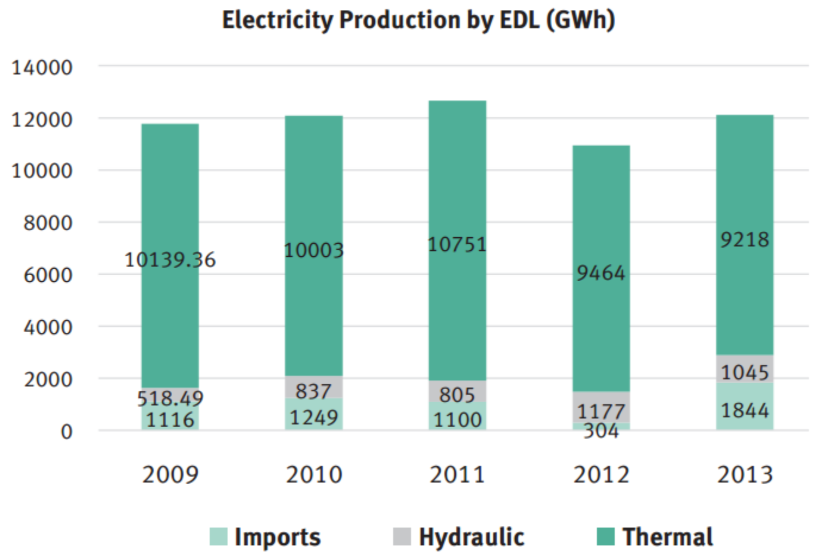

Figure 2.3: Electric Production by EDL (Berjawi, et al., 2017)

The main contributor to the energy mix by the EDL (Electricite du Liban) is mainly thermal power, with hydropower and imports coming in second place with contribution that does not reach 25%. Before 2013, electricity was imported from Egypt and Syria but due to the political instability in both countries, the imported power was reduced significantly and was compensated by power ships operating on heavy fuel oil (Berjawi, et al., 2017).

So, to sum up the resources for electricity generation capacity by the EDL, it is divided into the following: diesel fuelled combined cycle gas turbine (1051 MW), Heavy fuel oil steam turbine power plants (525 MW), heavy fuel oil barges (367 MW) and hydropower (40 MW).

The newest power plants Deir Ammar and Zahrani were built in the 1990s and were meant to operate on natural gas (NG). On the contrary, these two power plants heavy fuel oil due to the unavailability of gas imports. The use of power plants might change in the future if the government decides to extract the newly discovered gas offshore. (Council for Development and Reconstruction, 2016)

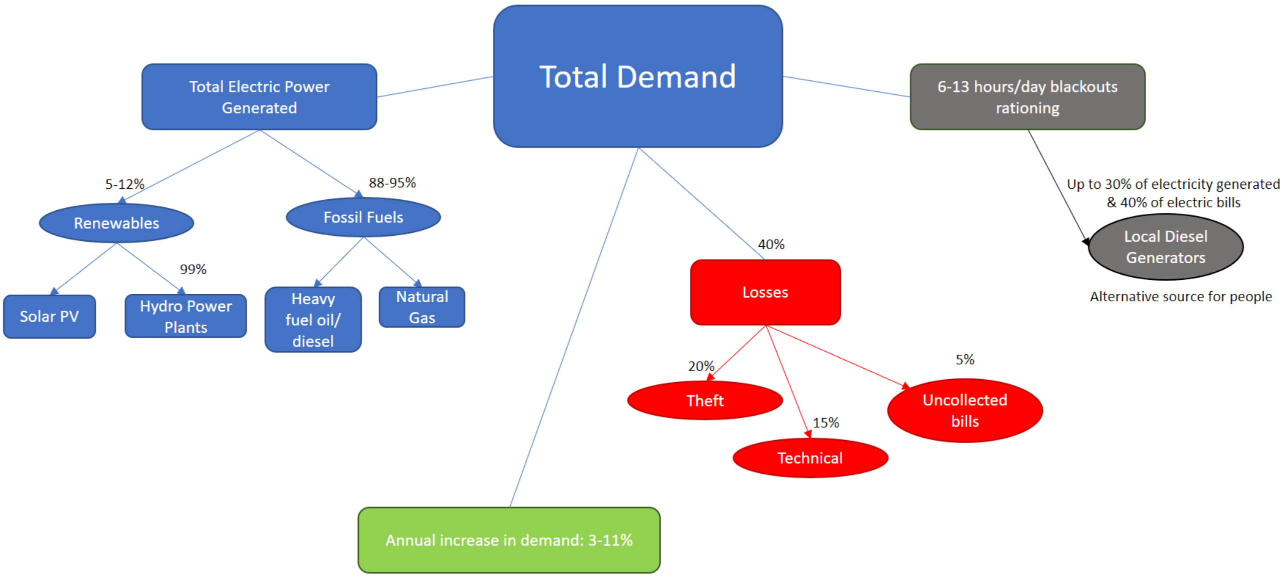

Figure 2.4: Electric System in Lebanon

2.1.3 Inefficiency/losses

There are significant losses in the system that can be divided into technical and non-technical. Technical losses include the week transmission lines and the rusty cables in addition to the technical issues the power plants have due to their ageing. For example, Zouk and Jiyyeh thermal power plants which already operate at low efficiency, must undergo periodic overhauling activities.

On the other hand, non-technical losses include uncollected bills by the EDL or power drawn from the system illegally (theft). These losses form 25% of the electric power supplied by the EDL or 15% of the total demand of the country. Unlike technical issues that require high financial and operational capabilities to solve, non-technical losses are relatively easier to solve but it would need a political/governmental decision to act on these issues. By solving this problem, an essential part of the burden would be lifted of the EDL financially which would increase its capabilities in dealing with technical losses and allowing it to do rehabilitation of the current power plants and even constructing new ones (Council for Development and Reconstruction, 2016).

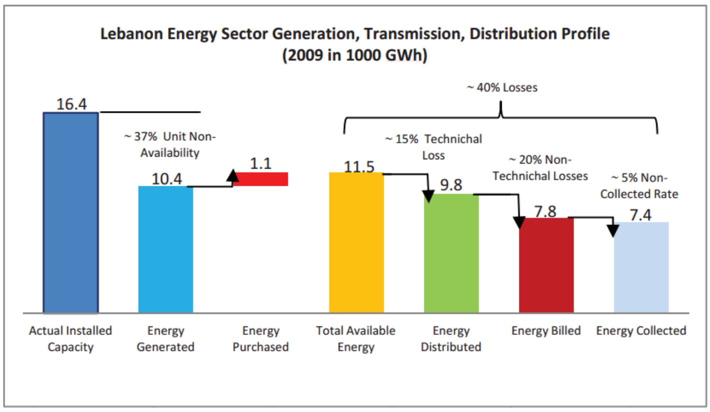

Figure 2.5: Transmission, Distribution and Losses (Fardoun, et al., 2012)

2.1.4 Demand profile:

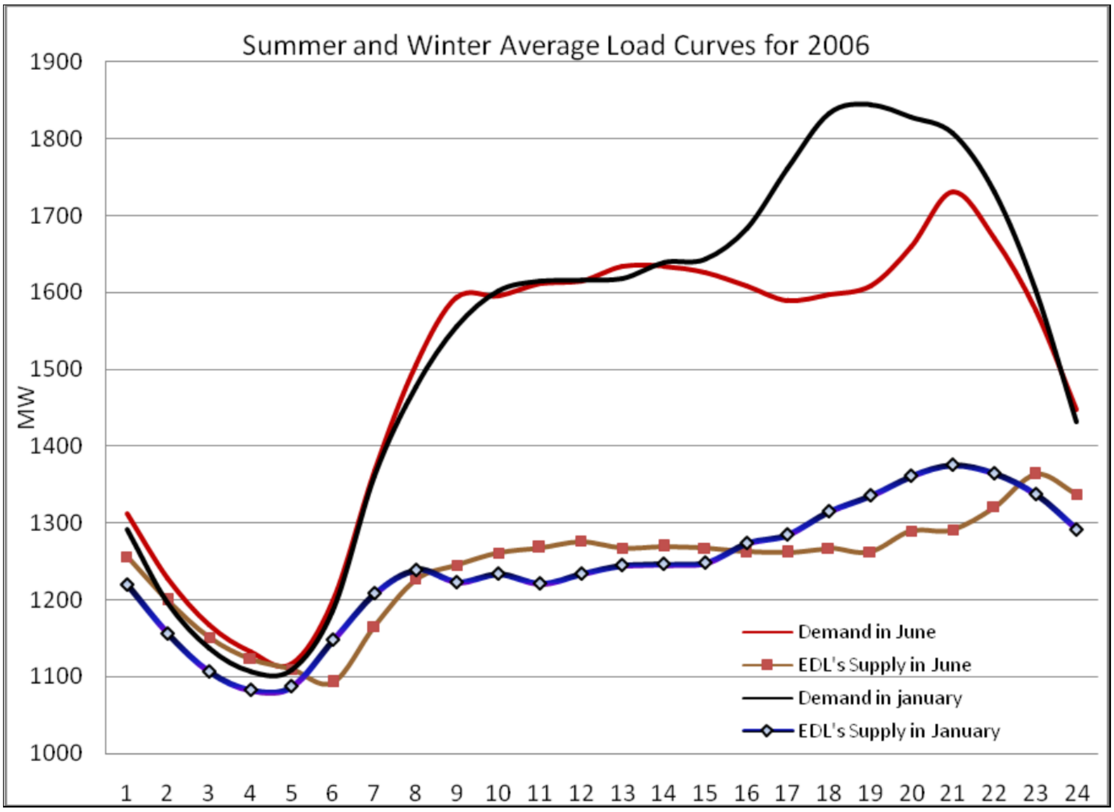

Figure 2.6 (World Bank, 2009, p.10)

The latest daily load curve data available is for summer and winter curves of 2006 provided by (World Bank, 2009) Figure2.7. By taking the daily demand curve for summer and winter 2006 and multiplying it by the annual growth rates the daily demand curve for 2018 can be obtained. Similarly, future demand curves can be estimated using the same process. By doing so it is assumed that the daily trend consumption remains similar.

2.1.5 Meeting demand

In 2010, the Lebanese government adopted the electricity reform plan designed by the Ministry of Energy and Water (MEW)which was structurally divided into three steps: short, medium and long term. This plan intended to optimise the current electricity system and increase the installed capacity. The ultimate target of the plan was to reach 4,000 MW by 2014 which would be increased to reach 5,000 MW in 2015. This would allow the EDL to meet the rising demand with a margin of spinning reserve. The plan included renting power barges with the capacity of 271 MW accompanied with a rapid increase in the installed capacity by 600-700 MW financed by the government. In addition, the plan was looking to importing electricity from Turkey through power purchase agreements (PPAs) but unfortunately was not possible because of the security situation in the region. This should have been synchronised with the rehabilitation of existing power plants leading to the increase in the capacity up to 245 MW. The plan outlined an increase in capacity of 2,500 MW using an independent power producer (IPP) modality with the collaboration in the private sector, along with the introduction of renewable energies through biomass, wind farms, and the rehabilitation of existing and the commissioning of new hydro plants. The investment needed by the Lebanese government for the restructuring of the generation sector was estimated to be between 988 and 1,114 million USD; the investment needed by the private sector was estimated to be between 2,645 and 2,745 million USD and, finally, 880 million USD were estimated to be needed by international loans. This does not cover the cost of importing from Turkey nor the cost of electricity bought from the floating barges.

Currently, imports from Turkey are not possible, as previously mentioned. In addition, the rehabilitation plan has been postponed, and two barges were connected to the electrical grid in 2013 and 2014. All these delays in the implementation of the plan, which have mainly been due to political reasons, have intensified the burden of EDL. (Bouri, E., & Assad, J. El., 2016)

Meeting the demand has been such a challenge to the Lebanese government and EDL due to many factors that include:

- Unforeseen increase in demand caused by sudden increase in population (1.5 to 2 million)
- Deterioration of the current power plants caused by ageing and reaching date of retirement from one side combined with lack of maintenance and strategic planning.
- The unstable nature of the region gives the country limited political and economic opportunities to build a solution upon.
- The economic state of the Lebanese government which has a significant international debt thus the weak financial ability stands as an obstacle in investment's way.

2.1.6 Role of renewables

Electricity generation in Lebanon is almost completely covered by imported petroleum products, consuming around 50% of Lebanon's Imports of fossil fuels (Ibrahim et al., 2013). Lebanon has pledged to cover 12% of the electricity by renewable energy sources by 2020 and signed to join the International Renewable Energy Agency (IRENA) in the same year (Hauge, 2011). This target has been further asserted in the electricity sector policy paper in 2010, the National Efficiency Energy Action Plan (NEEAP) and the National Renewable Energy Action Plan (NREAP). Through these two plans it is intended to move to reduce CO2 emission and reduce demand by increasing efficiency and reducing losses to move towards more environmentally friendly electricity generation. This can be shown in the government policy and confirmed by the submitted in the Intended Nationally Determined Contributions (INDC) in the Paris Climate Change Conference which committed the country to an unconditional target of 15% RE generation and a 3% reduction in power demand through energy efficiency improvements by 2030. (Berjawi, A. H., Najem, S., Faour, G., Abdallah, C., & Ahmad, A., 2017)

2.2 Solar

Lebanon is rich in solar irradiation with around 300 days of sunny days per year, resulting in daily insolation of 4.8kWh/m^2 (Fardoun, F., Ibrahim, O., Younes, R., & Louahlia-Gualous, H., 2012) which varies between 2 and 8 kWh/m^2/day and has

3,000 hours at an annual average irradiance of 5.01 kWh/m^2/day (Kinab, E., & Elkhoury, M., 2012). Despite the numbers, energy is still minimal due to not being feasible economically and less desirable in comparison to the low price of electricity production by EDL. However, thermal solar energy is widely spread in Lebanon due to its direct savings and simplicity of use.

Solar PV energy would provide a good alternative to generators in the future given that most of the electricity rationing occurs during the day. The relative lack of dust and sand with the moderate temperature make Lebanon favourable for solar PV farms and ensure high efficiency.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Abde	2044	3089	3875	6095	6464	7344	7035	6822	5312	3588	2734	2115	**4715**
Ksara	2518	3625	4943	6214	7702	8840	8758	7949	6762	4849	3424	3507	**5683**
Beirut	2308	3191	4380	5496	6461	7208	7018	6424	5380	4247	3004	2317	**4793**

Figure 2.7: Global Radiation (El-Jamal, 2014)

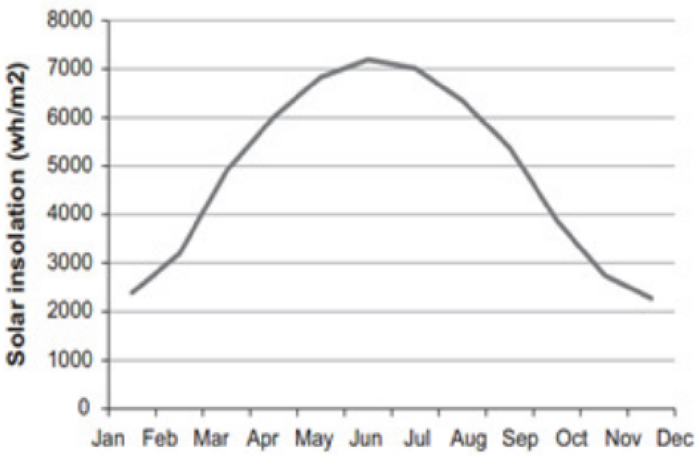

Figure 2.8 Average Daily Solar Insolation in Beirut (El-Jamal, 2014)

2.3 Hydropower

Hydropower is a combustion free energy resource which is well established on global scale, and in Lebanon. The chief natural resource in Lebanon, currently available, is water. The mountains give a high rainfall (widely over a meter a year in Mount Lebanon), and the porous fractured limestone makes a perfect aquifer which are refilled over spring and early summer by the slow melting of snow. (Fardoun, F., Ibrahim, O., Younes, R., & Louahlia-Gualous, H., 2012). Since Lebanon has a mountainous nature with 9 of its major rivers running from mount Lebanon and discharging in the sea, the country has a big potential in generating hydro power from large and small Hydro. With the water flow being of no use and most of the water is discharged to the sea wastefully, building dams and water storages can be advantageous for producing electricity from direct hydropower generation or pumped hydro and would can even make water resources available during dry seasons for domestic use, agriculture, and fighting forest fires. Although hydropower has low running cost when it comes to maintenance, operation, and long-life span (50-100 years), it needs a very high capital cost for the construction phase. In addition, the irregular rain and snowfall can affect production (Kinab, E., & Elkhoury, M., 2012).

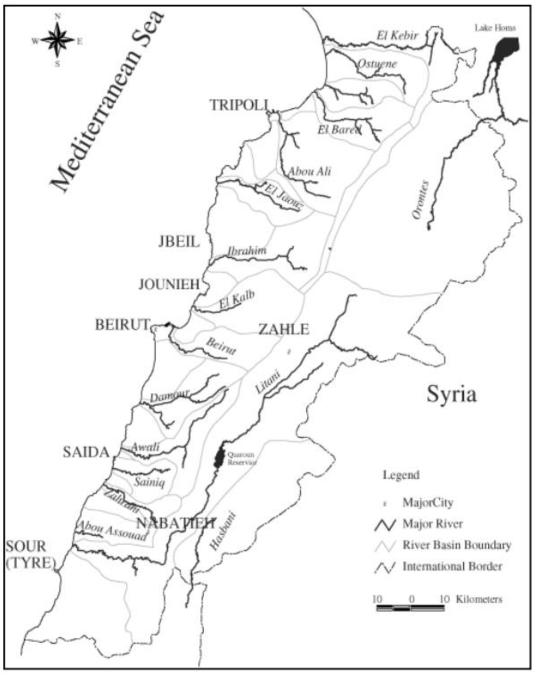

Figure 2.9 Major Rivers and Water Bodies (cas.gov.lb)

Lebanon has 16 major rivers that can be used for hydro power

2.4 Biomass

Forest in Lebanon does not cover more than 13.12% of the total land area which is equivalent to 1370 km^2. Forestry in Lebanon is regarded of high importance in Lebanon and is highly preserved specially with the climate change occurring in the region. However, Lebanon is considered to have important sources of biomass and for the most part represented by the municipal solid waste. This waste may be divided into two categories residential waste estimated at about 4200t a day, and nonresidential waste mainly commercial, industrial and estimated at about 600t a day. These wastes can be recycled, reused, transformed, burned or converted into electricity and heat while the remains could be consumed as natural fertilizers.

Landfills have always been an unfavourable in Lebanon and have created a huge controversy specially in the recent 5 years with the rise of social movements calling for segregating and recycling wastes. Using food and plant-based waste can be beneficial in energy from waste based on some of the many biomass and biogas processes/techniques used. Since direct combustion has been proven to have high emissions of CO_2 and other toxic gasses and solid wastes, the best process that can be used is purifying biogas and collecting it from the wastes. The biogas to be used in combustion while the solid remains of the waste to be used for fertilizers.

Several studies were carried out on Lebanese solid waste landfills (Bourj Hammoud, Quarantinah, Naameh, Normandie) and have shown high gas storage potential. If we take the case of Bourj Hammoud landfill, its gas storage potential is about 170 m3 for the period spanning from 2001 to 2015 with a methane percentage of 45–55% and thus a possibility of generating 850 GWh during the cited period. An averaged thermal energy based on various components of solid waste is depicted in Table. (Kinab, E., & Elkhoury, M., 2012)

2.5 Wind

Wind energy production is not that common in Lebanon except some privately-owned ones for personal use, but no wind farms exist in Lebanon today. There hasn't been a wide study to record accurate data for wind energy so far. Some locations in Lebanon has been subject to study to get the yearly average wind speeds of some. One of the studies was done by (Al Zoghbi et al., 2015) which aimed to wind and pumped hydro storage. Although some figures for wind are out there, it is not accurate or sufficient enough to create an energy model incorporating wind energy. UNDPR has already started mapping the whole country's wind map and hopefully more accurate data will be extracted in the future (Elkoury, Kinab, 2012, p. 4427). That would facilitate energy planning and modelling systems that include wind energy implemented.

Site	Easting (m)	Northing (m)	Elevation above Sea level (m)	V_m (m/s)
Daher El Baydar	706366	3682611	1524	9.50
Klaiaat	78097	3793722	5	7.80
Cedars	774278	3823977	916	7.30
Marjyoun	749026	3715206	760	9.35
Quaraoun	738724	3714557	855	6.9

Figure 2.10 Wind Speed Table (Al Zohbi et al., 2015, p.377)

Some of the gathered data seems appealing and are valuable for research and analysis. As much as these number are of good potential and reaching high speed which makes it suitable for wind turbine operation, a detailed hourly profile will be needed to design an energy model.

3 Energy Strategy for the Electricity System

You should list here all elements required by a third-party to reproduce the results described in your dissertation. A list of possible headings is provided below as reference, but you must decide what need to be reported considering your project.

3.1 Why EnergyPlan?

EnergyPlan model is used to analyse the energy, environmental and economic impact of energy strategies which is the aim of this study. By defining the inputs and outputs of the system, EnergyPlan optimises the associated parameters which allows the user to match and compare them with the aims of the strategies that are planned and developed through the model. It also includes some future technologies, such as biomass gasification and synthetic fuels which can be defined and included in the strategies developed for future energy systems. Therefore, EnergyPlan can be used to generate different strategies and scenarios that focuses and the future. These scenarios can then be compared based on their energy, environmental and economic impacts to finally decide which scenario(s) are feasible and in what ways are different ones better than each other.

In this study, EnergyPlan is used to create 2 future scenarios for the national electric power system in Lebanon. The first one having business as usual which means using the conventional energy resources and the second one aiming to integrate renewable energy resources. The results obtained from these two scenarios will then allow comparing them and assessing the impacts of each scenario and concluding the advantages and disadvantages of each one.

To fulfil this procedure, a base case is modelled to reflect the electric energy system of 2018. This base case is the key to modelling both future scenarios afterwards.

3.2 Base Case

3.2.1 Electricity Demand:

The base case modelled on EnergyPlan defines the current electric system in Lebanon as of the data collected for the year 2017. The data are collected from MEW and EDL reports, in addition to other individual studies and studies done by national and international bodies in collaboration with the Lebanese government (LCEC, UNDP, CEDRO, Lebanese Army, and other NGOs). Since not all studies were carried out by the same organisation and during the same period, some assumptions and estimations in values had to be made for a more realistic study and to get better results.

Energy system in Lebanon can be narrowed down to electricity. This is the case since Ministry of Electricity and Water (MEW) only supplies an electric grid. This can change in the future if natural gas becomes an available resource by extracting the natural gas and oil found offshore in the Lebanese regional waters. At the moment, there is no national transmission system or network pipelines to distribute gas to households and buildings. Therefore, the demand of the model plan of the base case does not include heating. Likewise, cooling included in the plan due to the insufficiency of data on that matter.

The total Electricity demand is estimated by using the demand of the electric energy demand reached in 2015 was obtained from the Council for Development and Reconstruction (CDR) report – Physical Infrastructure (Council for Development and Reconstruction, 2016). According to the report the annual demand in 2015 was 20,637 GWh or 20.637 TWh. After multiplying the total demand with the annual load growth (7%) the obtained annual demand is 25TWh. Further on, the hourly profile of the electric power demand for the whole year, which is needed to obtain more accurate results from EnergyPlan, needed to be established. This is done by manipulating the distribution of the loads so that it meets the winter and summer power distribution shown previously in the electric demand section. Similarly, the same thing is done for the spring and fall seasons. As a result, we get the following graph showing the hourly annual distribution of the national electric demand. It can be noticed that the maximum demand increases more than 1,000 MW between the winter and the summer. That is directly related to the electric cooling systems used in residential, commercial and industrial buildings. On the other hand, most of heating during the winter does not rely on electricity and is rather diesel oil, liquified gas or biomass heaters that are used with a small portion of the heaters being electric. In addition, the coastal cities where most of the population resides does not witness extreme cold weather conditions which avoids the need of intensive heating.

Although in summer boilers are not used as often as in winters, which would make us expect the difference in power demand to get smaller, the difference that is observed in the graph is more than 1,000MW. This shows how intensively air conditioning is used in the summer for cooling indoor areas.

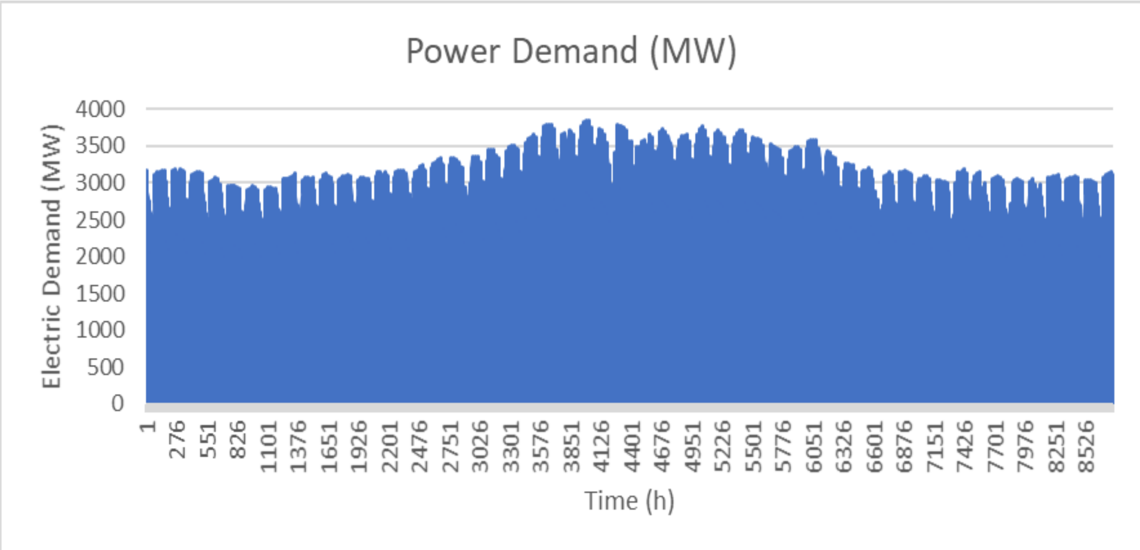

Figure 3.1: Base Case Year Demand

3.2.2 *Heating and cooling:*

Heating and cooling are not included in this seperately in this study but as part of the total electric demand. The reason for that is that cooling systems in lebanon are electric air conditionars. Therefore, cooling is included in the electric demand profile.

Heating in Lebanon is divided into four categories. Electric, Liquified Petroleum Gas (LPG), Deisel oil and Biomass (wood).

The electric heating is already included in the electric demand profile. LPG used for heating are mostly purchased as 20k kg cylindrical bottles. LPG amount used yearly is input in the transport tab which include LPG fuel consumed. Similarly the diesel oil used for transport and heating is inputted in the transport tab. Although the deisel oil can be divided into transport and heating, it is seen unnassercary as the aim of the anaylsis is electricity thus the changes in trasport and heating would not effect the results. This is the case since the scenarious to be drawn with renewables integration will not include electric vehicles and heating generated from different resources which could not be aplicable with the infrastructure available at the moment.

This study is aiming to find energy mix for the electricity in Lebanon without doing signficant changes to the grid and transmission infrastructure. Therefore, it is jut looking into using new energy sources and possibly replacing some of the present power plants by more environmentaly friendly ones depending on renewable resources.

The data for the shares of fuels used in different sectors are collected from The National Renewable Energy Action of Lebanon 2016-2020.

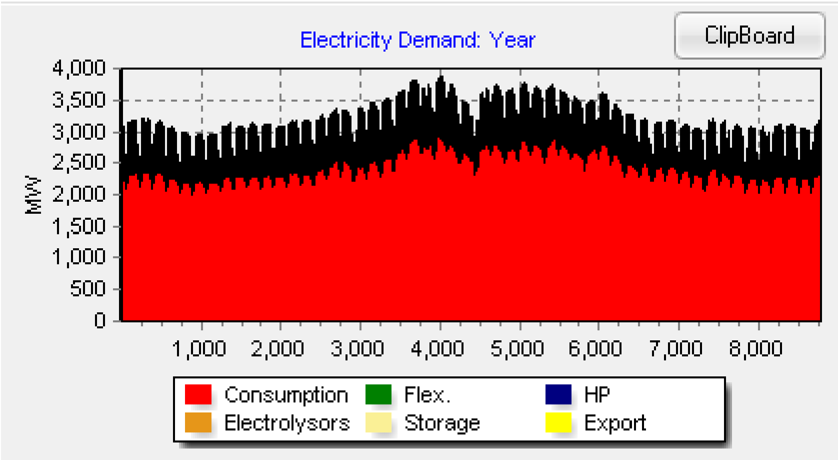

Figure 3.2: Year Demand

After Inputting the demand, the supply is to be entered according to the up to date data, available for the electric energy system in Lebanon. At the moment, there are no forms of district heating in Lebanon nor there is infrastructure available for applying big scale district heating. Therefore, to construct data for the elctricity supply the capacity of the currently operating power plants are added together and entered under “electricity only” tab. This includes all the thermal power plants and the power barges with a total capacity of 2,000 MW and efficiency of 45%. The fuel distribution of the operating power plants at the present is 100% oil. Lebanon does not have other central power plants such as nuclear or geothermal. In this section the renewable sources are also added with 280 MW dammed hydro power and 10 MW photovoltiac.

Table 3.1: CO_2 Contents in Fuel

Fuel	CO2 (kg/GJ)
Coal	98.5
Diesel	72.9
Oil*	72.9
Natural gas	56.9
LPG	59.64
Waste	32.5

*Oil: Fuel Oil, Diesel Oil, Petrol & JP.

The current electric energy systems does not have any sort of storage therefore the balancing and storage is kept empty. The demand and supply of this system are still highly unbalanced and this is where the private generators play the role in filling in the deficit created by the EDL's shortage in meeting the demand. It was seen that the best way to include the PG's contribution to the Lebanese demand is by considering it as an import to the grid. By doing so the contribution of the PG's to the electric power demand would be clear and thus the fuel needed to produce this power is calculated based on the average efficiency of the diesle generators. This fuel is included in the "Industry and Fuel" section under various fuel consumption. This allows EnergyPlan to include the cost of the fuel purchased and the CO_2 emissions seperately. Most of the fuels' CO_2 emission factors are included in the EnergyPlan Cost Database (Connolly 2015), yet diesel oil and methane are not. By looking into other sources it is found that the emission factors of diesel and methane are 72.5 kg/GJ and 35.9 kg/GJ respectively (Zijlema, 2018). Since these numbers are so close to the numbers as oil and NG, it is the values of the latter is used for diesel and methane for simplicity.

After inserting all the technical details of the system into EnergyPlan, the graphics for the electricity prodution profile can be obtained in the output. The yearly profile for 2018 is shown below which shows high variation in demand over the different seasons of the year with not as much variation in the supply. The small variation in the supply is due to the decrease in the `power plants' water resources during the Summer and early Autumn. On the other hand, the high variation of the demand curve is caused by the high variation in temperature between the winter and summer. During the summer the high temperature causes an increase in the electric air conditioning usage in closed areas causing a high increase in the power demand. Whereas during the winter, the temperature indoors is not as extreme and heating load is quite diverse and divided between oil, biomass, electric and LPG which relieves the electric grid from some of the heating load.

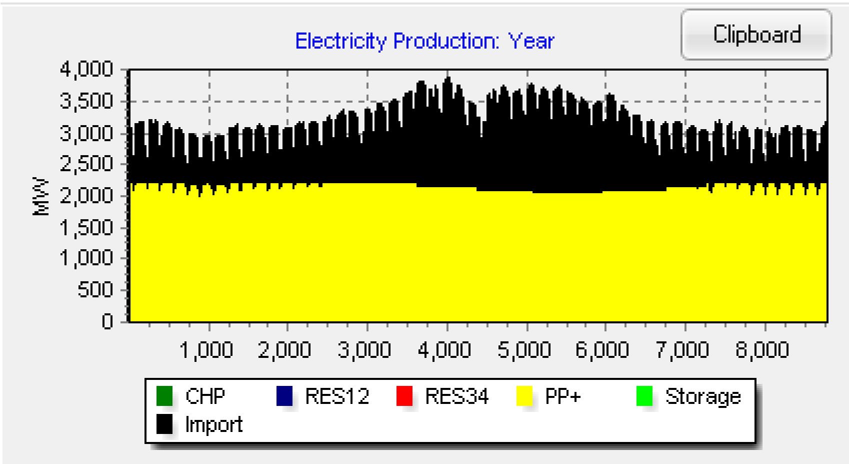

Figure 3.3: Variation of Hydro Power

The EDL performs rationing to supply the country with the electric power. That is done by having periodic cutouts in different regions or districts to shape a demand that meet the power produced by the EDL. This rationaing is rotational on a daily basis and has become a routine that has facilitated to private generators to sell electric power in local towns or neighborhoods to cover the cutouts created by the EDL's deficit power.

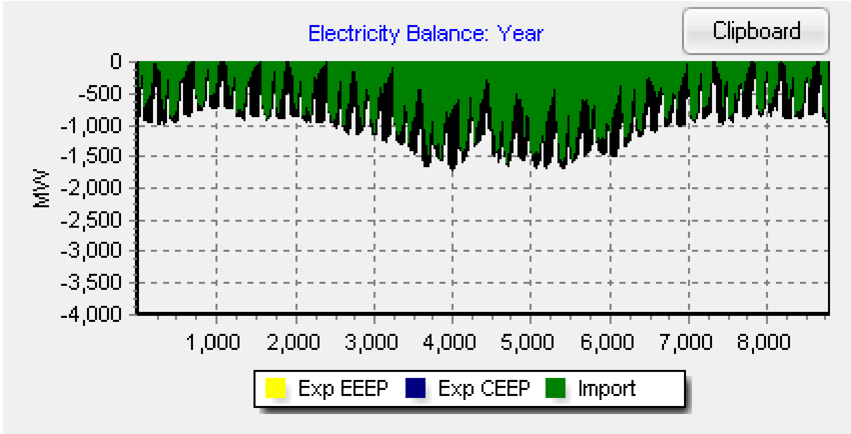

Figure 3.4: Deficit

As shown in the graph above, the Electricity Balance sheet shows upto 1,156 MW deficit during the summer peak demand. This is occurs when the demand reaches its maximum value which is 3,867 MW. The annual average demand is 2,846 MW.

Table 3.2: Supply and Demand Balance (MW)

	Elec. Demand	Solar PV	Hydro	PP	PG
January	2,670	4	60	2,000	607
February	2,584	4	72	2,000	509
March	2,699	5	60	2,000	634
April	2,805	5	48	2,000	752
May	2,975	5	48	2,000	926
June	3,199	7	36	2,000	1,156
July	3,132	7	24	2,000	1,102
August	3,128	6	12	2,000	1,110
September	2,960	5	22	2,000	933
October	2,696	5	34	2,000	656
November	2,649	5	49	2,000	595
December	2,644	4	61	2,000	580
Average	2,846	5	44	2,000	797
Maximum	3,867	10	72	2,000	1,821
Minimum	2,014	0	12	1,942	0

Power (MW)

3.3 Contributions of different types of renewables

A lot of the renewable resources can play a big role in shaping and making the electric power system in Lebanon more sustainable. For that aim, some of the selected renewables and non-renewable resources that are going to be included in this study are:

3.3.1 Solar:

Due to the lack of solar data a solar production constructed by using the data obtained from Solar-Med-Atlas through which the solar data can be extracted for any location in Lebanon (s.r.o., 2018). By using the solar farm recommended locations map in the Figure 3.5, it was decided to choose the strip highlighted on the eastern side of the country. The areas highlighted exclude areas exposed to hazards such as landslides, fires, earthquakes and floods. It also excludes agriculture land, forestry, historical sites and water bodies. This area has close proximity to the Baalbek power plants and the transmission line running in the Bekaa valley.

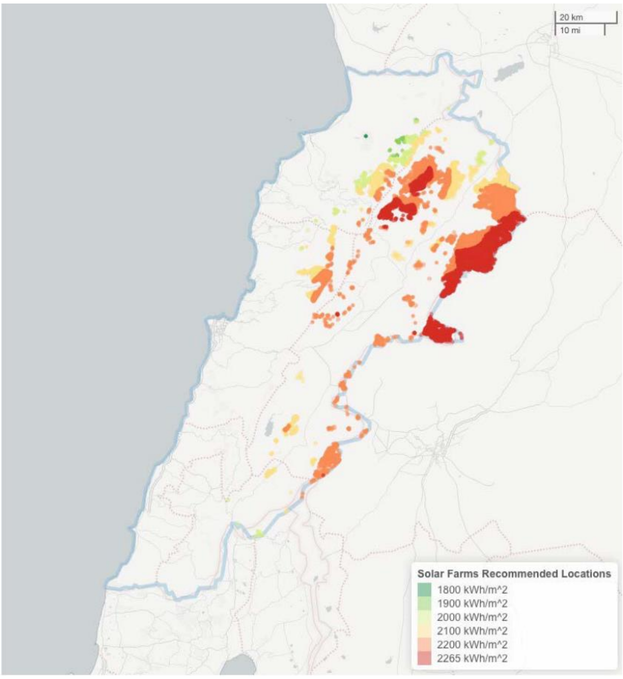

Figure 3.5: Appropriate Area for Solar PV Farm in Lebanon (Berjawi, et al.,2017)

The graph below in Figure 3.6 below shows an exaggerated contribution of the solar PV power output shows that even if the solar power produced is able to exceed the peak demand, it will not be able to cover all the varying demand without having storage or standby powerplants to cover the rest of the deficit. For this situation, pumped hydro storage would be able to play a big role in storing the surplus caused from solar power and balancing the demand through covering the deficit.

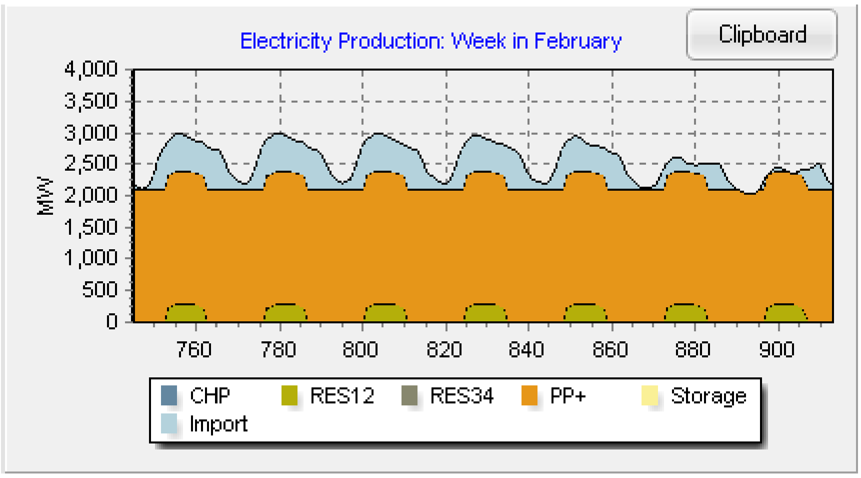

Figure 3.6: PV Output (MW)

By using Solar-Med-Atlas for the power generation curve is created. This is done by using the monthly power generated PVout, the daylight periods and the solar elevation (incidence angle). PVout takes into consideration the thermal efficiency of the PV panel effected by the temperature variation and the weather condition. This process produced an annual curve for the PV power production with the parameter being between 0 and 1. 0 is for the periods where there is no solar radiation and 1 is for the maximum production that usually occurs at noon with maximum thermal efficiency.

Due to the lack of daily data and using monthly data to make the hourly curve needed for EnergyPlan, all the days of the month had a uniform identical power coefficient curve. In an ideal projection of data that reflect the real world a lot of fluctuations occur between days in the same month caused by the weather conditions and other factors. This is a main point to remember but this is the closest we can get to the real solar PV production ratios from the available data.

Furthermore, by referring to solar-med-atlas (solar-med-atlas.org), the performance of a 1kW crystalline PV panel is observed over three different set angle 15º, 25º, 35º.

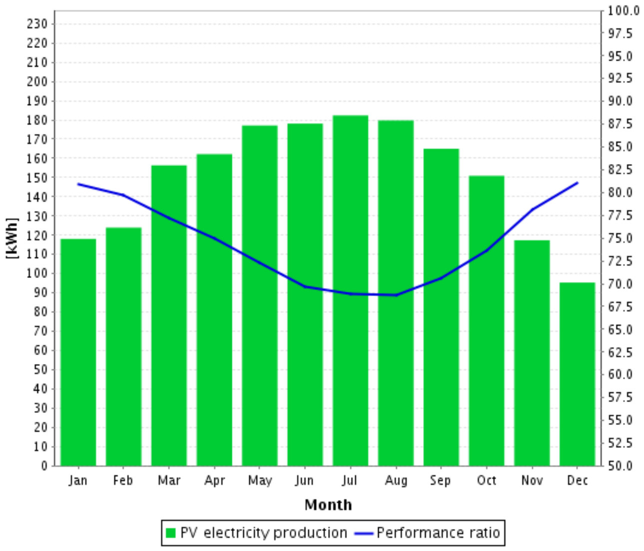

Figure 3.7: 1 kW PV Performance on 15° Plot

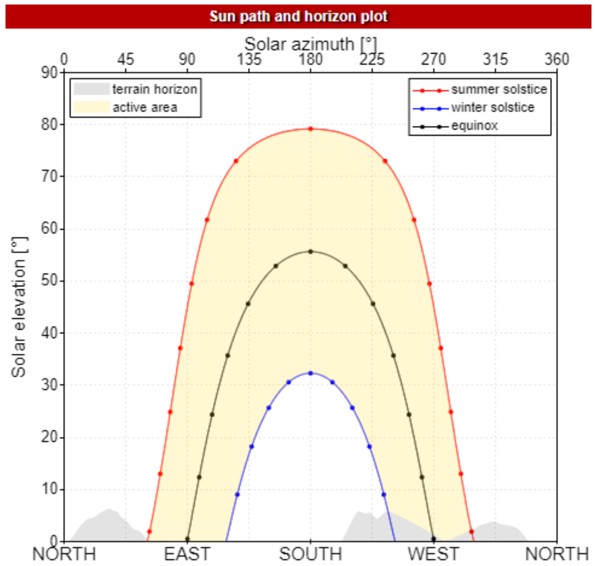

Figure 3.8: Solar Path and Horizon

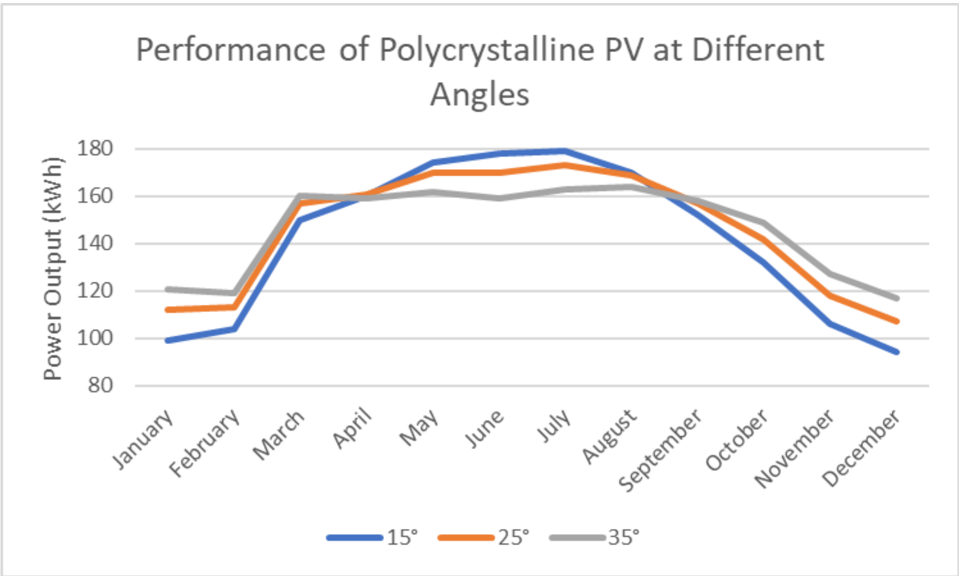

Figure 3.9: Variation of PV Power Output with Respect to change of panel's angle

3.3.2 Biomass:

Biomass energy has huge potential in Lebanon due to the variety of the products and their abundance in considerably large quantities that can be used in electricity generation. The biomass products have been grouped under the following categories:

forestry, wood and paper industries, agriculture, energy crops, food processing industry, municipal solid waste and non-hazardous industrial waste.

Lebanon has a large potential in using biogas powerplant(s) to produce electricity as the country is throwing away in landfills massive amounts of municipal waste which according to the National Bioenergy Strategy for Lebanon report (2012) contains 50% organic waste of food products. It is estimated that the total municipal solid waste generation is 1,569,500 tons/year or 4,300 ton/day where the organic waste is 863,225 tons/year or 2,365 tons/day. The total energy potential of the bioenergy stream in the solid wastes is 743 GWh nationwide and the methane potential is estimated at 278 GWh. Manure is another methane producer through an anaerobic digestion process with a total annual production of methane at 494.5 GWh with 4 main poultry slaughter houses producing 157 GWh. In addition, spent grains in the beer industry present interesting methane potential with total annual potential being 1,703 MWh.

Due to the abundance of wastes that have the potential in methane production, it is seen that biogas power plant using methane would be a stable and main contributor component of the energy mix in the future. Methane with other conventional fuel sources can form the base of the power generation on top of which intermittent renewable sources would contribute to close the fluctuating part of the demand.

3.3.3 Hydro power and pumped hydro storage:

It is seen from the base case electricity production graph that the power supplied by the power plants is not 100% stable. That is due to the reduction in power generation during the summer caused by the drop of water levels in the hydro dams.

3.3.4 Wind & Wave:

Wind and wave can be a vital component in the future of the renewables in Lebanon but due to the scarcity of the data and studies on these two topics, it was not possible to include them in the analysis. Although some data was obtained for wind energy, it was not detailed enough to generate an annual hourly profile.

3.3.5 Natural Gas

Natural gas has many benefits over fuel oil. Natural gas is cheaper, cleaner and more efficient in electric generation. Therefore, phasing out form fuel and diesel oil into natural gas would be very essential to the economy, environment and power generation efficiency. This might become even easier with the potential offshore gas and oil extraction in the future.

3.4 2030 Scenario – Renewables Integrated

According to the estimated annual increase in electric energy demand, the total demand in 2030 is projected to be round 40 TWh/year.

In order to model the energy mix of the electric energy to be generated to meet the demand of 2030 we start from the base case and add on that the different the different electric supply resources. That is done according to the availability of the resources and the priority depending on the environmental, financial and convenience. For this purpose, the following sources are considered: Solar PV, hydro & hydro storage, biogas, biomass and natural gas. Although natural gas is not renewable resource, it is added to this list since it is more environmentally friendly, when it comes to CO_2 emissions, compared to the conventional fuel sources used.

The aim of this scenario is not only to meet the growing demand without using imports or supplementary generators, but also reach a 20% contribution towards the supply from renewables. By these means, the electric system would be considered self-sustainable and it would meet the Paris conference commitment.

3.4.1 Solar PV:

After constructing the 10 MW Beirut river PV plant, the LCEC on the behalf of MEW is aiming to install 300 MW as a part of the renewable energy plan to achieve the commitment of 12% electric energy form renewables by 2020. This is to be done through private investments willing to be part of three different projects. The projects are PV farms with the capacity of each farm ranging between 70 MW and 100 MW with minimum battery energy storage of 70 MW and 70 MWh storage capacity. So far there have been 75 expressions of interests which are all expected to be valid. (PV Magazine)

Although the final list of investor and action plan is yet to be announced in September 2018, this seems as an essential and positive leap in the right direction. This also means that there is an appetite from private investment to cover the inability of the government on a financial level to carry on such projects and this will open the door to even more projects to come. If the advancement in the solar PV sector stays on the same pace, Lebanon would be able to reach 1,500 MW total capacity from solar PV easily by 2030.

Therefore, the PV capacity for the renewable energy scenario on EnergyPlan is set to 1,500 MW.

3.4.2 Biomass and Biogas:

Biomass and biogas are essential energy resources that are present in Lebanon either as a resource that is present in the market and ready immediately for electricity production such as most biogas, or as raw material that need to be treated and go through chemical process to produce the biogas fuel. These two components can be an essential part of the electric energy mix that is able to produce constant power contributing to the stable base of the power supply alongside the fossil fuel power plants. The most significant advantages of using biomass and biogas as fuel are their availability at a lower cost and having reduced CO_2 emissions when compared to the conventional heavy fuel / diesel oil used.

According to The National Bioenergy Strategy for Lebanon, a study that was done in 2012 that estimated the potential energy estimates for different sources of biomass, biogas through methanation and other biofuels. The focus is going to be aimed more on biomass and biogases since their application is more related to electricity generation than biofuels (cooking oil, grease, etc.).

The table below shows the main potential contributors for the biomass energy mix by combustion. Although the numbers will be expected to grow higher by 2030, it is assumed that they will stay constant.

Table 3.3: Biomass

		Yearly TJ/year	TWh/yr.
Residues from fellings	low	1,378	0.38
	high	1,771	0.49
	average	**1,575**	**0.44**
Residues from olive trees	low	842	0.23
	high	9,680	2.69
	average	**5,261**	**1.46**
Residues from Fruit trees		**2,110**	**0.59**
Residues from cereal	low	2,116	0.59
	high	2,233	0.62
	average	**2,175**	**0.60**
olive cake	low	460	0.13
	high	1,083	0.30
	average	**771**	**0.21**
Total		**11,891**	**3.30**

The total estimated energy produced by biomass is 3.3 TWh/year which, at a constant rate, would form 7.5% of the total annual electric energy demand (40 TWh).

When it comes to biogas methane production from bio-waste, not all the components were given by the same measurement unit. The energy capacity estimates of different sources were given in terms of total energy potential or methane potential. In order to find the total potential, they all had to be converted to annual methane potential (TWh). That is done by multiplying the total annual energy by the ratio of methane production from the total gases produced in the biogas plant. This ratio varies between 0.6 (60%) (European Environment Agency, 2016, p.4). The specific ratio for the different components are as follows: crops, manure, MSW, fat wastes from slaughter houses, beer residues and sludge.

Estimates of methane gas losses are assumed to be in the range of 2-3% (Silber S., 2014). The methane losses in transmission pipes are not included in the total annual methane production as they are added later on in EnergyPlan.

Table 3.4: Biogas

	Total Energy (TWh)	Methane Energy (TWh)
Crops	1.90779	1.14
Manure	1.40404	0.5
MSW	0.74300	0.27
Slaughter-house fat	0.07167	0.054
Beer	0.00324	0.0017
landfill		0.163
Sludge	0.25010	0.163
Total	**3.52341**	**2.3**

This table show the annual methane production from the top 7 available sources in the country. Although the numbers were estimated in 2012, they are expected to continue to increase with time. It assumed that the total energy would increase according to the continuous increase of the population to reach, in 2030, 1.5 times the amount taken in 2012. Therefore, a total annual methane production is considered to be 3.45 TWh in the 2030 energy mix.

3.4.3 Hydropower:

Hydroelectric power has a total installed capacity of around 280 MW but due to the ageing of the facilities and poor maintenance the total capacity has dropped to around 200 MW. It is distributed on six different hydro power plants shown in the table.

Table 3.5 Source: Hydropower in Lebanon

River Stream	Plant Name	No. of Units	Capacity MW
Litani/Awali	Markabi, Awali, Joun	7	199
Nahr Ibrahim	Chouane, Yahchouch, Fitri	8	32
Kadisha Valley	Bechare, Mar Licha, Blaouza II, Abu-Ali	11	21
Nahr Al Bared	Al Bared 1, Al Bared 2	5	17
Safa Spring	Richmaya-Safa	3	13
Total Capacity Installed (MW)			282

Table 3.6 Source: Energy Status in Lebanon and electricity

River	Plant	Capacity(MW)	Dam
Litani	Bisri	6	No
	Khardali	20	Yes
Safa	Zibli	4.5	No
	Richmaya	4.5	No
	Damour	4.5	No
Ibrahim	Hneidi	20	No
	Jannah	40	Yes
Assi	Yammouneh	10	Yes
	Hermel	50	Yes
Bared	Boumoussa	12	No
	Hamra	16	No
	Kasim	5	No
	Kottine	17.5	No
Abu-Ali	Bchnine	4	No
Total Capacity		214	-

The installed total capacity can be retained by performing the necessary rehabilitation of the power plants. In addition, MEW has previously developed a 10-year plan to take advantage of available water resources. This plan was never executed and had a capacity of additional 214 MW. The breakdown of rivers and plant for this plan are illustrated in the table below.

In addition to the available upgrade of the hydropower system through rehabilitation of old hydroelectric power stations and the construction of new ones mentioned above, there is a potential of 5 MW micro-hydro capacity. This capacity of 5 MW micro-hydro estimation includes irrigation channels, wastewater treatment plant intakes and electric power plant outfall channels l (Hdr.undp.org, 2014).

The volume capacity of the dammed water in Lebanon is majorly defined by the Qaraoun reservoir of the Litani river was estimated to store 222.8 MCM in the 1950's but is found to be only 200.7 MCM in 2013 due to natural sedimentation causing loss of 3% only in the last 50 years (Databank.com.lb., 2013). The effective capacity of the Qaraoun is 160 MCM which is used for hydropower and irrigation. On the other hand, 60 MCM are used for water storage for the dry season. (Arif, Doumani, 2013, p.50) SWIM.

In addition to the Qaraoun reservoir on the Litani river, a new reservoir that will be ready for filling April in 2022 is being constructed on Nahr Ibrahim river. This reservoir will have the water storage capacity of 38 MCM (Ebml.gov.lb, 2014).

Other dams that are planned to be added in the future are Bisri dam and Damour dam. Bisri dam designed to withhold a 125 MCM storage capacity at normal water level (NWL) with minimum water level of 10 MCM and maximum of 148 MCM and a power capacity of 11.2MW. The Damour dam is expected to have 32 MCM (Documents.worldbank.org, 2014).

Figure 3.10: Planned Bisri Dam (Council for Development and Reconstruction, 2014,vol.1, p.66)

There is also a potential of adding water reservoirs on the Assi river in the Hermel valley. The two dams that where planed and under construction by a Chinese contractor in 2015 which had water volume capacity of 27 and 37 MCM for two dams. Unfortunately, Israel bombed the construction site during the 2006 Lebanon war.

Creating hydro storage is very essential for a sustainable power supply by the hydro plants in Lebanon. As this process allow the power generation to stay constant to a certain extent throughout the year especially during the dry season which usually extends from midsummer to Autumn. Through the circulation of the water using pumped hydro storage, the water resources can be used more than once by being pumped through the low demand periods (night time, weekends, winter, etc.) to cover the deficit through peak demand periods. By doing so only smaller portion of water flow would be lost in the process.

According to the volume capacities of the projects mentioned above Lebanon is capable of achieving a volume of 600 MCM of water reservoirs and storages without technical and logistic obstacles if the investments and funding are available. Therefore, for the 2030 scenario for renewables' integration, 600 MW maximum installed capacity and 600 MCM is considered for the hydropower plants.

By taking 80m as an average height for the water reservoirs, the annual power rate can be calculated through the following equation:

$$W(J)= \rho(kg/m^3) \text{ x } V(m^3) \text{ x } g(m/s^2) \text{ x } h(m)$$

$$\text{Therefore, } W = 1000 \text{ x } 600 \text{ x } 10^6 \text{ x } 9.82 \text{ x } 8 = 131 \text{ GWh}$$

Natural Gas:

The natural gas has an important role to play in the renewable integration electric energy strategy due to what it offers in reduction of CO_2 emissions and cost. Although oil is the primary component in the energy mix today since it is easier to transport and store, natural gas would become much easier to handle when the infrastructure and facilities become available. This is said especially due to the oil and gas reserves that are discovered in the Lebanese water which carries a big potential in facilitating the shift from oil to gas as the main resource for electric power generation. Four of the seven thermal power plants in the countries are actually designed to operate on natural gas which would make them relatively ready for the using gas instead. Due to the reasons above, it is seen technically feasible for the thermal electric power generation to become 100% reliable on natural gas instead of fuel oil.

EnergyPlan Setup:

After gathering and computing all the parameters of the different resources for the energy mix, it is all set properly on EnergPlan to obtain the results and compare the different scenarios.

Demand:

The demand of 2030 was based on the demand of 2018 considering that it will be the same daily and seasonal trend of electricity consumption. is set to 40 TWh/year considering that it will be 1.6 times the demand of 2018. The factor is taken as a combination of an annual increase 0.5 annual increase in demand and 0.008 annual reduction due to the efficiency enhancement. This is assumption has been made since

Lebanon has pledged in the Paris 2016 climate change conference to achieve 10% reduction in power demand by 2030.

No changes have been made to the other demand components of the software which include heating, cooling, transport, industry fuel and water. This is due to the lack of the data collected and in the case of Lebanon they are completely independent of the electric energy system.

Supply:

In the Supply section, all the work done is limited to the following tabs: Electricity Only, Fuel Distribution and Biogases in Liquid & Gas Fuels.

Despite the desire to shift to 100% HFO free energy mix, two of the power plants that are currently operating on fuel oil have been recently rehabilitated and upgraded. Therefore, it would not be a good idea economically to get rid of them and it is seen better if these power plants serve their time until retirement date. In the meanwhile, all the other power plants would start to shift to NG after a rehabilitation which upgrade their capacity to 700 MW. In addition, to new power plants need to be constructed to meet the target 5045 MW capacity.

Table 3.7 Power Plants

Power Plant	**Fuel**	**Capacity**
Zouk	HFO	486
Jieh	HFO	359
Tyre	NG	700
Baalbek	NG	700
Zahrani	NG	700
Deir Ammar	NG	700
New PP1	NG	700
New PP2	NG	700
Total		5045

The methane production is set in the bio gas plant by inputting the amount of dry biomass and wet biomass in terms of total annual energy TWh/year. Therefore, the values attained before for the biomass is inserted here with dry biomass being 4.13 TWh/year and wet biomass being 0.25 TWh/year. Assuming the production of methane and the electric generation of this resource will be constant, the

The electricity consumption of a biogas plant is estimated to have an average of 8.5% relative to the total electric production (3.45 TWh). (Hans-Joachim, N., Andreas, L., Hans, O., Thomas, J. 2012, p. 5200) Although this consumption ranges between 3.7% and 17.4%, it is assumed that only 8.5% consumption would be guaranteed due to the technological advancement by 2030. This makes the electric energy consumption bio the biogas plant 293.25 TWh/year.

The numbers obtained for the biogas are used in EnergyPlan as they are. By inputting the annual dry biomass (4.13 TWh/year), annual wet biomass (0.25TWh/year) and the electricity consumption (293.25 GWh/year). On the other side the biogas output is set to 3.45 TWh/year. The methane produced in this process is to be added to the grid later on where it substitutes some of the NG used in the thermal power plants.

After setting the thermal power plants and the biogas plant, the fuel distribution is ready to be defined and is set in table:

Table 3.8 Table: Fuel Distribution

Fuel	NG	Oil	Biomass	Total
Capacity (MW)	4200	845	376.7	5421.7
Ratio	0.774665	0.155855	0.06948	1

The renewable resources are then added in the Supply section under "Electricity only" tab. The renewable technologies used in this scenario are limited to solar PV, dammed hydro power and pumped storage for dammed hydro. The Solar PV's total capacity is set to 1,500 MW as discussed earlier through the report. It will be associated with battery storage later on, but in this section only the capacity and the solar production distribution curve are defined. The distribution curve used in this scenario is the same curve generated in the base case using the solar data available. The only difference in this case is that EnergyPlan would multiply it by the 1,500 MW capacity instead to generate the output power.

The dammed hydro total capacity is set to 650 MW with an annual production of 6 TWh/year and pump efficiency of 0.8. The storage for the dammed hydro is defined with a 145 GWh and pump with the same specifications as the turbine which are 650 MW capacity and an efficiency of 0.8. The transmission line capacity of the system is set to 1,000 MW. Even though this system is aimed to not have any imported power, this option is set to make it easier to track any deficit and its amount which makes it easier to do corrections and changes to the system to fix it.

Balancing and Storage:

Balancing and storage is a really important tool in EnergyPlan especially when using intermittent renewables. This section allows a more flexible distribution by using the excess potential power produced during off-peak time as surplus and using it later during peak demand to cover the deficit in the system. The electricity storage does not specify the type of storage but rather the fundamental characteristics of the storage used. This makes it flexible to be used for any kind of energy storage such as compressed air energy storage, batteries, flywheel, etc. In this scenario it is used for battery storage which is provided to store the surplus produced by the solar PV.

The battery storage is defined by a charge and discharge capacity of 1,050 MW with an efficiency of an efficiency of 0.85 and 0.95 respectively. The total storage capacity is 1,500 MW.

Final Energy Mix:

The final energy mix is set by using unchanging capacities for renewables which comprise of solar PV and hydro power. In addition to that a changing capacity for the operating power plants' is considered between the values of 5,040 MW and 5,421 MW. This is done to test the variation in the energy mix contributing to supply the total demand with the observation being focused on the performance renewables and energy storage including stored hydro and batteries.

Preliminary Results:

After providing EnergyPlan with all the parameters of the renewables 2030 electricity scenario, the following figures are obtained showing the variations of the supply and the demand.

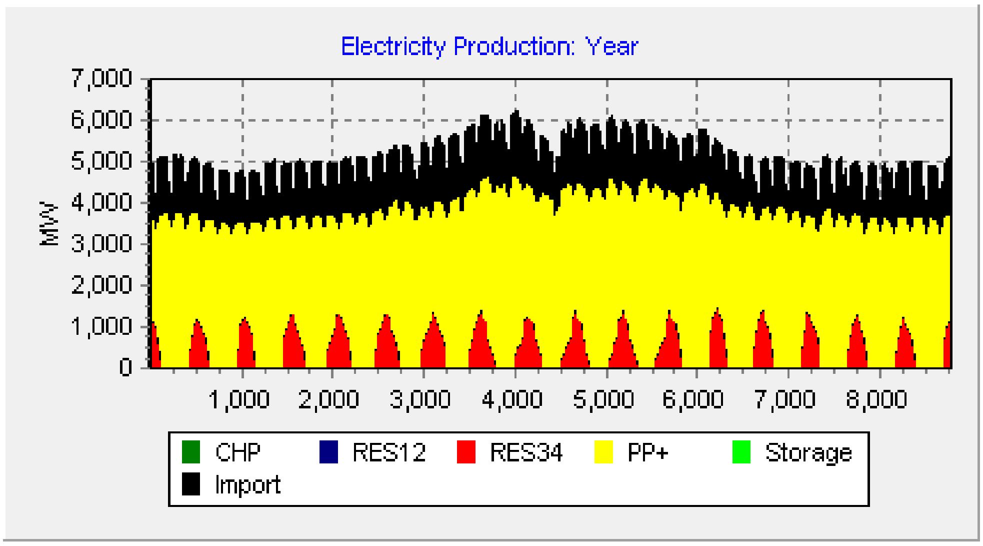

Figure 3.11: Electricity Production

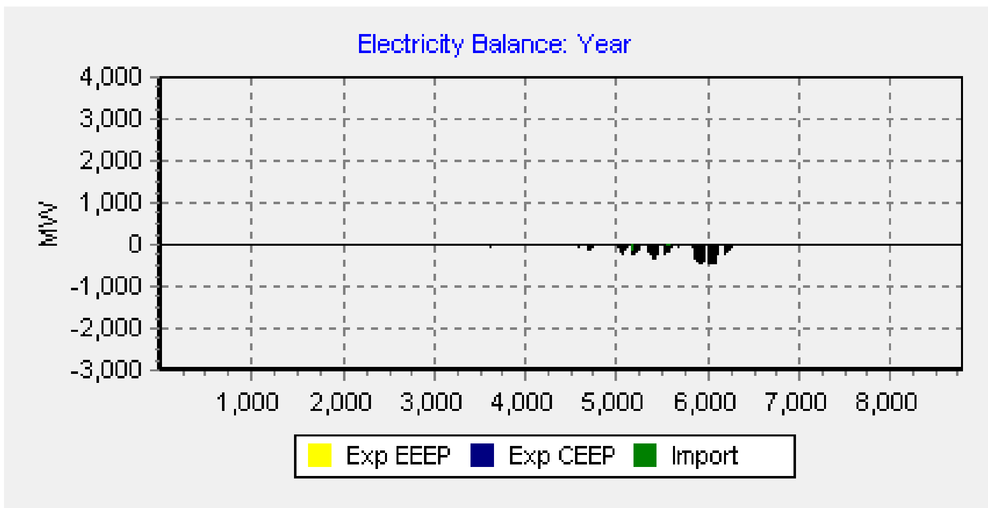

Figure 3.12: Deficit During High Demand Season

The results show a certain amount of deficit during July, August and September period of the year. The main reason of having the deficit is because the storage is not working in this case. This is due to the allowance of imported electric capacity which is covering the deficit instead of letting the potential surplus from the system to be stored and balance the unmet demand. Although, these results will not be used in the analysis ahead, this step is important to identify the period of the year in which the storage system needs to be used in order to balance the system.

The graphs below show the electric balance of a week in august which shows when, specifically, the storage is needed. The deficit is occurring in late hours of the day's peak demand just outside the daylight period which is caused by the decrease in the power supplied by solar PV. It is important to also point out at this point that EnergyPlan uses the flexibility of the power plants to block any excess power generation of power to feed the storage. Thus, to fix this, the imports should be disabled, and the minimum power supplied from power plants set. This would allow the power generated to exceed the demand during off peak periods allowing storage to occur. Unfortunately, this process cannot be applied on just certain periods or hours of the year as EnergyPlan uses one setting for the whole year. In order not to let that stand in the way of the analysis, the results taken from this case exclude August and September which will be extracted later on from the case where minimum power plant generation is set to allow charge and discharge take place.

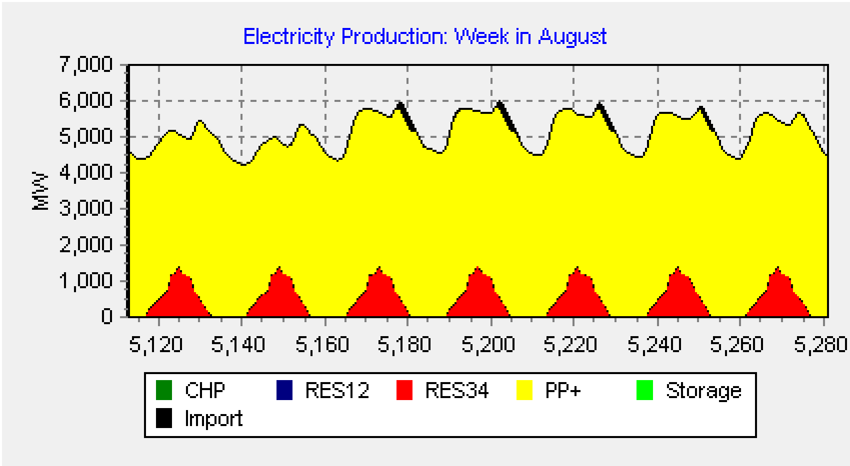

Figure 3.13Sugut Peak Demand Unmet

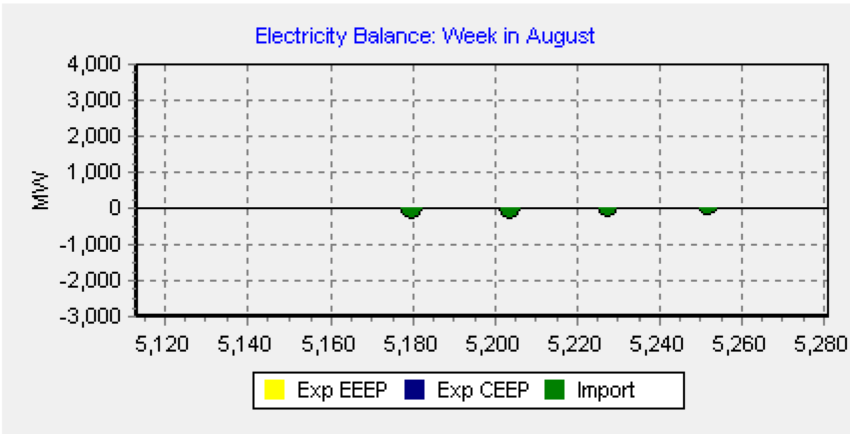

Figure 3.14: August Deficit

In order to close the gap between the supply and demand which is causing the deficit in the system, 3,000 MW is set as the minimum capacity for July and 4,470 MW is set as the minimum capacity for August and 4,000 MW for Sptember. By doing so, the storage charge and dicharge is activated covering the deficit in power supply. This makes the system self-sustainable and prevents the need of additional power to be imported to privately generated. Although in reality there is no need for the power plants to opertate The electricity production profile for a week in August can be seen in the figure below.

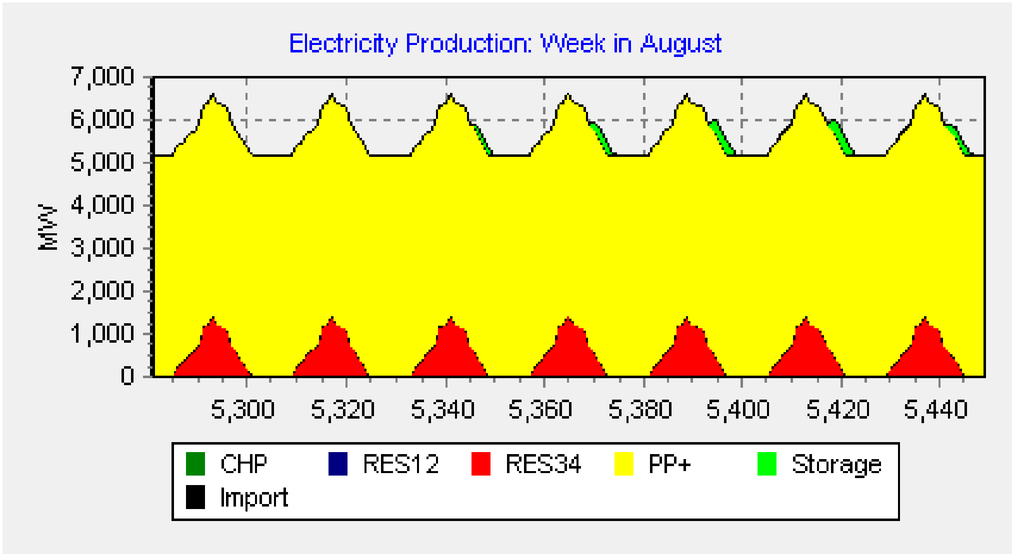

Figure 3.15: Storage Activated and Discharging Through Deficit Period

3.5 2030 Scenario – Fuel Oil / Diesel Oil

The oil-based power generation scenario is constructed based on the current electric power system. It is obtained by multiplying all the components of the supply and demand by the energy growth factor for the next 12 years which is 1.05^{12}. The fuel distribution is kept the same as the base case assuming no change in the supply except for their total capacity.

Peak demand is during the summer, with the electricity demand rising till it reaches its maximum. During this time the system reaches its highest deficit.

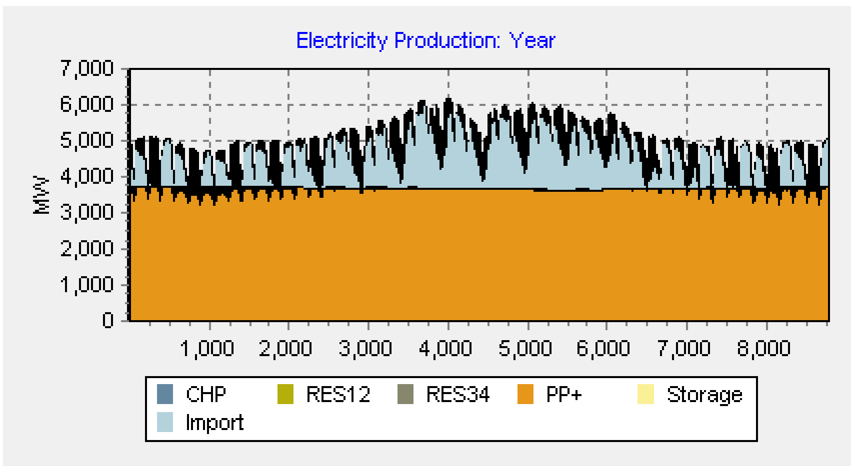

Figure 3.16: Electric Supply VS Demand

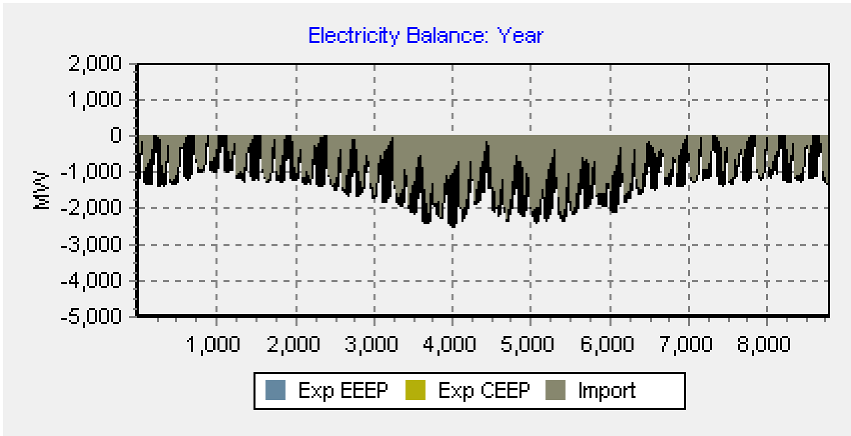

Figure 3.17: Deficit (MW) Covered by Private Generators

Cost and CO_2 Parameters Database

The EnergyPlan Cost Database provides the fuel costs, carbon dioxide costs and emissions, variable operation & maintenance costs, investment costs, fixed operation & maintenance costs and lifetimes. These details are available for heat & electricity, renewable energy, liquid & gas fuels, road vehicles, and water. The extracted data from this database are those that are essential and included in the scenarios modelled. The tables below illustrate the costs associated with fuel storages, thermal power plants, biogas plants and renewable energy. The costs in the original database are set in EUR which are converted to USD by using the exchange rate 1.16 $/€ extracted from XE Currency Converter (xe.com, 2018).

The cost of batter storage is Battery storage 69.5 $/kWh, which makes it 69.5 M$/GWh (Peters, 2018)

The interest rate assumed is 3%.

Table 3.9: Fuel Price

Fuel Prices ($/GJ)							
Year	Fuel Oil	NG	Diesel	Straw	Wood chips	Wood Pellets	Energy Crops
2020	13.80	10.56	17.40	4.52	5.92	11.83	5.45
2030	15.43	11.83	19.26	4.99	6.96	12.64	6.03
Average	14.62	11.19	18.33	4.76	6.44	12.24	5.74

Table 3.10: Investment Cost

Investment Cost (M$/Unit)									
	Hydro	Hydro Storage	Biogas plant	Biogas Upgrade	Large Power Plant	PV	Gas Storage	Oil Storage	Inter-connection
unit	MWe	GWh	TWh/year	MW Gas Out	MWe	MWe	GWh	GWh	MWe
2020	3.83	8.70	278.40	0.35	1.15	1.51	0.12	0	1.392
2030	3.83	8.70	278.40	0.35	1.14	1.28	0.12	0	1.392
Ave	3.83	8.70	278.40	0.35	1.14	1.39	0.12	0	1.392

Table 3.11: Fixed O&M

Fixed O&M (% of investment)										
Year	Large Power Plants	Hydro Storage	Pump/ turbine	Gas Storage	Hydro Power	PV	Biogas Plant	Biogas Upgrade	Oil storage	Inter-connection
2020	3.12	1.5	1.5	1.0	1.5	2.09	6.96	15.79	0.63	1
2030	3.16	1.5	1.5	1.0	1.5	1.38	6.96	17.65	0.63	1
Avr.	3.14	1.5	1.5	1.0	1.5	1.735	6.96	16.72	0.63	1

Table 3.12: Variable O&M Cost

Variable O&M COST($/MWh)	
Hydro Power	1.19
Condensing	2.654

Table 3.13: CO_2 Price

year	CO2 Price($/Ton)
2020	33.18
2030	40.14
Average	36.66

Table 3.14: Lifetime

Lifetime (years)					
Large Power Plant	Interconnection	PV	Hydro storage	Hydro pump	Biogas Plant
27	40	30	50	50	20

4 RESULTS

Following the modelling of the two different scenarios, the results are extracted to be analysed and discussed. These results include the final energy mix of the systems' produced power, the balance of the demand & supply showing any deficit in the form of imports and the financial cost of each system which is divided annually.

4.1 Model A – Renewables Integration

4.1.1 Energy Mix & Balance:

Table 4.1: Total Capacity and Annual Contribution

Supply	PV	Hydro	Biomass	Biogas	NG	Oil
Capacity (MW)	1500	650	376	385	4200	845
Annual (TWh)	4.1	4.8	2.2	2.0	22.7	4.9

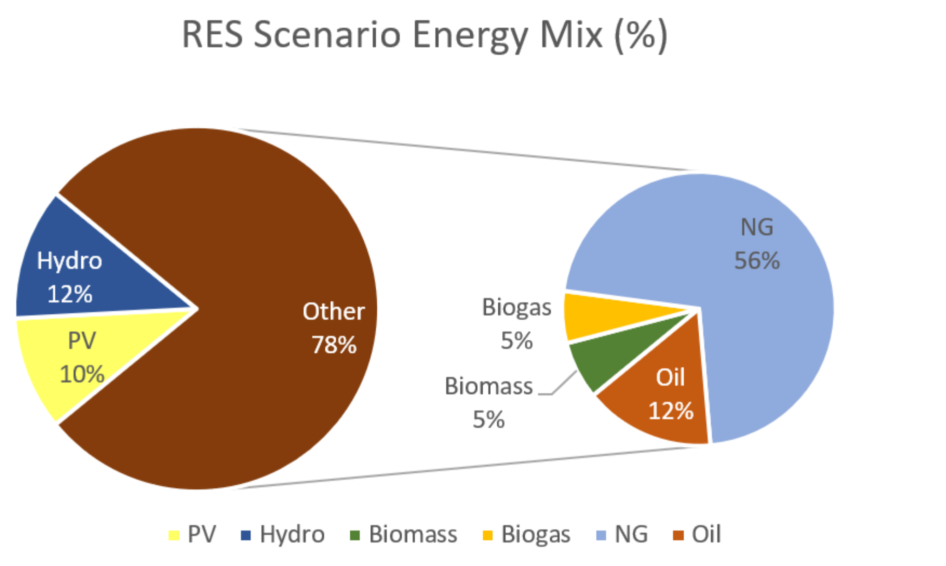

Figure 4.1: RES 2030 Energy Mix

The energy mix represented in the chart above shows that 22% of the total demand is supplied by solar PV and hydro power. This is significant in terms of the contribution to the CO_2 reduction the two technologies offer due to their low carbon footprint. Furthermore, 10% of the electric power is produced by biomass and biogas (5% each).

The rest is covered by fossil fuels, with 56% covered by NG and 12% by oil. This composition should reflect positively in the reduction of CO_2 emissions since all the components, except biomass, produce less CO_2 than fuel oil and diesel which are used in the current electric power generation. Biomass on the other, has more CO_2 emissions but brings in economic advantage as it is available in the national market and at relatively lower cost considering most of it is collected from residues.

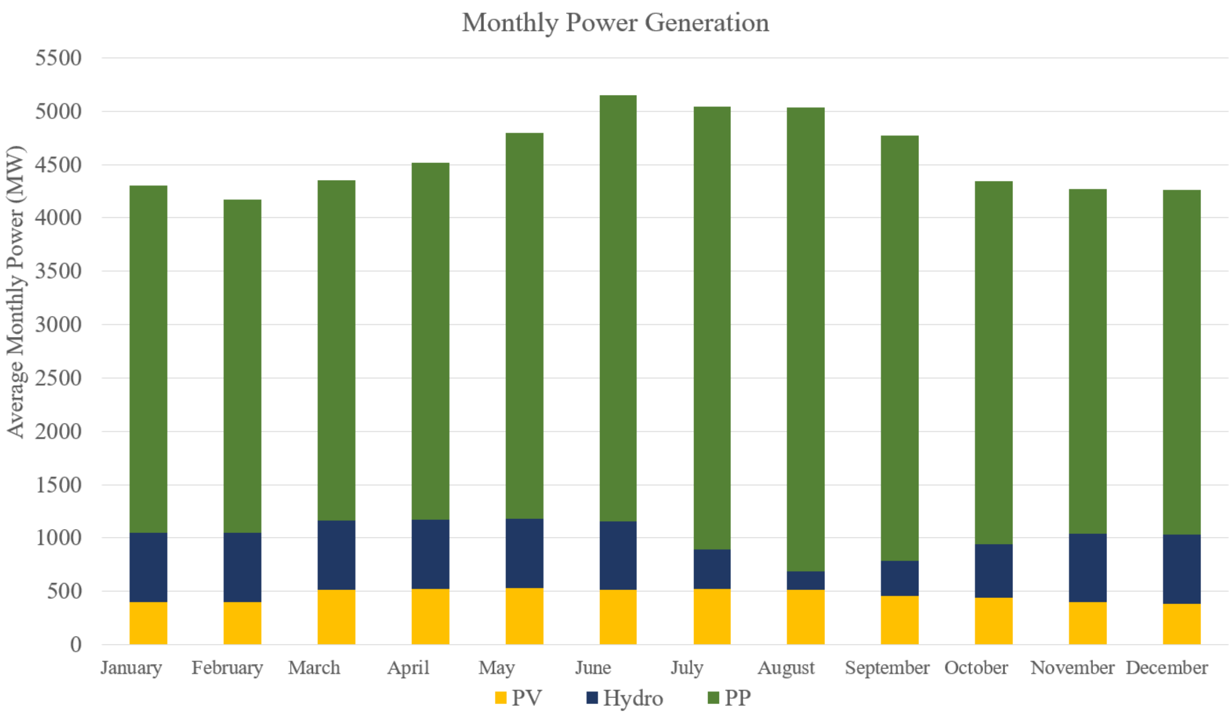

Figure 4.2: RES 2030 Monthly Power Generation

The chart above shows the variation of the monthly generated power between different energy sources. The PP generation includes the power produced by NG, oil, biomass and biogas power plants in addition to power supplied by batteries. The intermittency of the renewable resources is seen clearly as hydro reaches its minimum during the dry seasons and solar PV has its best performance during the sunny season through Spring and Summer.

Table 4.2: Monthly Average Power

MONTHLY AVERAGE VALUES (MW)						
Month	Demand	PV	Hydro	PP	CAES	PP+CAES
January	4306	396	650	3259	1332	4591
February	4168	398	650	3120	1274	4394
March	4352	514	650	3188	1302	4490
April	4521	521	650	3349	1369	4718
May	4799	527	650	3622	1480	5102
June	5151	515	638	3999	1633	5632
July	5044	521	373	4150	1696	5846
August	5038	515	175	4348	1776	6124
September	4770	459	327	3983	1628	5611
October	4346	441	497	3409	1392	4801
November	4271	402	638	3232	1321	4553
December	4264	384	647	3234	1321	4555
Annual Average	4587	466	544	3576	1461	5037
Annual Maximum	6220	1500	650	5400	2206	7606
Annual Minimum	3256	0	175	1917	783	2700
Annual (TWh)	40.29	4.1	4.78	31.41	9	44.25

4.1.2 Pumped Hydro Storage and Batteries Providing Flexibility

Pumped hydro in this system can provide high flexibility in terms of contributing to hydro storage which is essential for high peak demand periods. This can only be done by specifying a minimum operating power production from power plants. Otherwise, the system does not provide excess electricity as it prioritises the power produced by renewables and the role of the power plants will be top up the power produced by renewables just to meet the demand. This process should also enhance the charging and discharging of batteries thus improving their performance towards better contribution to the system. To observe the variation of the hydro power and storage with respect to the power plant power production, two cases are compared. In the first case having 0 MW as minimum power and the second having 3,000 MW.

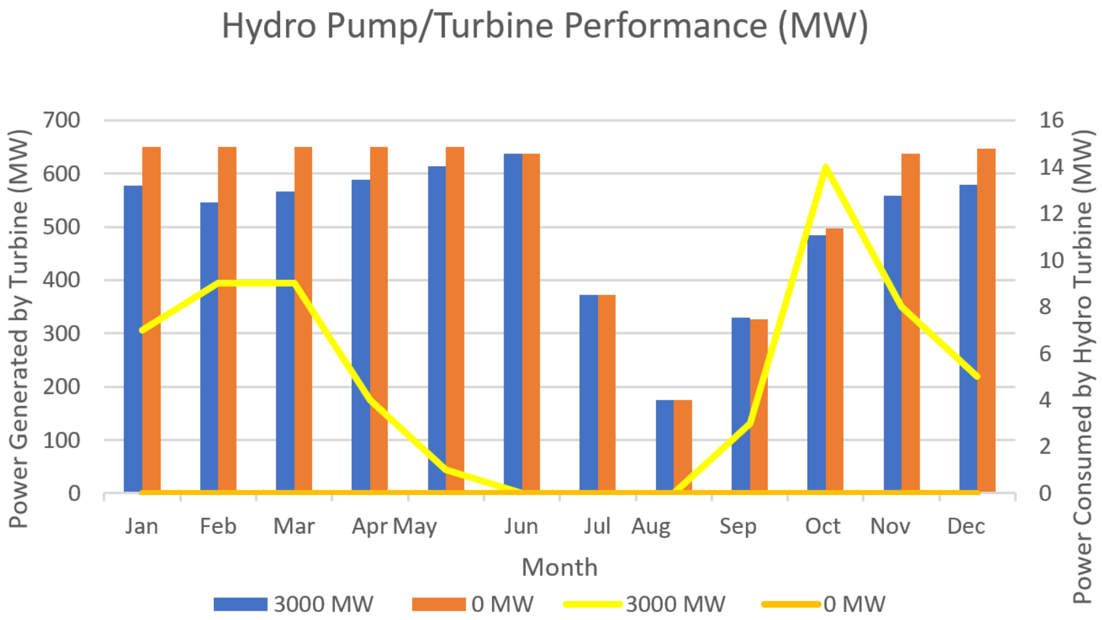

Figure 4.3: Variation of Hydro Power Production w.r.t Minimum PP Power

The chart above constitutes of two sets of data. The first one presenting the monthly electricity production by hydro turbine (MW) and represented as a bar. The second one is presenting the power (MW) consumption of hydro pump in the form of a curve. Taking the cases of 3,000 MW and 0 MW minimum PP power production, the graph shows that as the operation of the pump is activated the power produced by the turbine is reduced. It also shows that as the pump stops operating during the high electric demand period of the year, the power supplied starts decreasing drastically. This is caused by the lack of recovery of the hydro storage which causes reduction in capacity for the turbine. This can be seen in Figure 4.4 which shows that after the period after the pump stops operating (June), the storage drops to almost 0 GWh. Eventually, the pump gets back in service after the high demand season causing the refilling of the storage and the increase in the power produced by the turbine.

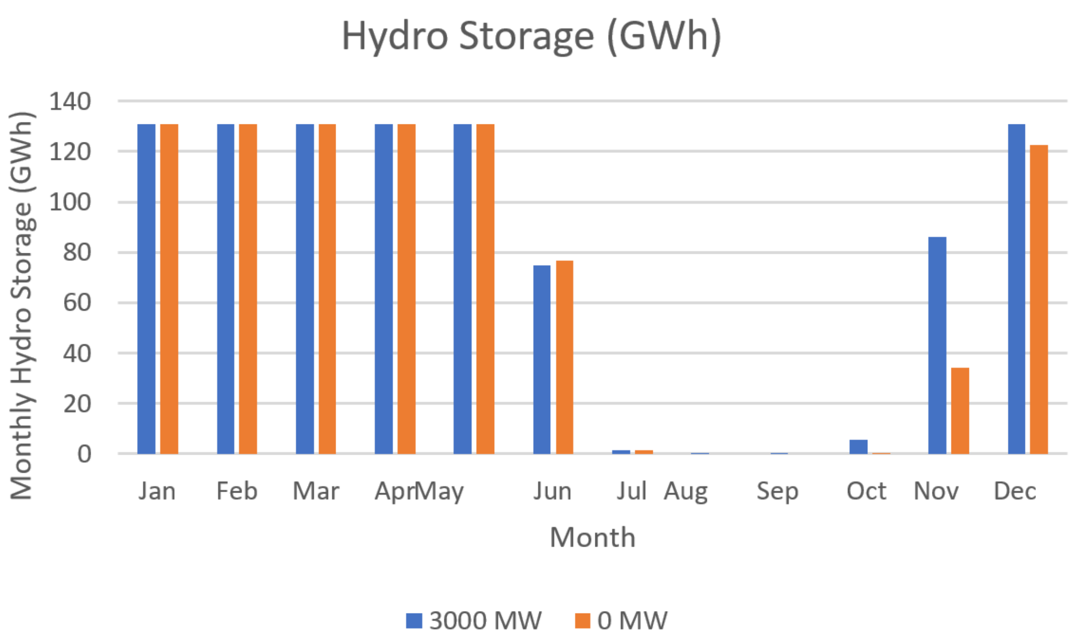

Figure 4.4: Variation of Storage w.r.t. Minimum PP Power Specified

This process shows its high importance to the recovery of the water in the hydro storage. Before applying the 3,000 MW minimum PP production, the hydro storage was not able to recover high capacity by the end of the year. Due to that the storage starts the new year from a capacity lower than the original capacity and if it happens consistently over the years the hydro storage system will not be able to contribute s it should to the grid.

As mentioned before, applying minimum PP power production does not reflect only on the hydro storage system but also on the battery effectiveness. The battery is included in the system under Compressed Air Energy Storage (CAES), yet the power produced and consumed by batteries cannot be easily traced as it is included within the total PP power produced. Although that is the case, there is an easy way to calculate the difference in the net monthly average power (MW) produced or consumed by the batteries. Since the demand and solar PV production are unchanged, the net difference in the battery performance between the 2 cases (0 and 3,000 MW minimum PP) can be calculated. Thus, the net difference in the net monthly average power consumed/produced by batteries can be calculated by the following equation:

$\Delta i_p = \Delta P_T + \Delta P_p + \Delta P_{CAES}$;

Where ΔP_{pp}: Difference in power produced during 3,000 MW minimum PP and 0 MW PP; ΔP_T: difference in the power produced by the turbine; ΔP_p: difference in the power consumed by pump; ΔP_{CAES}: difference in net power produced by batteries.

Table 4.3 CAES Performance

Power (MW)				
Month	$\Delta P_{Turbine}$	ΔP_{pump}	$\Delta P_{PP+CAES}$	ΔP_{CAES}
Jan	72	7	111	32
Feb	104	9	160	47
Mar	83	9	131	39
Apr	61	4	90	25
May	36	1	51	14
Jun	0	0	-1	-1
Jul,	1	0	1	0
Aug	0	0	0	0
Sep	-2	3	1	0
Oct	12	14	37	11
Nov	80	8	123	35
Dec	68	5	102	29
Annual (TWh)	**0.37**	**0.04**	**0.58**	**0.17**

4.2 Model B - Business as usual with electricity sector heavily dependent on Fuel Oil and Diesel Oil

The Fuel Oil and Diesel oil scenario is modelled based on a scaled version up of the electric energy system of present day Lebanon to meet the demands estimated for 2030. The aim of this model is to observe the outcomes of the current mix and its impacts on the economic, environmental and social life. By doing do, conclusions can be drawn to the advantages and disadvantages of this system compared to the first scenario which is aiming to integrate renewable resources into the system.

4.2.1 Energy Mix and Balance

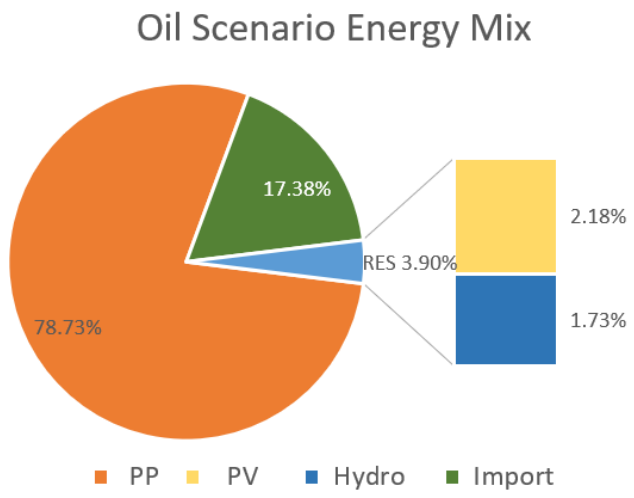

Figure 4.5: Oil 2030 Energy Mix

Figure 4.5 represents the percentage of the different energy sources contributing to the electric power system. PP which depends purely on heavy fuel oil, covers more than three quarters the demand with the percentage of its power production provided being 78.73%. The second highest contribution comes from import which represents the private diesel generators which operate to cover the deficit unmet by the EDL. The contribution of renewables in this scenario is only 3.9% which is divided to 2.18% solar PV and 1.73% Hydro power. The corresponding annual power (TWh/year) are shown in the table below.

Annual Power (TWh/year)			
Oil	Diesel	Solar	Hydro
31.49	6.95	0.87	0.69

The average monthly power generation (MW) is shown in the graph below. From the graph, it is seen that the PP power generation is constant and running at full capacity throughout the year. In this case the operation of the power plants is considered risky as there is no room for timeout. This type of operation holds the powerplant subject to fatigue and lack of maintenance and even break downs which would create a bigger burden of deficits and costs on the system. The performance of renewables is similar to their performance in the first model's scenario yet on a smaller scale. Hydro power is reduced to its minimum production during the dry season and peaks up during the winter. On the other hand, Solar PV's production reaches highest production during the Summer and early September.

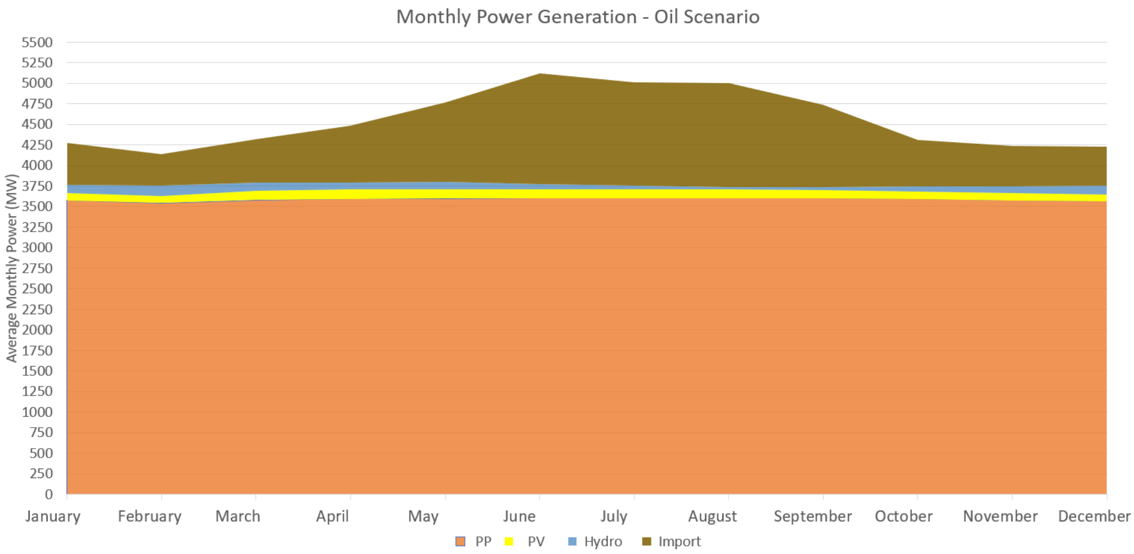

Figure 4.6 Monthly Power Generation for Oil 2030 Scenario

4.3 CO_2 Emissions

The CO_2 emissions are broken down according to each fuel's CO_2 emission factor (kg/GJ). After that, the final added sum of emissions from the system (Mton) is multiplied by a uniform price which is 36.66 $/ton. The total CO_2 emissions in the RES 2030 Scenario produced by oil, NG, methane, biogas and biomass is 10.707 Mton. After being multiplied by the CO_2 price, the total emission cost obtained is 393 MUSD. These figures reach 10.859 Mton annual CO_2 emissions and 398 MUSD cost when operating at minimum PP power production of 3,000 MW. On the other hand, for the oil 2030 scenario, the annual CO_2 emission produced is 23.01 Mton which costs 844 MUSD. This high increase in CO_2 emissions is linked directly to the high emission factor for fuel oil and the high amount of it used in the oil scenario energy mix

4.4 Cost Analysis

4.4.1 RES

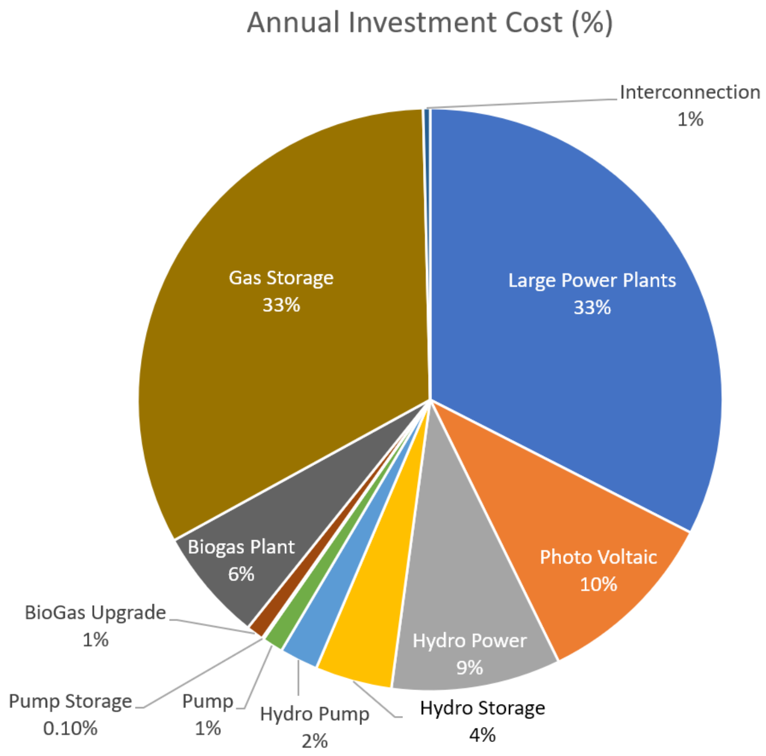

Figure 4.7 RES 2030 Annual Investment

The figure below shows the annual investment cost distribution in percentage. The annual investment cost is the yearly payment for the total cost of the infrastructure and equipment essential for the establishing the system. The distribution represents a total annual investment cost of 1,063 MUSD with the two highest percentages in the chart being large power plants and gas storage. Both have the same share and together they form 2 thirds of the total annual investment cost. That is natural considering that the highest contribution to the energy mix for electricity production is from NG at 56%. The lowest investment is made in pump storage which turned out to have a very vital role in the system in stabilisation of surplus and deficit.

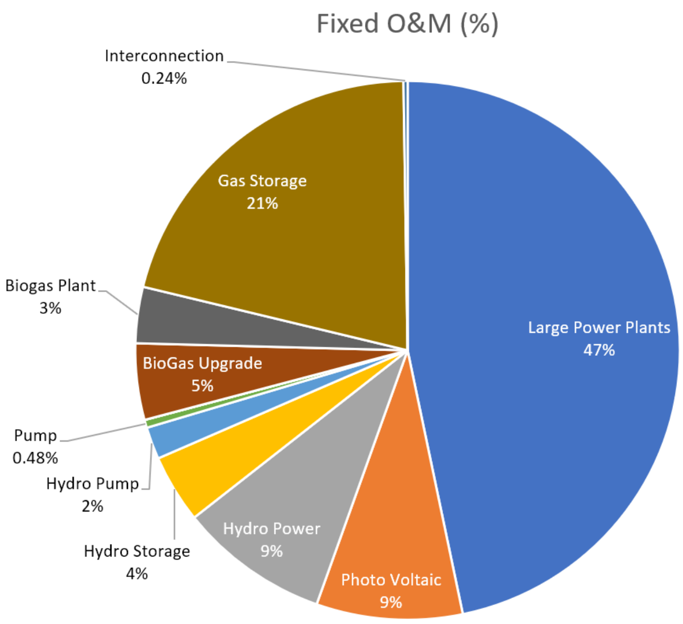

Figure 4.8: RES 2030 Fixed Operation & Maintenance Cost

Figure 4.8 represents O&M which is the operation and maintenance of the equipment and facilities to stay in good shape and serve properly for the longest period of time it applicable. The chart is a representation of the 415 MUSD cost of O&M in the RES 2030 energy plan. As expected, the large power plants (47%) have the highest percentage of the O&M cost with the second being gas storage (21%). With an equal percentage, both hydro and PV have the third highest percentage at 9%.

The variable annual cost (Figure 4.9), which is the highest among the costs (2,329 MUSD), represents the fuel costs, marginal operation cost and CO_2 emissions costs during the operation of the power system. These costs are subject to many different variables such as the demand, the availability of resources in the market, etc. NG has the highest percentage as a variable cost. In second place come the fuel oil costs and the CO_2 emissions costs, both at 17%.

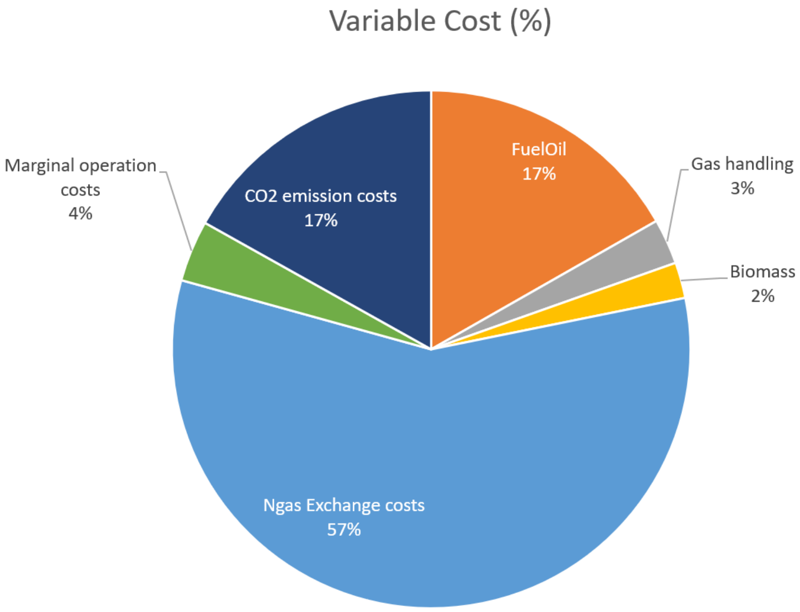

Figure 4.9: RES 2030 Variable Cost

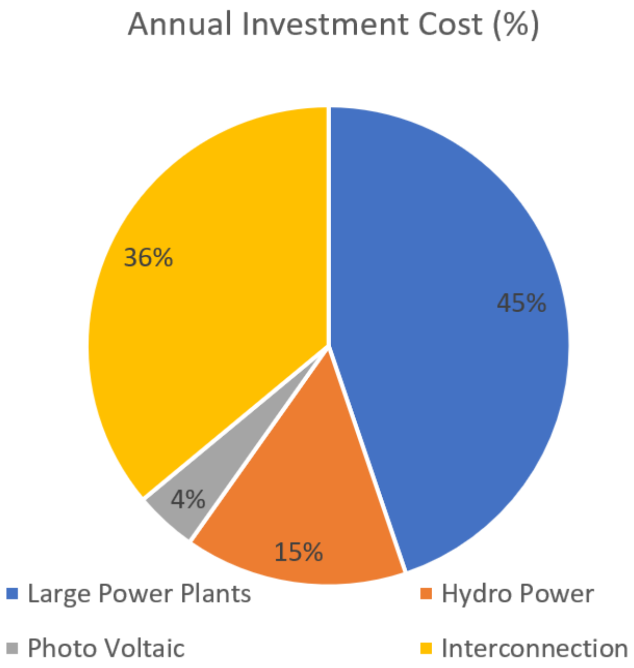

Figure 4.10: Oil 2030 Annual Investment Cost

4.5 Oil Scenario:

The annual investment cost for the Oil 2030 scenario in Figure 4.10 shows highest percentage for large power plants at 45%, interconnections at 36%, hydro power at 15% and PV at 4%. Although it might seem like a significant amount of the investment is going into interconnections, the actual the total cost is 502 MUSD only. It can be seen in the Oil 2030 scenario that not much infrastructure is needed to be built. That is because a relatively small capacity was specified for the fuel oil power plants and the system is still strongly dependant on private generators.

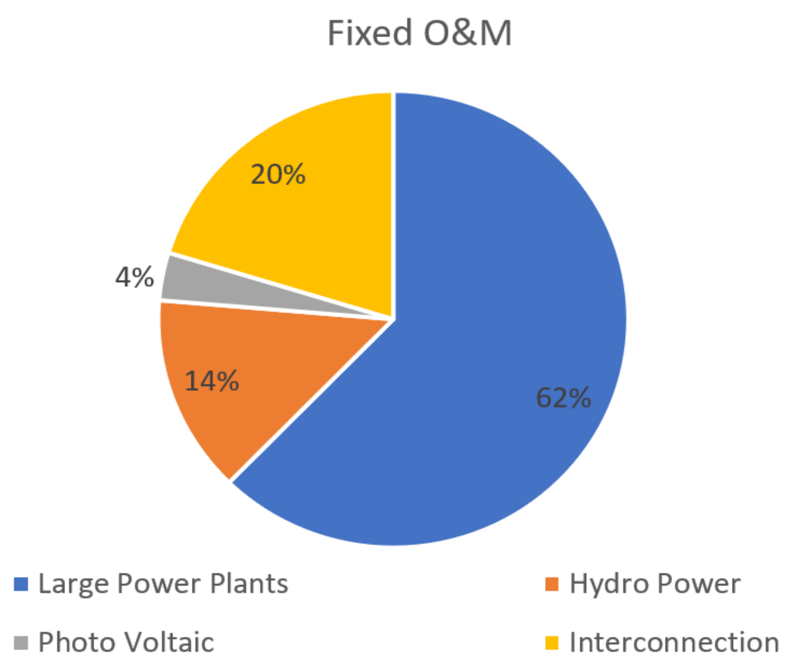

Figure 4.11: Fixed Operation & Maintenance Cost

The fixed O&M costs distribution is as follows: 62% large power plants, 20% Interconnection, 14% Hydro power and 4% PV. The chart represents 207 MUSD in total.

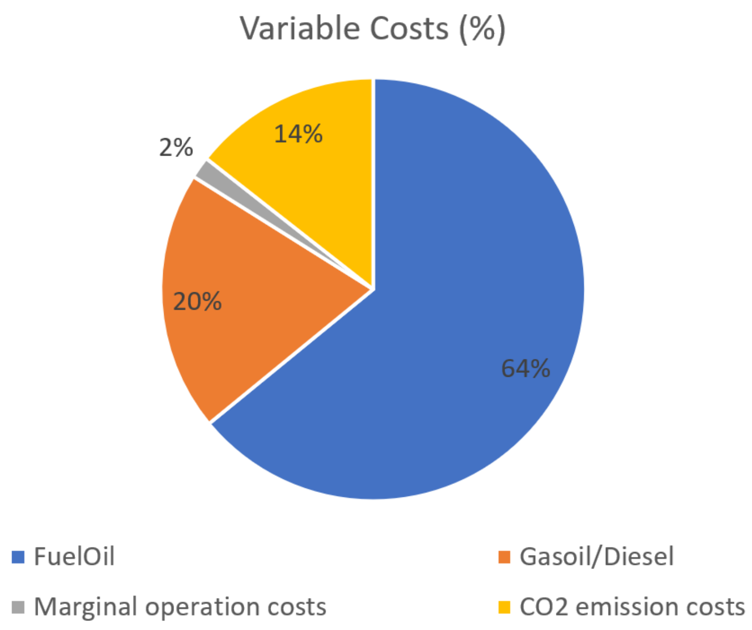

Figure 4.12: Oil 2030 Variable Cost

From the cost comparison table shown in table 4.4, it is seen that the annual investment cost for the RES 2030 is higher than the annual investment cost of Oil 2030 scenario by 534. RES 2030 also has a higher fixed O&M than Oil 2030. This time the difference is 208 MUSD. On the other hand, the variable cost changes things around as Oil 2030 scenario has a higher variable cost by a difference 3540 MUSD.

This shows that the RES 2030 would be more economic based on the variable cost in which the lack of heavy fuel oil usage and depending more on renewables cut the costs by a big margin.

Table 4.4: Cost Comparison Between RES & Oil 2030 Scenarios

	RES 2030 Scenario	Oil 2030 Scenario
Annual Investment Cost (MUSD)	1,036	502
Large Power Plants	337	225
Photo Voltaic	106	21
Hydro Power	97	75
Hydro Storage	44	0
Hydro Pump	22	0
Pump	12	0
Pump Storage	1	0
Biogas Upgrade	10	0
Biogas Plant	65	0
Gas Storage	338	0
Interconnection	4	181
Fixed O&M Cost (MUSD)	415	207
Large Power Plants	194	129
Photo Voltaic	36	7
Hydro Power	37	29
Hydro Storage	17	0
Hydro Pump	8	0
Pump	2	0
Pump Storage	0	0
Biogas Upgrade	19	0
Biogas Plant	14	0
Gas Storage	87	0
Interconnection	1	42
Variable Costs	2,329	5,869
FuelOil	390	3,759
Gas handling	66	1,168
Biomass	52	0
Ngas Exchange costs	1339	0
Marginal operation costs	89	98
CO2 emission costs	393	844
Total Annual Cost	3,780	6,578

Advantages and disadvantages of both scenarios

The advantages of the RES 2030 Scenario are: its flexibility in operation as it is capable of having standby powerplants, do maintenance and switch between different energy sources. On the other hand, if that was done without a study it might end up having even more costs than the Oil 2030 scenario. The advantages of Oil 2030 scenario are that it is simple and straight forward when it comes to operation and does not need any change in the infrastructure except for scaling up with the increase in demand. Yet this also mean that it will not have any positive impact on enhancing the infrastructure which would carry the country into more development. On an economic and environmental levels, RES 2030 definitely have the advantage. If implemented, RES 2030 will reduce the CO_2 emissions by margins, on the long term it can help finding solution for the reducing water levels each year through the infrastructure for the dams and storages and the country will be able to get a bit more sustainable.

Taking the renewable path will provide economic saving compared the fossil fuel-based electricity production. This kind of step will help enhance and advance the infrastructure while providing relatively cleaner energy and would create a better environment economic growth.

5 FINAL REMARKS

5.1 Conclusion

With the right amount of funding and investment Lebanon can reach 20% of electricity generated from renewables by 2030. This target is achievable if the investment is available due to the lack of environmental barriers. In fact, the country's environment plays an essential role in making such a shift occur due to the abundance of solar insolation throughout the year and the rivers that can be exploited for hydropower. These factors play a big role

In addition, such projects would solve a number of problems if achieved. For example, biogas plants have a big potential in solving the municipal waste disposal issues, high CO_2 emissions causing air pollution, providing water storages for use through the decline of water resources, and a step forward in enhancing the infrastructure on a national scale. Therefore, this kind of projects will provide an enhancement on the quality of life on a social, economic and environmental level

5.2 Limitations of this study

Lack of data stood in the way of including other renewable resources if otherwise available. It would have also made the analysis conducted more accurate.

Power data for the Lebanese current system are different from different sources and this is due to the high instability and variability of the power systems especially on the supply side.

Also, there were limitations in the EnergyPlan that could have done some of the analysis easier and more time efficient. For example, being able to use different settings for different periods of the year will be really helpful and assisting.

5.3 Direction for future investigations

5.3.1 Transmission Lines

The increasing load on the grid will demand that the transmission lines' capacity. Therefore, a study should be conducted for that purpose.

5.3.2 Environmental Impact Assessment

Environmental impact assessments should be specially carried out for infrastructure like dams since projects of this size might have enormous.

5.3.3 Wind and Wave

More studies need to be done in this area to gather more data that can contribute to the renewable energy plans .

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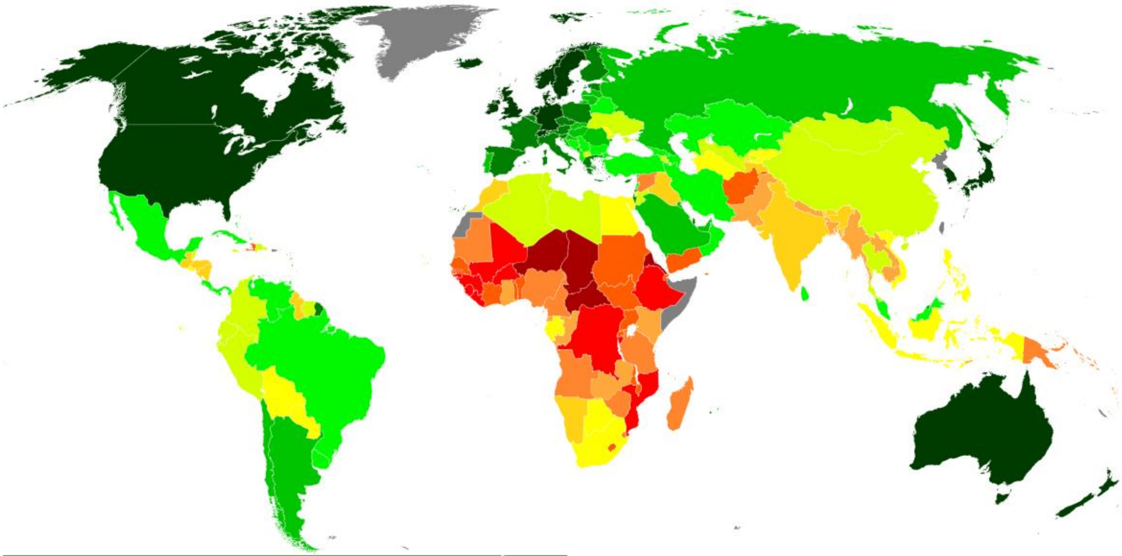
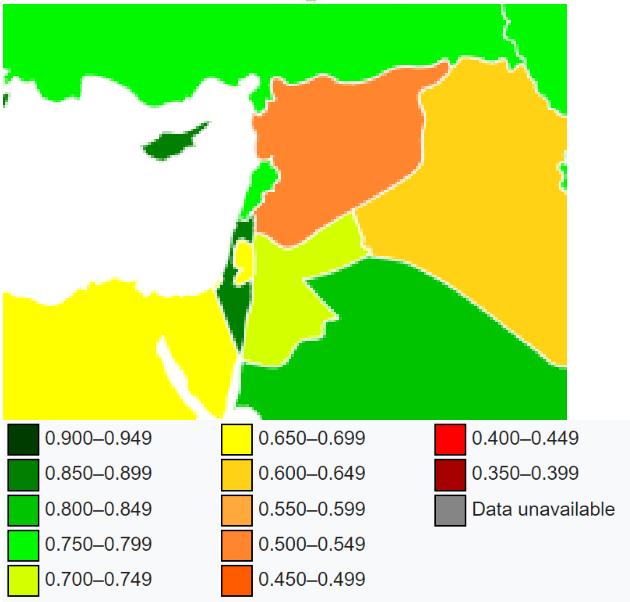
APENDIX

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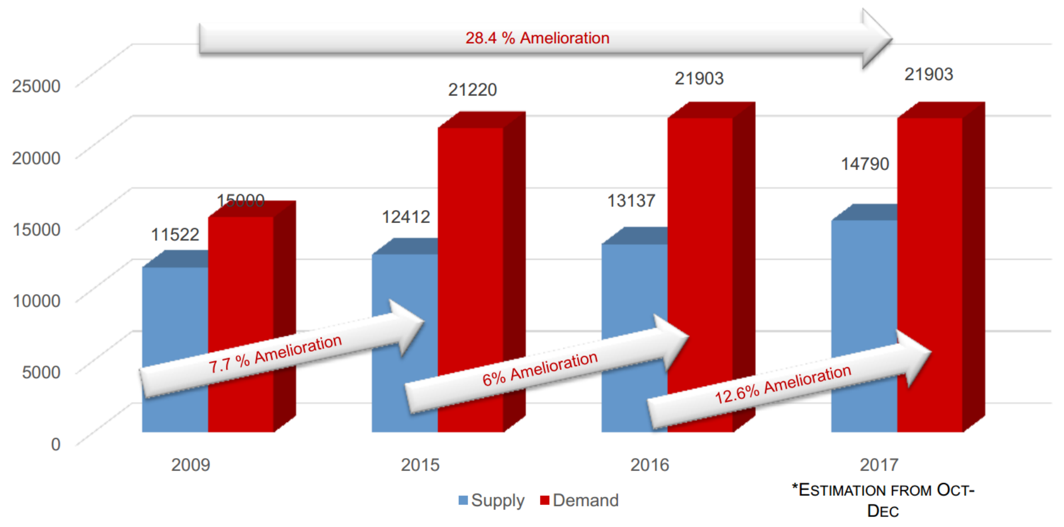
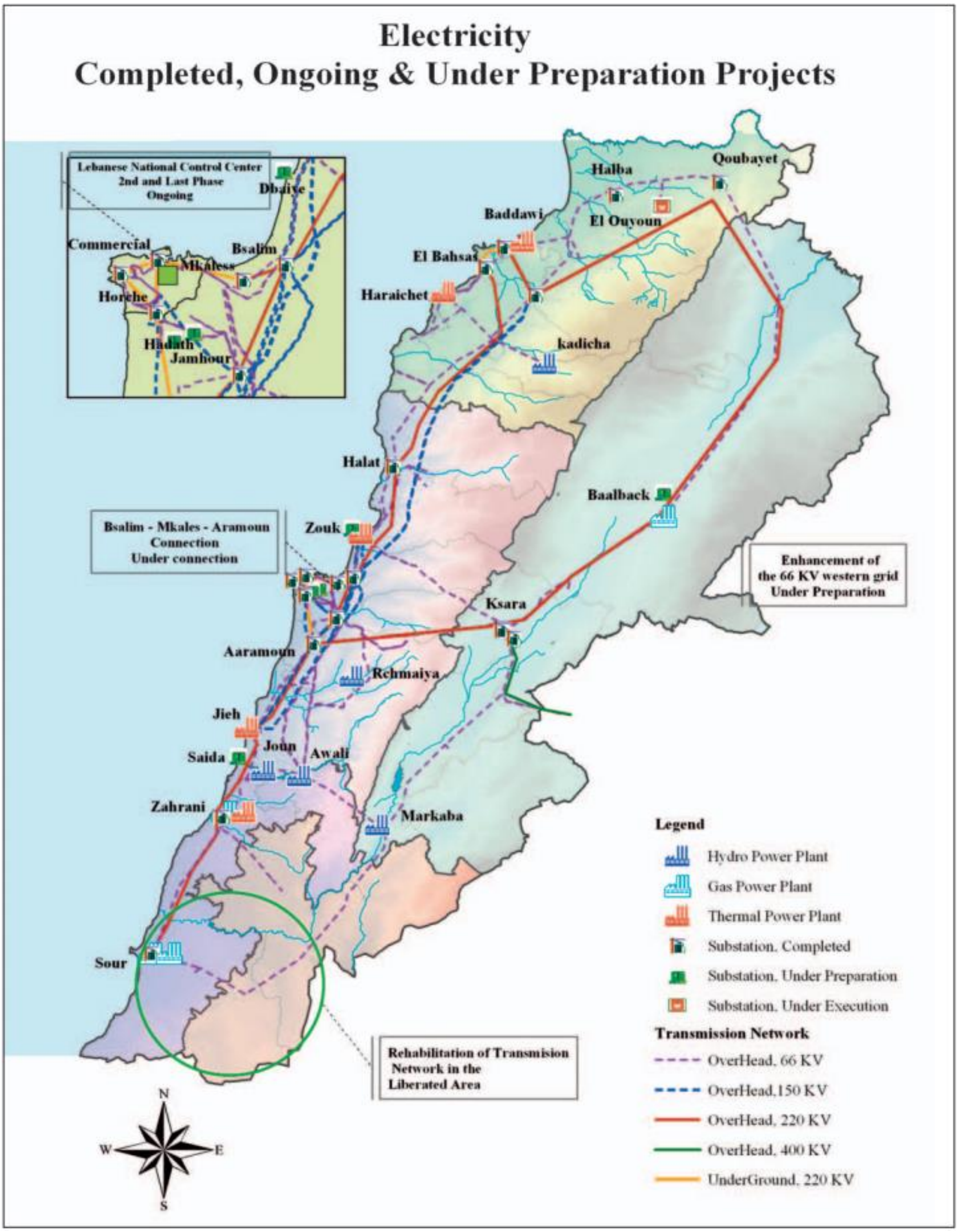


Table 5
Installed capacity of thermal power plants (data source: 1. [29], 2. [5], 3. [34]).

Thermal plant name	Installed capacity (MW)	Available capacity in 2008 (MW)	Commissioning date	Date of retirement	Type of fuel
Zouk (ST)	607[1]	365[3]	1984–1987[2]	2015[2]	HFO
Jieh (ST)	346[1]	187[3]	1971–1981[2]	2010[2]	HFO
Alhreesha (ST)	75[1]	60[2*]	1983[2]	2010[2]	HFO
Tyre (GT)	70[1]	70[3]	1996[2]	2021[2]	DO or NG
Baalbek (GT)	70[1]	70[3]	1996[2]	2021[2]	DO or NG
Zahrani (CC)	435[1]	435[3]	1997–1999[2]	2025–2030[2]	DO or NG
Deir-Ammar (CC)	435[1]	435[3]	1997–1999[2]	2025–2030[2]	DO or NG
Total	2038				

Table 6
Generation KPIs of power plants (data source: [42,43], and *[41]).

KPI	Availability factor (%)			Load factor (%)			Thermal efficiency (%)			Total cost/kW h sent out (US$)		
Year	2006	2007	2008	2006	2007	2008	2006	2007	2008	2006	2007	2008
Zouk	52.0	54.0	53.0	44.0	40.4	53.0	34.2	36.0	33.2	9.1*	0.11	0.19
Jieh	62.0	74.4	74.0	53.0	54.0	63.0	29.7	28.9	30.3	10.42*	0.13	0.20
Deir-Ammar	64.4	96.0	97.0	59.5	53.0	82.3	44.4	46.0	47.7	11.64*	0.13	0.21
Zahrani	77.9	92.0	91.0	50.8	73.0	76.3	44.9	46.0	46.1	11.4*	0.13	0.21
Tyre	44*	80.0	NA	20.8	24.1	43.4	26.8	28.7	28.1	19.2*	0.22	0.32
Baalbeck	44*	97.6	NA	22.9	64.5	42.7	28.4	28.0	28.1	18.2*	0.20	0.32
System Average	62.0	78.0	77.0	47.8	49.8	60.0	39.6	38.8	40.0	NA	0.13	0.20



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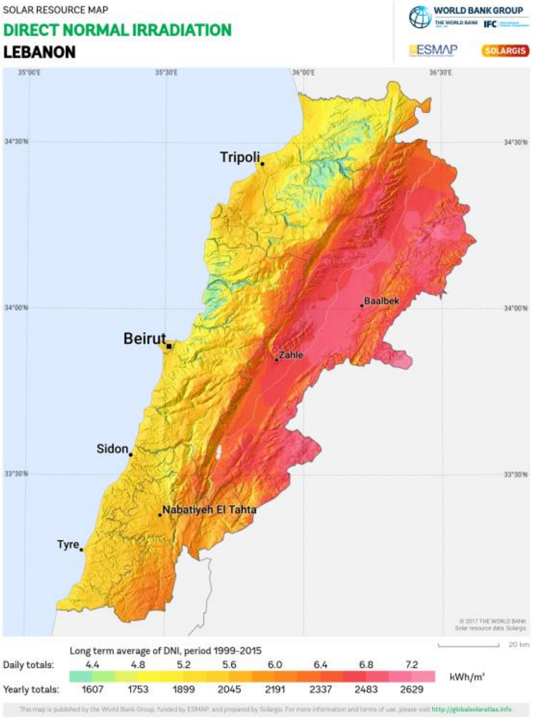
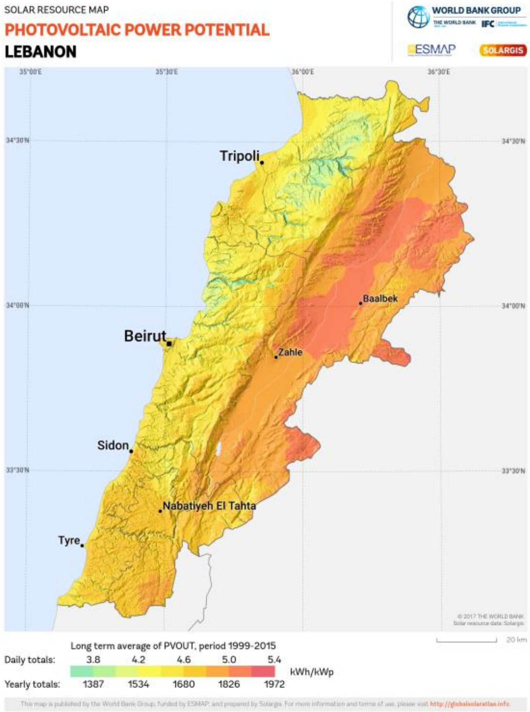
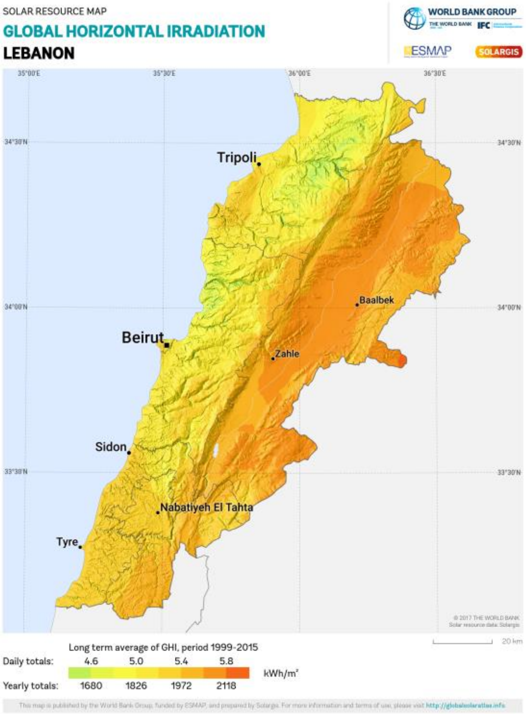
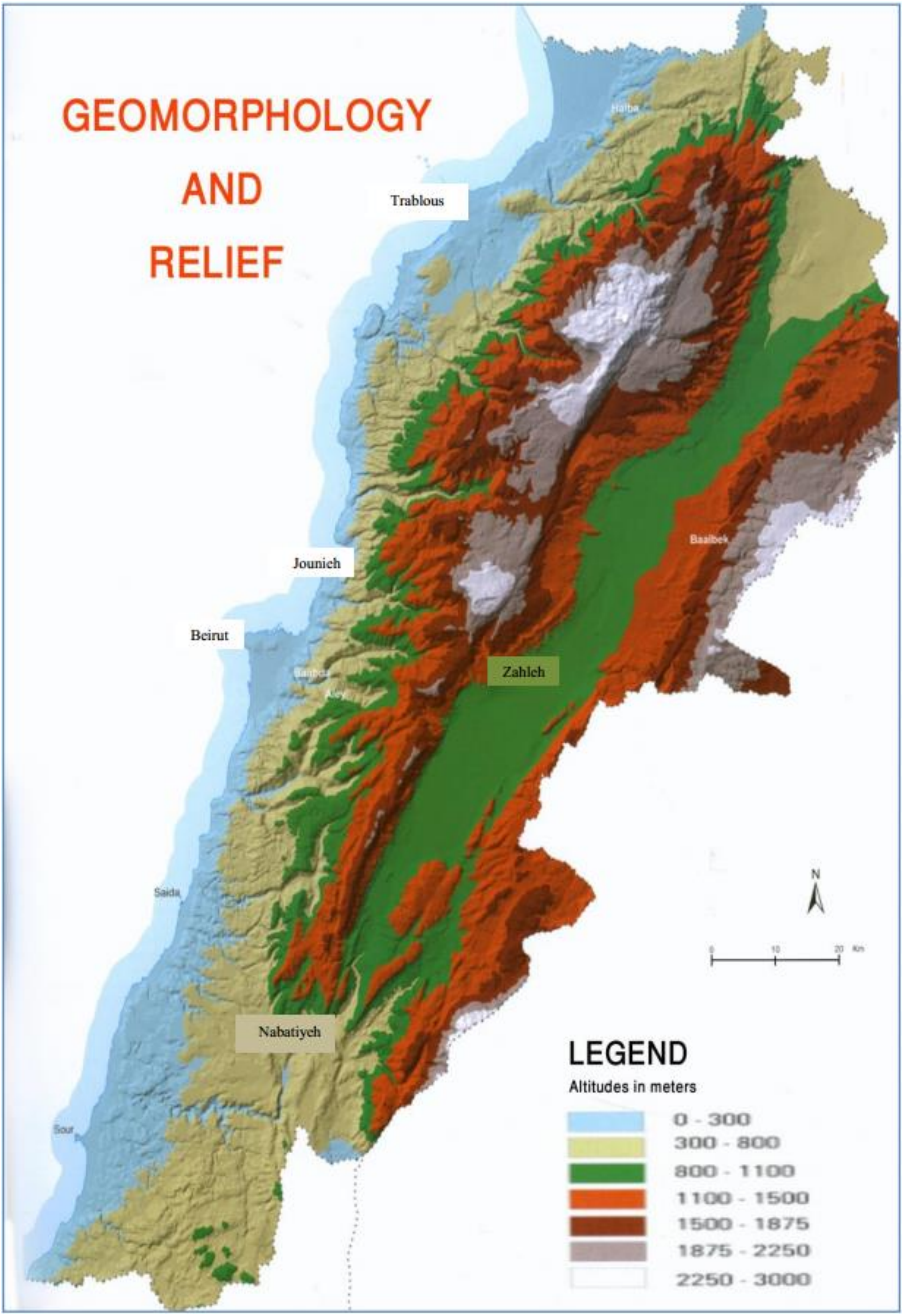
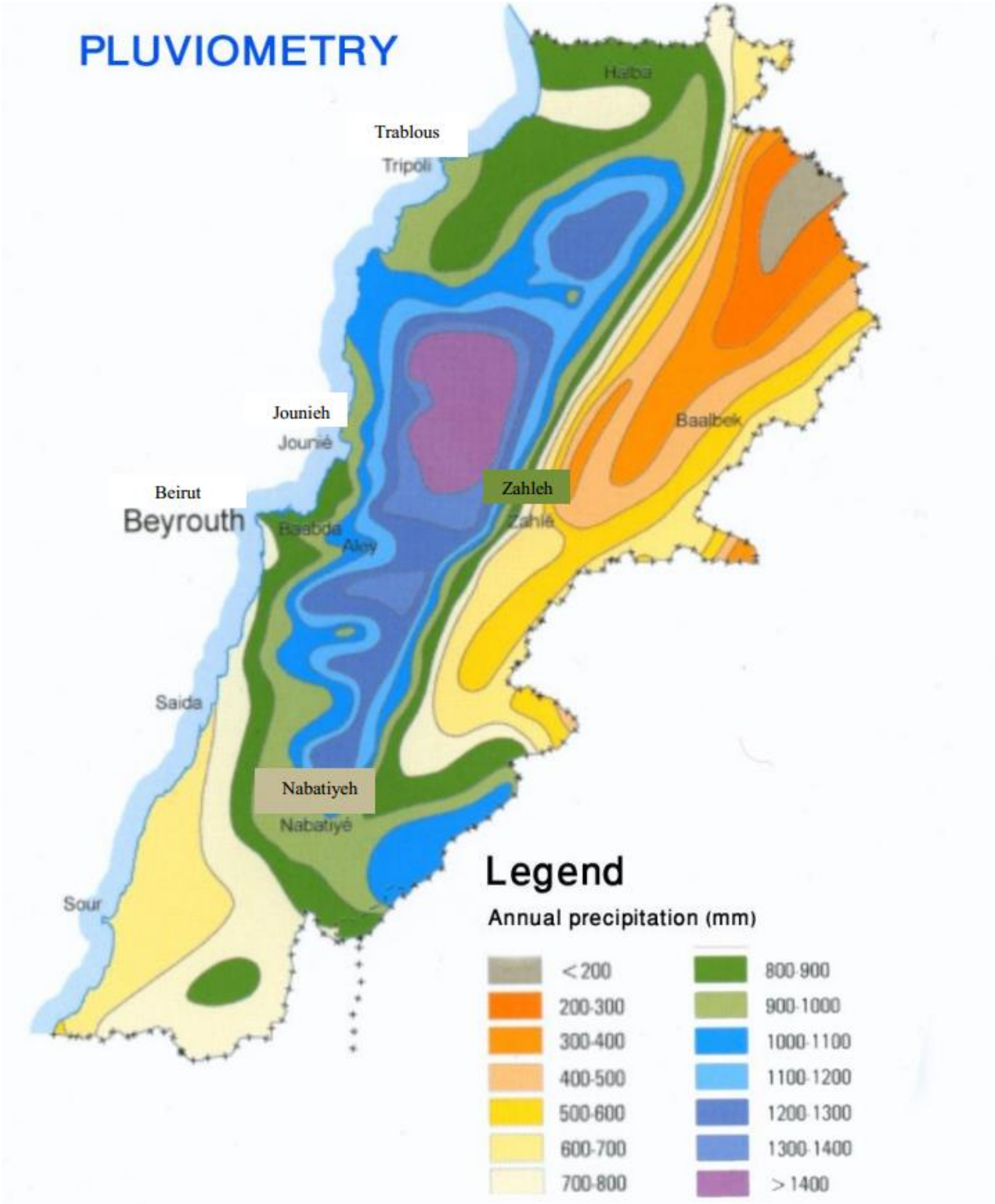
Solar


SOLAR RESOURCE MAP
DIRECT NORMAL IRRADIATION
LEBANON
WORLD BANK GROUP
ESMAP
SOLARGIS
Tripoli
Baalbek
Beirut
Zahle
Sidon
Nabatiyeh El Tahta
Tyre
Long term average of DNI, period 1999-2015
Daily totals: 4.4 4.8 5.2 5.6 6.0 6.4 6.8 7.2
Yearly totals: 1607 1753 1899 2045 2191 2337 2483 2629
kWh/m²


SOLAR RESOURCE MAP
PHOTOVOLTAIC POWER POTENTIAL
LEBANON
WORLD BANK GROUP
ESMAP
SOLARGIS
Tripoli
Baalbek
Beirut
Zahle
Sidon
Nabatiyeh El Tahta
Tyre
Long term average of PVOUT, period 1999-2015
Daily totals: 3.8 4.2 4.6 5.0 5.4
Yearly totals: 1387 1534 1680 1826 1972
kWh/kWp


SOLAR RESOURCE MAP
GLOBAL HORIZONTAL IRRADIATION
LEBANON
WORLD BANK GROUP
ESMAP
SOLARGIS
Tripoli
Baalbek
Beirut
Zahle
Sidon
Nabatiyeh El Tahta
Tyre
Long term average of GHI, period 1999-2015
Daily totals: 4.6 5.0 5.4 5.8
Yearly totals: 1680 1826 1972 2118
kWh/m²


GEOMORPHOLOGY
AND
RELIEF
Halba
Trablous
Baalbek
Jounieh
Beirut
Zahleh
Saida
Nabatiyeh
Sour
N
LEGEND
Altitudes in meters
0 - 300
300 - 800
800 - 1100
1100 - 1500
1500 - 1875
1875 - 2250
2250 - 3000


PLUVIOMETRY
Halba
Trablous
Tripoli
Jounieh
Jounié
Beirut
Beyrouth
Baabda
Aley
Zahleh
Zahlé
Baalbek
Saida
Nabatiyeh
Nabatiyé
Sour
Legend
Annual precipitation (mm)
< 200
200-300
300-400
400-500
500-600
600-700
700-800
800-900
900-1000
1000-1100
1100-1200
1200-1300
1300-1400
> 1400