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Renewable Energy in Lebanon

Economic, Technical and Environmental Feasibility

By

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A thesis

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# Renewable Energy in Lebanon

## Economic, Technical and Environmental Feasibility

Suzan M. Rakha

### Abstract

This thesis examines the current situation of electricity in Lebanon by highlighting the gaps and shortages from the supply side. It draws an estimation of the growing gap between electricity supply and electricity demand in the long-term. Moreover, it studies the economic feasibility of several electricity systems as Natural Gas CCGT, Diesel CCGT, Wind and concentrating solar power by taking into account the related initial cost, the generating cost and the environmental externality cost. Then, a technical feasibility is drawn in the Lebanese context to show the readiness of Lebanon to launch the green energy and to shift to cleaner energy as natural gas. Besides, this thesis highlights the mechanism of the electricity sector under current monopoly and under a liberal scenario with market competition. It shows how the role of legislations is crucial in drawing market efficiency and power diversification based on pure profit motives. This study observes the economic, environmental, and technical feasibility of the renewable energies and natural gas without ignoring the legal side as the key for sector success.

Keywords: Electricity Sector, Power Gap, Renewable Energy, Green Energy, Monopoly and Competition.

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## **List of abbreviations**

ALMEE: The Lebanese Association for Energy Saving & for Environment  
AUB: American University in Beirut  
BM: Build margin  
BTU: British Thermal Unit  
C: Carbon  
CCGT: the combined cycle gas turbine  
CDM: Clean Development Mechanism  
CDR: Council of Development and Reconstruction  
CEDRO: The Country Energy Efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon  
CER: Certified emission reduction  
CO<sub>2</sub>: Carbon Dioxide  
CSP: Solar Concentrating Power  
DNA: Designated National Authority  
DNI: Direct Normal Irradiance  
EDL: Electricité du Liban  
Elard: Earth Link and advanced Resources Development  
ETSAP: Energy Technology System Analysis Program  
EU: European Union  
FIT: Feed in tariff law  
GDP: Gross Domestic Product  
GEC: Global Environment Center Foundation  
GHG: Greenhouse Gas Emissions  
GW: Gigawatts  
HCSS: The Hydrocarbon Strategy Study  
HFO: Heavy Fuel Oil  
IEA: International Energy Agency  
IPPs: Independent Power Producers  
LNG: Liquefied natural gas  
MBTU: One thousand British Thermal Unit  
MEEZ: Middle East Economic Survey  
MMBTU: Thousand Thousand of BTU  
MW: Megawatts  
NG: Natural gas  
NO<sub>x</sub>: Nitrogen Oxide  
NREL: National Renewable Energy Laboratory  
NSCC: The National Control Center  
O&M: operating and maintenance  
OM: Operating margin  
PAH: Polycyclic Aromatic Hydrocarbons

RE: Renewable Energy

SCADA: the Supervisory Control and Data Acquisition

SCC: the social cost of Carbon

SO<sub>x</sub>: Sulfur Oxide

Sq.km or Km<sup>2</sup>: square Kilometer

Sq.m or m<sup>2</sup>: Square Meter

UNEP: United Nation Environmental Program

UNFCCC: United Nations Framework Convention on Climate Change

World Bank: WB

# **Chapter I**

## **An overview of the electricity issue in Lebanon**

The detrimental situation of the electricity sector in Lebanon lies in the security of supply, the astronomic economic cost paid for electricity, and the exclusive dependency on oil.

EDL( Electricité du Liban) is incapable of supplying the electricity demanded by households on a consistent and reliable basis. Many Lebanese regions are suffering from severe outages and power cutoff sessions reaching in some areas around 18 hours during summer 2012. It is crucial to note that this electric instability is progressive with time due to a perpetual increase in demand and perpetual decay of the existing power plants. Moreover, the electricity sector in Lebanon is capturing around one fifth of the public expenditure while holding a sterile development state. During 2011, the electricity sector alone received around \$1.75 billion in form of public transfers in order to subsidize electricity generated and provided to the main user (Ministry of Finance, 2012). These transfers are mainly to pay for the progressively increasing cost of oil on which the Lebanese sector is strictly dependent.

This chapter sheds lights on the barriers forbidding a security of supply; it identifies the economic loss endured by the society due to electricity sector failure and it highlights the environmental loss that occurs due to oil dependency.

## **Security of Supply**

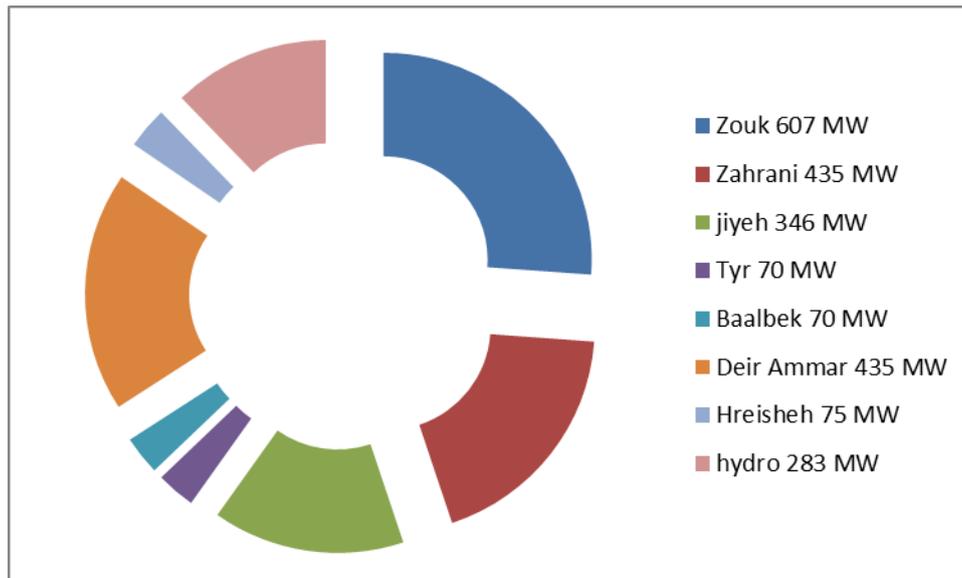
In Lebanon, there are 7 thermal plants from which there are 3 plants operating on HFO (Heavy Fuel Oil), and there are 4 plants operating on diesel<sup>1</sup>. The total capacity of thermal plants is around 2038 megawatt (MW), but they are operating at a capacity less than 1500 MW due to fuel shortage and technical decay. Moreover, there are hydro power energy plants along the various Lebanese rivers, installed for 283 MW of total capacity but actually accounting for 190MW due to aging equipment (see figure 1 for plants initial capacity shares). Also, Lebanon is importing around 68 MW of electricity from Syria and 60 MW from Egypt. But these imported sources of energy were never reliable and consistent neither in frequency nor in volume. According to EDL data records, Syrian imported electricity supply was frequently fluctuating and sometimes totally cut, while the Egyptian electricity imported was totally cut since March 2012<sup>2</sup>. This inconsistent electricity imported and estimated to be around 7.5% of the total electricity supplied, imposes a question of energy independency as an option to secure reliable supply.

The Lebanese electricity plants, thermal and hydro, are not operating at full capacity and the power generated is not fully consumed by the end user due to a considerable amount of electricity loss during the generation, transmission and distribution processes.

---

<sup>1</sup> These plants are designed to operate on Natural Gas but due to unavailability, they are operating on diesel.

<sup>2</sup> Last EDL record received for this paper was for August 2012.



**Figure 1: Plant initial capacity shares**

**The detrimental situation of the plants and the networks.** The civil war and delayed contingent reform inflicted upon EDL several damages of physical, financial and managerial nature. During July 2006 War, Israel targeted the storage tanks of Jieh power plants located in the South and fuel storages along the coast<sup>3</sup>. Moreover, During summer 2007, the battle of Nahr Al Bared in the North caused fractional plant damage in Beddawi which resulted in a decline of the electricity supplied in North Lebanon. The CDR (Council of Development and Reconstruction) in Lebanon dedicated 17% of the money invested in the postwar reconstruction in the power sector which is about \$1.6 billion (CDR, 2010). Also due to inefficient managerial process and technical deficiencies, EDL is operating yearly at a cost surpassing \$ 2 billion (Ministry of Finance, 2011). These subsidies are subject to increase due to oil dependency and inefficient generation process.

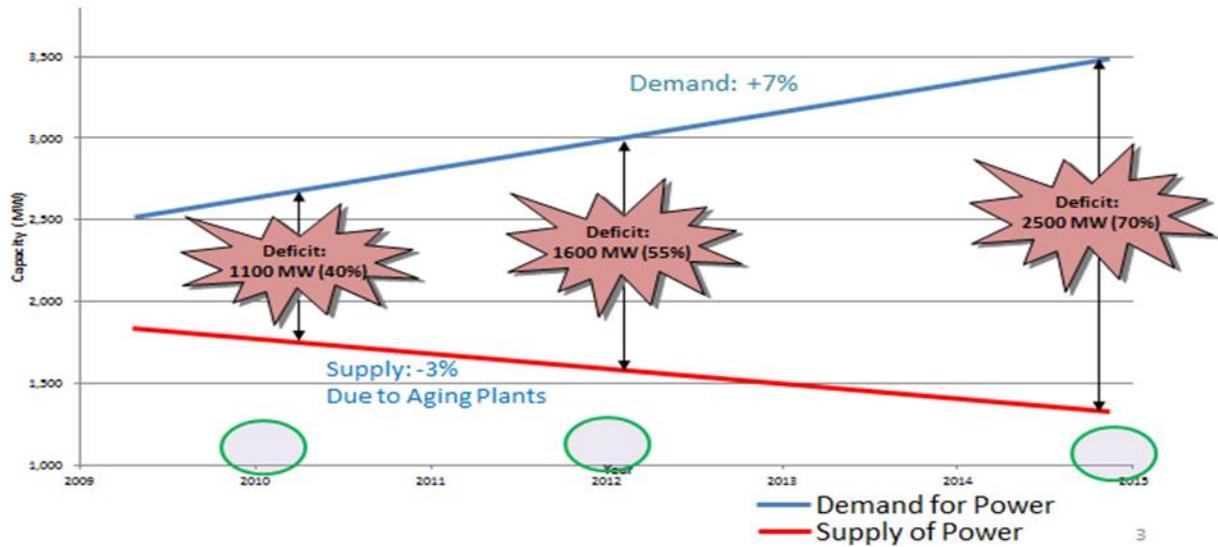
Many reasons are contributing to the drop of electricity supply provided by these plants and to the inefficient use of electricity generated. First, *plants decay* and the absence

<sup>3</sup> The destruction of oil storages during the WAR 2006 caused intense environmental damages along the Mediterranean coast due to oil spills.

of systematic plant rehabilitation are resulting perpetually and progressively in a drop in generating capacity. Plants are becoming less efficient due to insufficient and inconsistent maintenance and due to unreliable asset.

The non-rehabilitated plants, Zouk and Jieh, for example, are suffering from a deviation in their efficiency in terms of fuel/KWh generated, and this deviation is measured to be around 15 to 25% less than the original design of the plants. The maintenance of the existing power plant would have the effect to stretch up operated capacity (Ministry of Energy and Water, 2010). Rehabilitating and upgrading existing plants may be a worthy opportunity to meet a part of the growing demand, whereas neglecting the prevailing progressive decay would cause economic cost due to draining resources and inefficient generation processes. The plant rehabilitation and upgrade has the ability to shift the existing plant capacity around 245MW upward (Ministry of Energy and Water, 2010).

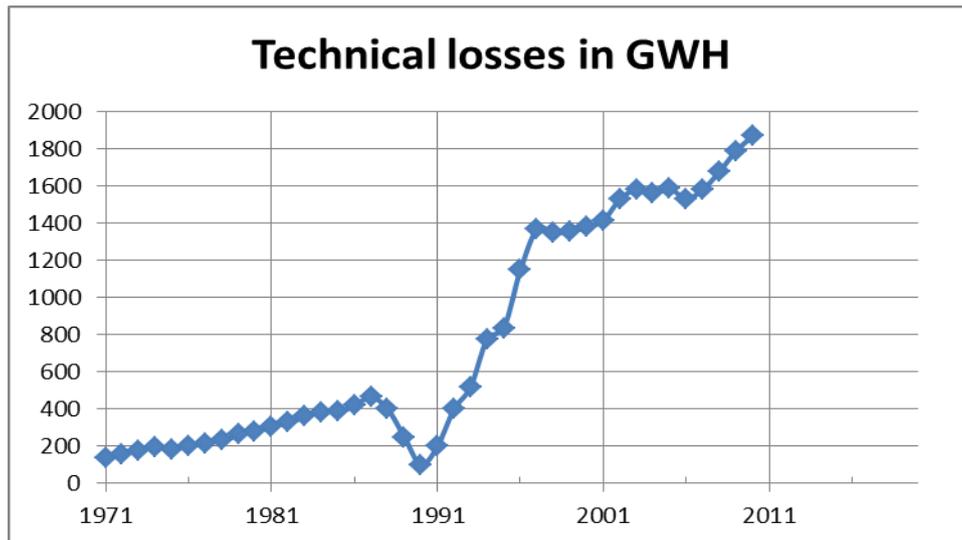
The volume of electricity supplied in Lebanon is estimated to be shrinking by 3% on yearly basis due to aging plants, while demand for electricity is increasing each year by 7% (Ghajar,2011 )(see Figure 2 for the estimated increasing electricity gap). This perpetual increase in electricity demanded and progressive drop in electricity supplied will upshot a widening gap resulting in an electricity deficit of around 70% in year 2015.



**Figure 2: Estimated increasing gap between electricity supply and electricity demand (MWh) (2009\_2015) (Ghajar, 2011)**

Then, The inefficiency does not only occur in the generation process but also at the distribution and transmission process with a *technical loss* estimated to be over 18% reaching around 22% in some areas. The physical transmission and distribution networks in Lebanon are crucially damaged. This decayed network is contributing in technical losses that reach at minimum about 15%, and this percentage is subject to increase with distance; for example, in some areas as Hermel the losses are about 22%. In general, the normal percentage of electricity technical loss range between 6% and 8% (ABB, 2007). By assuming the relatively conservative dimension of 18%, the **technical loss** is dragging a financial loss estimated to be around \$M 150<sup>4</sup>(World Bank (WB), 2008). (See figure 3 for the increasing technical losses in Lebanon.)

<sup>4</sup> At the average 2007 tariff of US \$9.4/KWh

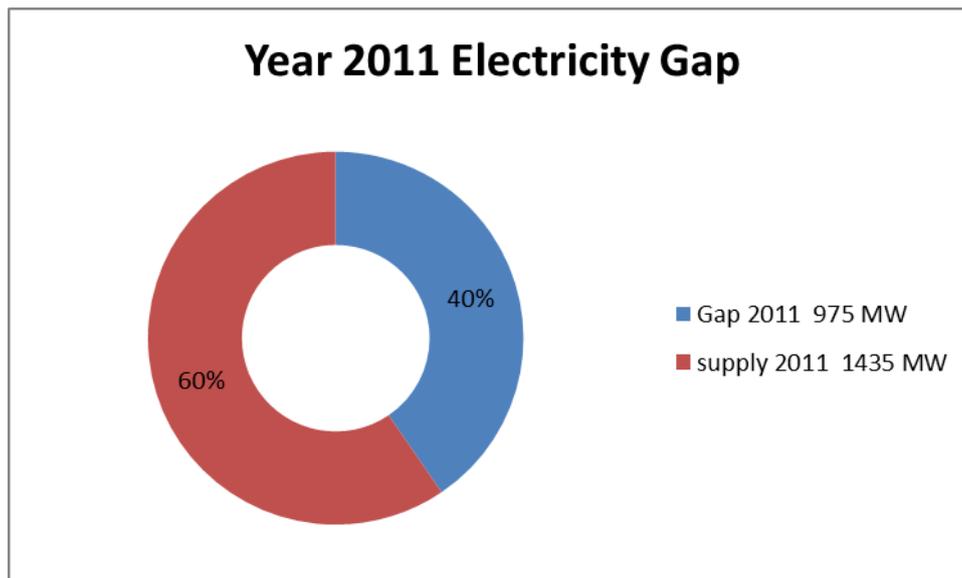


**Figure 3: Technical losses in the Lebanese electricity sector (KWh) (indexmundi)**

In order to achieve a well-established network, it is important to complete the high voltage grid: 400KV network, and 220KV network. Also, it is important to establish the NCC, the National Control Center, which includes the Supervisory Control and Data Acquisition (SCADA); it is a center from which it is accessible to control and operate the whole system (world Bank, January 21, 2008). It controls maneuvers and prevent economic load dispatch. In addition, it has a critical role in the interconnection of the 7-Nation grid, a transmission network project linking Jordan, Syria, Iraq, Lebanon, Egypt, Turkey and Libya, which facilitates regional electricity entities to be connected to the national grid.

The rehabilitation of the electricity network would have the ability to capture about 100 MW of lost electricity generated (World Bank, 2008). Hence, it would save the Lebanese economy from the reallocation of around 80 to 100 million US Dollars as new power plant investment of similar rated capacity.

**The increasing electricity gap.** Due to technical losses, the unavailability of fuel, and plant decay, the gap between electricity demand and electricity supply is getting bigger every year reaching around 40% year 2011. (Refer to figure 4 for year 2011 Electricity Gap).

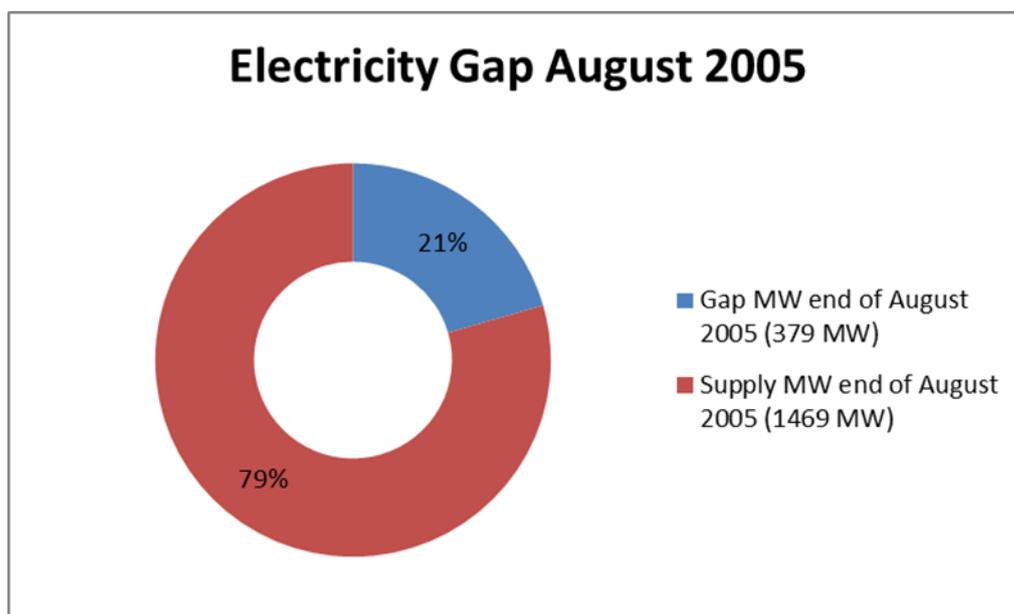


**Figure 4: Year 2011 Electricity Gap**

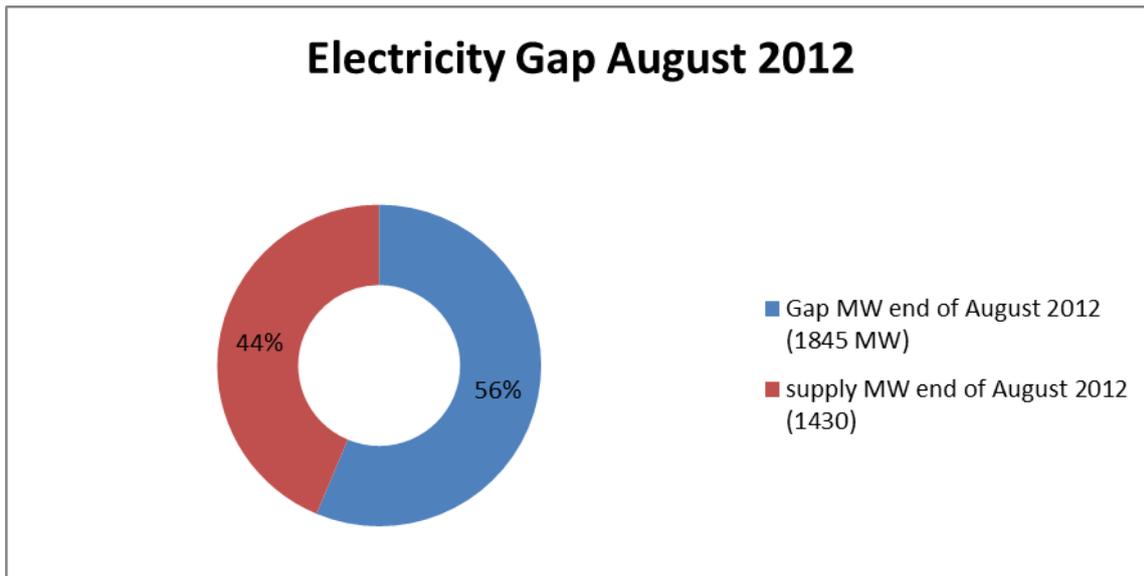
In the meantime, measuring the electricity demand while at the same time measuring the electricity gap would not reveal the actual and real figure. Actually the electricity demand is strongly affected by the availability of a reliable and consistent electricity service. Due to the lack of a quality service, many entities, especially in the industrial sector and tourist sector, are having their own independent source of energy, and many households are refraining from shifting to an upper electricity demand level by owning new appliances, or using existing ones at their highest potential. With electricity being available, the shift of independent entities operating off grid to the national grid and the extended consumption from actual users will shift estimated demand upward. The underestimated electricity demand makes the gap underestimated.

Moreover, any attempt to minimize the gap should take into consideration the natural increase in electricity demand which accounts for 7% as annual increase (Ghajar,2011). By comparing the Gap between a typical day at the end of August in 2005 and 2012, it could be observed that the Gap is getting tremendously wider whereas the electricity supply slightly drops. Year 2005, around the end of August, the maximum electricity provided was 1469

MW/day, and the estimated electricity demand is 1848 MW which makes a gap of 379 MW. However, after 7 years and during the same period, the electricity supply dropped modestly reaching 1430 MW, while the demand for electricity shift upward significantly to shift the gap up to 1845 MW which is 56% of the estimated demand. (See figure 5 and figure 6 for the electricity gap year 2005 and for year 2012). Therefore, by studying the market potential it is important to take into consideration the underestimated electricity demand and the progressive increase of electricity demand in Lebanon.



**Figure 5: Electricity Gap August 2005**



**Figure 6: Electricity Gap August 2012**

During August 2012, the electricity imported from Syria was just 35 MW (25,535 MWh per August) and that imported from Egypt was totally suspended (EDL data, 2012). During summer, electricity demand in Egypt and Syria peaks which leaves these countries with insufficient spare electricity to export. It happens that in the same period of the year, mainly in summer, demand for electricity peaks also in Lebanon which exacerbates power shortage under the joint effect of limited supply and increased demand<sup>5</sup>.

### **The Economic Cost of Electricity in Lebanon**

The average tariff paid by electricity end user per KWh in Lebanon is around US \$9.58, whereas the cost of production by EDL reaches in some plants more than US \$40 per KWh produced<sup>6</sup>. Another source of energy for Lebanon is 200MW of imported electricity

<sup>5</sup> Demand is increased heavily in summer due to Air conditioning loads, and the significant increase in visitors and tourists who contribute in extra loads.

<sup>6</sup> This is typically the production cost for year 2013 the open cycle plants operating on diesel Baalbeck plant and Tyre plant.

from Syria and Egypt at an average price of ¢12/KWh and sold for the Lebanese end user at the average tariff ¢9.58.<sup>7</sup>

This gap between production cost and electricity tariff is getting progressively wider due to increasing cost of oil, pegged electricity tariff, and perpetually dropping aging plants efficiency and technical losses in the network.

According to a report directed by the Ministry of Finance, the annual fuel subsidies or fuel transfers paid by the Minister of Finance to the energy sector year 2008 are \$400 per capita whereas in year 2009 they were \$375 per capita (Ministry of Finance,2010).

**The potential increase in cost and subsidies.** These per capita transfers are subject to unpredictable fluctuations due to many factors:

- The unpredictable history of fuel oil price fluctuations in the market.
- The undervaluation of the actual value of fuel transfers due to the high risk related to this commodity in the long term.
- The increasing technical loss due to the detrimental situation of Power plants.
- Demand increase due to natural population increase
- The uncollected revenues

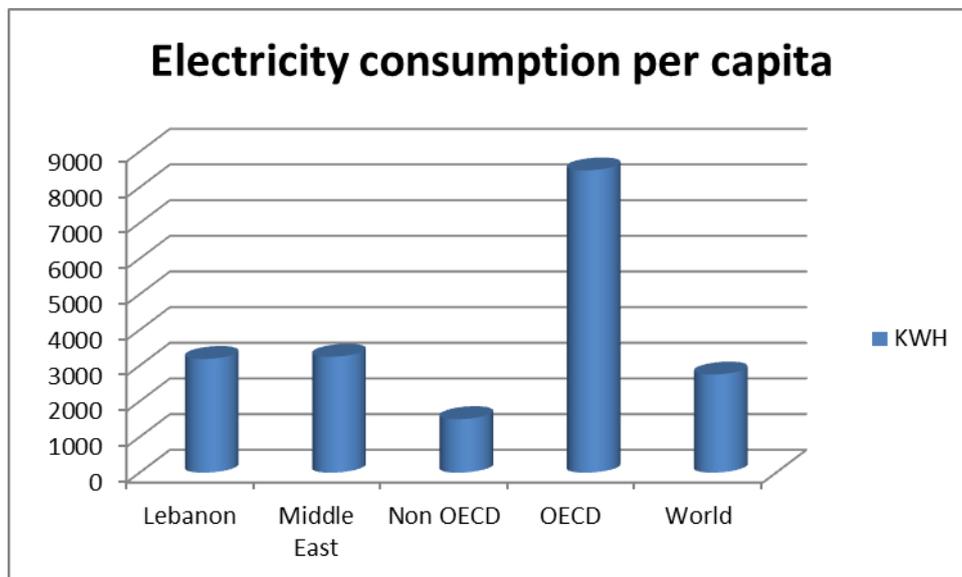
These payments of \$1.6 billion in 2008 and \$1.5 billion in 2009 take the form of subsidies to the electricity sector. To have an actual and real figure concerning the yearly per capita electricity spending in dollar value, the per capita subsidies transferred to the electricity sector should be included in the annual cost of electricity spent by each resident.

By taking 2010 as a base year, *the real national per capita consumption of electricity* in dollar value could be calculated. According to EDL Energetic data, the per capita electricity consumption in 2010 in Lebanon was around 3188 KWh (ALMEE, 2011)

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<sup>7</sup> The Egyptian electricity import has been totally stopped during year 2012, while the Syrian electricity import dropped dramatically during the same year.

(see figure 7 for electricity consumption per capita). The average electricity tariff imposed is about ¢9. According to the ministry of Finance, the 2010 EDL transfers were about \$1.25 billion. These transfers are actually paid by the Lebanese community for the electricity sector. So the yearly per capita electricity spending is  $\$312 + 3188 * 0.09 \approx \$600$ . These payments are the price for inconsistent, unreliable and insufficient electricity which oblige the end user to pay for backup energy to satisfy his electricity needs. In Lebanon, the private generator bill is an electricity subscription based on available voltage or capacity and not based on monthly electricity consumption. It was assumed that the average payment for backup energy is around \$53 per month per each household (World Bank, 2009). Year 2012, the regular 5-Ampere private generator fee has soared to reach LL180,000 (\$120) (El Amanine, Daily star, July 2012) with a monthly average of \$70 for the same capacity subscription<sup>8</sup>. (personal communication at Electrical Utility of Aley).



**Figure 7: ALMEE 2011.**

<sup>8</sup> Electrical Utility of Aley, site visit, 2012

## The Real Economic and Social Loss

Indeed, this is not the end of the story. To have an accurate figure of social and economic loss estimation, some indirect and direct costs should be included in this assessment:

- The cost of power cuts and frequent electricity outages
- The cost of shifting to alternative instant power.
- The technical loss due to inefficiencies in the whole process  
( generation, transmission and distribution)
- The uncollected revenues
- The forgone benefits due to pegged tariffs
- EDL unproductivity
- The forgone value of new electricity projects due to the no activation of law 462.

Concerning the cost of power cuts, we should highlight the cost which occurred due to the interruption and the cost of shifting into an alternative source of power.

First, the *interruption cost* refers to the energy that this outage has not been able to offer and is estimated in US\$ per KWh. Many studies in different contexts prove that the cost of interruption can reach serious and critical levels resulting in tremendous economic and financial losses. According to Ghajar and Billinton(2006), there is a great variation in the interruption cost due to the characteristic and conditions of this interruption as time of occurrence, duration and frequency and due to the type of customer whether small or large user. By gathering interruption and power unreliability data from different sectors in Canada, they found that in some cases the outage cost especially in agricultural and industrial sectors are about 3.39 \$ per KW (Canadian context). Besides, in a study conducted by Kerin, Dermelj, and Papić (2007), the annual financial impact on the Slovenian industry due to

unreliable power supply shows to be over 3,000,000 Euro. In Lebanon, there is on average about 220 interruptions per year and this is varying heavily due to geographic variations. It may reach about 300 interruptions outside the capital Beirut. Substantial losses are reported in all economic and residential areas. The average firms' loss is about 7% and the size of the firm is positively correlated with the percentage of loss related to power interruption. Large firms are more capable of compensating these interruptions than small firms. So, they report a sales loss of about 6% whereas the latter announce a sales loss reaching about 8%.

Moreover due to the variation of interruption in different geographic areas, firms located outside the capital are enduring an additional loss of 8% when compared to those located in Beirut (ICA, June 2006). The statistics shows that industries and sectors are proportionately affected by frequent power outages; hotels and resorts report an average percentage loss of 9% of total sales, while clothing industries declare losing around 10.5% of their total sales.

The economic loss in 2004 as sales loss due to power interruption in Lebanon is estimated to be US\$ 360 million per year (ICA, June 2006). According to The World Bank report, The outage cost affecting the Lebanese industrial sector in 2008 is estimated to be about \$400 million in sales loss (World Bank, 2008).

Moreover, in a study developed by Targosz and Manson (2007), the result of European survey held in 25 countries revealed that the interruption cost has exceeded 150 billion Euros.

In fact, the characteristic and conditions of electricity interruption in Lebanon (occurrence, duration and frequency) are remarkably compared to the European, Canadian or even the Slovenian context, since the outage in Lebanon reaches more than 16 hours in some rural areas, and it is important to note that these specific rural areas held the higher percentage of the Lebanese industry mostly affected by the financial cost of interruption.

Second, if an industry chooses to cut its sales losses affected by these electricity interruptions by securing an alternative source of electricity, additional costs are accumulated through their supply chain. Therefore, based on *the average cost of backup generation* as a percentage of total electricity spending in year 2007, it is estimated that the backup energy systems cost the population more than 25 % of electricity spending per month (ALMEE, 2011). And it is worth mentioning that the private generation supply in Lebanon has increased dramatically the last decade as an alternative to cover the gap which occurred in the market between the electricity demand and the electricity supply. Dr. Marwan Iskandar estimated that the capacity of the self-generating power over Lebanon is about 900 MW which is in fact about 60% of the electricity generated by the EDL.( personal communication with Dr. Marwan Iskandar on April 22, 2012).

Private generation could be divided into two different groups:

- First those who generate electricity for their own use as residential, sanitary, industrial, educational and tourist sectors.
- Second, those who generate electricity in order to distribute it among various end users in the neighborhood.

The full capacity of these generators is not efficiently and fully in use due to limited hours of generation and sometimes due to limited subscribers in a neighborhood which makes the generator capacity not fully used. Also, the pay range for these private electricity providers is not based on the amount of electricity used by the subscriber measured through metering, but it is a fixed monthly amount dependent on the capacity subscribed and not on the actual electricity used by the subscriber. For example, it is an average of 70\$ per month for 5 Amperes whether the end user consumes electricity or not; this amount is subject to increase based on the outage hours. Besides this inefficient usage, and in the absences of any

cohesive official control, the private generation sector is subject to many developing issues of legal, managerial, and environmental nature.

From January 2010 till January 2012, a study conducted in Hamra, one of the main residential, economic and diplomatic hubs in Beirut monitored the levels of polycyclic aromatic hydrocarbons (PAHs) by surveying 184 buildings in 20 different districts. It realized that out of 184 there are 109 buildings using diesel self-generation as backup energy during the rationing hours shifting by rotation at an interval of 3 hours a day per each district between 6 am and 6 pm. the study concluded that the operation of diesel self-generation is contributing in almost 40% of Hamra's resident daily exposure to PAHs which is 2.5 times more than if diesel generators were switched off. PAHs are resulting from incomplete combustion of fuel and it is categorized as being carcinogenic and it has many adverse health effects such as genetic mutation and physical growth related problem ( Shehadeh & Saliba, 2012).

Third, the technical losses are affecting the electricity output and inflicting direct economic losses in the sector. As a percentage of total electricity output, the electric power lost during distribution and transmission is about 15.32%. This loss is negatively related to proximity: as the distance between the point of supply and the end user increases, the technical loss tends to be higher reaching 22%. The technical losses in transmission between points of supply and points of distribution and between distributions to consumers are estimated to be more than \$45million per year. Due to these technical flaws our electricity system is losing about 300 megawatt of capacity, and any project for investing in an equivalent amount of electricity generation would not cost below \$80 or \$100 million (WB report); Whereas, the Policy Paper For The electricity sector stated that rehabilitation, maintenance, and upgrade of existing plants will cost about \$418 million in order to assure an increase of 245 megawatt of capacity. Although we find exaggeration in the cost proposed by

the Policy Paper compared to the World Bank report, in both cases, the cost of reinvesting or the cost of rehabilitation as a means to compensate the technical losses reflects the cost of the forgone 300 megawatt which is an indirect costs carried by the whole community. (It could be added to the per capita cost of electricity mentioned above.)

Forth, the *non- technical cost and the uncollected bills* have a significant effect in shrinking the overall public benefit and electricity revenues. The nontechnical loss is the loss not associated with physical characteristics and functions of the electricity system. Thus, it is a loss associated to meter reading and tampering, pilferage, and billing; it is usually due to human error and could be intentional or not. According to the policy paper for the electricity sector, these losses vary widely by regions, between 15% to 78%, and by provinces, between 9.6% to 58%. The revenue collection losses constitute more than 30% and the collection rate varies widely according to provinces between 83% and 97% and to regions between 62% and 97.5%. ( Ministry of Energy and Water ,2010). Nontechnical losses are related to a fragile administrative system, especially to a weak billing system, and to political corruptive interventions in the administrative operations (Earth Link and advanced Resources Development (Elard), 2010). it was assumed that the forgone revenues due to uncollected bills are around \$310 million each year (As-safir, 2012)

Fifth, Since 1964 EDL has been given the exclusive right to operate in the electricity market; it is the solo player without any competitor. Law 462 , enacted year 2002, highlights the major reforms towards a competitive market. Unfortunately this law is still inactive due to political issues. This delay in reform prevents new electricity firms from entering the market. Moreover, the pegged tariff for an average \$0.09/KWh discourages potential competitors who are perceived as losing the cost advantage. However, it is important and crucial to include the financial and social economic cost related to the outrageous situation of plants and network and the exclusive oil dependency, which are translated into huge financial

transfers as subsidies. The inactive legislative reform and the pegged electricity tariff are contributing in repelling any new potential development in the market causing *forgone electricity project opportunities* in the sector. The market remains totally stagnant without any development action taken by EDL or allowed to be taken by potential independent power producers (IPPs).

Sixth, EDL managerial deficiencies lead to very high rates of *labor unproductivity in the electricity sector*. Year 2000, EDL labor productivity was about 2.3 GWh per employee whereas the international benchmark is around 8.23 GWh per employee (El Fadel et al,2009).

Year 2012, labor productivity dropped significantly to reach 3 MWh per employee (0.003 GWh) which is the lowest among all electricity sectors in the Arab World: 8436 MWh for Saudi Arabia, 4152 MWh for Kuwait, 1847 MWh for Jordan and 876 MWh for Egypt (Auptde, 2012). The drop in productivity is mainly due to the drop in the technical system efficiency and to over unproductive human capital. This missed out productivity is a forgone economic benefit for the Lebanese economy that should be internalized in the economic loss assessment.

The electricity sector in Lebanon is detrimental from all possible measurable aspects. Uncollected bills, frequent electricity interruption, electricity investment stagnation, the progressive drop in the technical situation of the plants and networks, the unproductive human capital, the astronomic cost of back up generation<sup>9</sup> or the endured unproductive daily hours of blackout, all these, are daily economic loss paid by the Lebanese society.

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<sup>9</sup> Estimated to be around \$27 as an average.

## Oil Dependency

More than 90% of the electricity sector in Lebanon is dependent on heavy fuel oil and diesel to produce electricity. Zouk plant, Jiye plant, and Hreishah plant are operating on Heavy fuel oil whereas Baalbeck, Tyr, Zahrani and Deir Ammar plants are designed to operate on natural gas (NG), but due to its unavailability they operate on diesel. Due to inefficient management, inefficient technical operation and due to a pegged electricity tariff far below operational cost, EDL is relying strictly on governmental transfers in order to finance the inefficient sector. Around 93% of these transfers are paid as fuel bills. The increase of the fuel bill between 1993 and 2010 is around 87%<sup>10</sup>. This evolution is not linked just to the increasing fuel prices but also to the decreasing plants generation efficiencies which makes the plants use more units of oil to produce a unit of electricity. As more than 90% of electricity generation cost is directly linked to oil prices, any minor fluctuation in the latter will result in major increase in the former. Year 1996 the cost of oil was around 21 \$/barrel, year 2008 the oil price reached 133 \$/barrel, and 111 \$/ barrel year 2011. This fluctuation trend did not reflect any change in the tariff pegged at an average €9 per KWh since 1996. However, those fluctuations are reflected in the volume of financial transfers subsidizing the sector; year 2008, transfers reached about \$1.6 billion and Year 2011, they reached \$1.58 billion (Carboun, May 2012). Year 2012, oil constituted around 25% of total Lebanese imports which is equivalent to 7% of the Gross Domestic Product (GDP) (Byblos Bank, 2012) and the EDL financial transfers from the ministry of Finance reached \$2.27 billion (Ministry of Finance,2013).

Moving toward more diversified sources of energy will pave the road toward an electricity market less dependent on risky, intense and frequent oil price fluctuations and with less environmental and health risks combined with gas emissions.

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<sup>10</sup> Calculated from data collected by ALMEE 2010

## **Natural gas as substitute**

First, Concerning the existing plants operating on fuel, a shift toward natural gas has a major effect in decreasing the cost of generation, increasing electricity supply and shrinking the fuel financial allocations.

A substitution of oil with natural gas as a medium to operate the plants originally designed to run on gas, would lead to major shift toward more efficient and effective levels in the electricity sector. This shift to gas has many benefits for the sector due to :

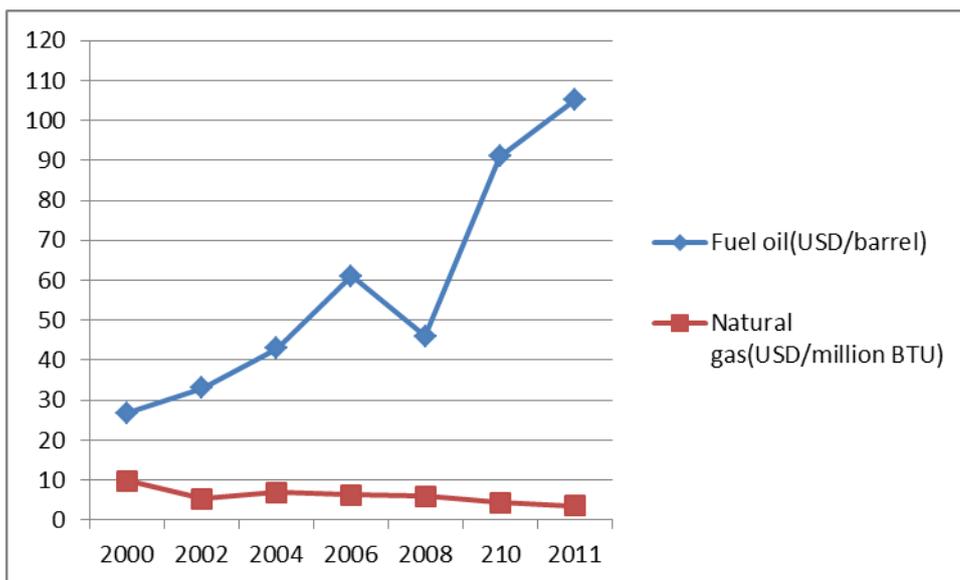
- Cheaper price of gas compared to oil
- Higher burning capacity
- Less fluctuations and variations of natural gas prices compared to those of oil
- Lower maintenance charges when plants are operating on gas
- Longer lifespan of generating units when working on gas
- About 60% less gas emissions due to NG operation

If natural gas were used instead of gas oil (diesel) in the combined cycle plants, Zahrani and Deir Ammar, between year 2004 and 2008, Lebanon would have saved around \$1505 million. Nowadays, comparing to diesel and Gasoline, natural gas is getting even cheaper due to new reserve exploration. If this comparison is based on the cost of 1 MWh generated in terms of the dollar value of the fuel consumed at a CCGT plant; 1 MWh generated from diesel would cost \$147.5 whereas it costs around \$16.5 if generated from natural gas ( Based on the prices average of diesel and NG from January 2012 until October 2012).

Natural gas has a burning capacity of 11464 Kcal/kg, whereas that of fuel oil is around 10035 Kcal/kg. When adopting same plant technology, combined cycle plants for

example, with same generation process for both natural gas and diesel, this difference in burning capacity gives the natural gas an advantage in generating more units of electricity with less units of fuel and makes the generating process more cost efficient due to NG shift.

Substituting diesel with natural gas would be financially less risky due to the fact that natural gas price increases less harshly than those of crude oil (Abi Saiid,2012). When the electricity sector is relying on a relatively stable fuel commodity, the volume and the value of commodity consumption would be better predictable and scheduled and it would be less vulnerable to market fluctuations. Moreover, between 2001 and 2011, the cost of natural gas dropped significantly by 63% whereas the cost of Fuel oil soared by 74.4% .(see figure 8 for Fuel price variation).



**Figure 8: Fuel Price Variation. Source (US- EIA 2012 in UNDP, 2012)**

The use of natural gas in the plants originally designed to run through gas use will require less maintenance frequency and less maintenance charges, which extend hours of operation per year and life span of the turbine. The maintenance cost rate per year relative to the initial investment cost is  $\frac{1}{2}$  and  $\frac{1}{8}$  respectively for gas oil and natural gas while the lifespan of the plants is 20 and 22 respectively with gas oil and natural gas operation.

Moreover, the gas emissions drop significantly with natural gas use as a substitute of diesel; This reduction is 100%, 60%, and 70% respectively for C, CO<sub>2</sub> and NO<sub>x</sub> (Carbon, Carbon Dioxide, Nitrogen Oxide). It was estimated by the World Bank that the shift to natural gas in the Lebanese electricity sector, for the period between 2005 and 2020, has the ability to reduce health and environmental damages between \$740 million and \$1800 million (Abi Said, 2008).

### **Renewable energies**

As the Lebanese electricity system is mainly based on thermal energy, tons of dangerous gases are emitted in the atmosphere every single day. The Lebanese energy sector was estimated to be responsible for around 75% of the total CO<sub>2</sub> emissions in Lebanon (UNFCCC in Beheshti, 2010). Year 2006, EDL emissions reached around 6.39 Million tons of CO<sub>2</sub> (MOE/IFI,2009).

The highest contribution is made by the thermal plants operated on heavy fuel oil ( Zouk, Jieh, Hreisheh) and by the open cycle gas turbine plants ( Baalbeck,Tyr).

In 1994, Lebanon has ratified United Nations Framework Convention on Climate Change (UNFCCC). In 2007, Lebanon signed the Kyoto protocol and committed to reduce its greenhouse gas emissions (GHG) through cutting energy demand, increasing energy supply and increasing renewable energy mix to 12% by 2020. At a primary phase there is no specific volume of GHG reduction but the emphasis was to launch a control mechanism (Ministry of Environment, 2011). Lebanon was supposed to meet environmental targets by taking national measures and by adopting market based mechanism as Clean Development Mechanism (CDM). In order to define, oversee and assess the CDM, The ministry of Environment set the Designated National Authority (DNA).

By implementing GHG reducing projects, Lebanon is supposed to sell its reduced emissions units to an Annex 1 industrialized country that implements emission –reduction projects . These emission reduction projects earn sealable certified emission reduction (CER). The unit of measurement of CER credits is tons of CO<sub>2</sub>; each unit of reduction is counted in the process to meet Kyoto CO<sub>2</sub> reduction targets. With regard to this commitment, some limited reserved steps were taken by the Lebanese ministries. Ministry of Energy and Water stated energy regulations and electricity generation alternatives. These steps have been stacked in the theoretical framework with no active achievements. First, Law 462, enacted year 2002, is still inactive forbidding private contribution of investors in the electricity sector. Second, due to financial and administrative failure, EDL is not able to bear the development of alternative renewable power system.

Worldwide, the Renewable energy (RE) technologies have grown progressively and have caught a significant share of investments. Between 2004 and year 2008, the worldwide solar photovoltaic capacity has grown six times to reach around 16 Gigawatts (GW), while the global wind power capacity was increased around 250 % to reach 121 GW (REN21, 2009). Year 2008, RE investment has increased around 88% comparing to year 2002 with a \$180 billion, whereas year 2010 it reached about \$243 billion (United Nation Environmental Program (UNEP), 2011)

Year 2011, the capacity of wind power technology increased about 20% compared to year 2008 capacity to reach 238GW; the solar photovoltaic power exceeded to reach a capacity of 70 GW which is more than 74% compared to year 2010; the Solar Concentrating Power (CSP) increased from 1.3GW (year 2010) to reach more than 1.8GW, and the hydropower increased 2.5% reaching 970GW (REN21, 2012).

## **CO<sub>2</sub> Emissions in Lebanon**

These Renewable Energy projects are reflected in a worldwide decrease of CO<sub>2</sub> levels in several countries.

This accelerated global increase of RE results in a positive effect on the expected levels of CO<sub>2</sub>. The myriad of RE projects resulted in a potential avoidance of around 0.8 billion tons of CO<sub>2</sub> that would have been emitted from fossil fuel electricity generation of similar project capacity. Considering the hydropower technology added since 1992 onwards, the estimated CO<sub>2</sub> avoided would have been around 1.7 billion tons (BPL Netherlands Environmental assessment Agency and European Commission (BPL & EC), 2012).

Lebanon did not have the opportunity to be part of this potential CO<sub>2</sub> avoidance with any new investment in RE and with a pure usage of HFO and diesel in its power generating portfolio. Between 1994 and 2004, the trend of CO<sub>2</sub> increase by the energy sector was around 4.18% as an average. Year 2010, the CO<sub>2</sub> emitted from thermal and heating production in Lebanon was around 11 million metric tons and it actually constituted 60% of the total amount of CO<sub>2</sub> emitted (YChart, 2013). If the 4.18% trend was projected into year 2012, the total CO<sub>2</sub> emissions would have been 11.93 metric tons of CO<sub>2</sub>. This trend may actually be distorted due to inconsideration of the progressive increase of private generations as a substitute of the progressive increase of electricity outages.

In Lebanon, the volume of CO<sub>2</sub> emissions differs from a plant to another due to technology, open cycle or combined cycle, due to fuel used, HFO or diesel, and due to the extent of plant decay. Due to the discrepancy in the volume of electricity among the various plants, the volume of CO<sub>2</sub> emitted by each plant is measured relatively to the electricity generated as MWh and not as absolute volume. It is the measurement of the tons CO<sub>2</sub> per MWh generated which is the emission factor. An emission factor is the average of the build margin (BM), and the approximate operating margin (OM). The former is the weighted

average emissions, tCO<sub>2</sub>/MWh, of the most recent power capacities added to the electricity system; it is derived as the most recent 20% of the plants or simply the 5 most recent plants<sup>11</sup>. The latter, OM, is the weighted average emissions, tons of CO<sub>2</sub> per MWh, of all operating thermal plants ( Ministry of Environment, Global Environment Center Foundation ( GEC) and Climate Expert, 2004).

Based on gathered data for the whole thermal system<sup>12</sup> for the 3 consecutive years 2010,2011, and 2012, the emission factors for the OM and BM were estimated to be 0.6722 and 0.6277 respectively which makes their weighted average to be around 0.65 tCO<sub>2</sub>/MWh (equal weights)(LCEC,2011).(see Table 1 for the OM emission factor for year 2011). A study conducted in 2009, by the IEA (International Energy Agency), serves as a comparison material between Lebanon 's emissions factors value and that of some other countries. In this comparison the Lebanese emission factor is estimated to be around 0.717 tons of CO<sub>2</sub>/MWh. (see the figure 9 for Electricity emission ratio (tCO<sub>2</sub>/MWh))

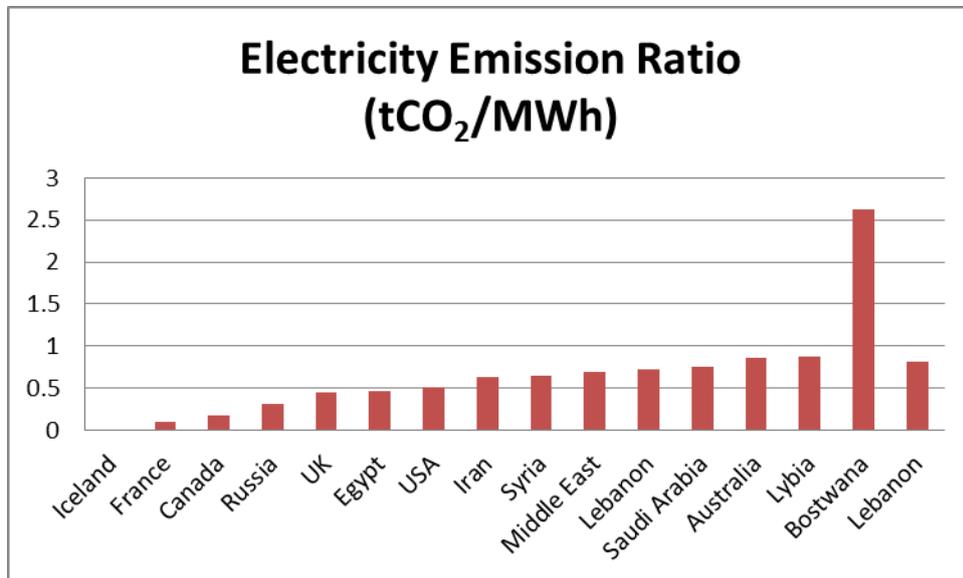
**Table 1: Operating Margin (OM) emission factor for year 2011 (LCEC, 2011)**

<b>Power Plant</b>	<b>Fuel Type</b>	<b>Net Electricity Delivered (MWh)</b>	<b>OM emission Factor (t CO<sub>2</sub>/MWh)</b>
Zouk	HFO	2,334,885	0.7906
South (Jiyeh)	HFO	1,502,664	0.9452
Zahrani	Diesel (CCGT)	3,110,420	0.5567

<sup>11</sup> In Lebanon the BM emissions factor takes into consideration the 5 " most recent" plants Zouk, Zahrani, Deir Ammar, Baalbeck , and Tyr.

<sup>12</sup> Hydro power is excluded due to negligible contribution to the volume of emissions and due to their low impact concerning GHG emissions

Dair Ammar	Diesel (CCGT)	2,890,842	0.5572
Baalbeck	Diesel (OCGT)	200,875	0.8915
Tyre	Diesel (OCGT)	334,902	0.9447
Hreicheh	HFO	284,003	1.0056



**Figure 9:** ( Source: IEA,2009 Via LCEC, 2011)

**The Social cost of CO<sub>2</sub>.** The necessity to decrease CO<sub>2</sub> emissions is due to a proven positive correlation between these emissions and adverse health risks. CO<sub>2</sub> has multiple adverse health effects characterized as physiologic, toxic, lethal and anesthetic. The concentration and duration of exposure are major factors in toxicity occurrence as well as the individual factors related to age, health conditions, and lifestyle (Rice, 2004). The CO<sub>2</sub> pollution in the atmosphere is creating a situation in which the population is persistently

exposed to a relatively low to medium CO<sub>2</sub> levels( from 1%-15%). This prolonged exposure proved to have many adverse effects on health:

- Decreased bone formation and increased bone resorption<sup>13</sup> to those having bone disease.

- Blood calcification
- Benign effect
- Increased intracranial pressure (Rice, 2004).

Another major pollutant emitted from thermal power plant operated on fuel oil is the NO<sub>x</sub>, the Nitrogen Oxide<sup>14</sup>( Adamkiewicz/ Kołwzan, 2007). This pollutant is emitted at a rate around 15g/KWh generated<sup>15</sup>.

The exposure to NO<sub>x</sub> has negative major side effects on human health and on environment (Environmental Protection Agency, 2013)

- Respiratory disease such as Bronchitis and Emphysema
- Aggravation of heart disease.
- Formation of Trioxxygen which may cause lung damage and reduction in lung function.( due to NO<sub>x</sub> reacting with volatile organic compound)
- Destruction of Ozone in the stratosphere.

Moreover it is worth mentioning that the NO<sub>x</sub> and CO<sub>2</sub> are not the only pollutants emitted due to thermal plant operation, but there are also the Sulfur Oxide, SO<sub>x</sub>. It is emitted at a rate of 12g/KWh generated from fuel oil plant operation. This emitted pollutant has also related health risks:

- Acid rain formation

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<sup>13</sup>destruction or solution of the elements of bone.

<sup>14</sup> The usage of NG instead of fuel oil has the ability to reduce emitted NO<sub>x</sub> by 70%.

- Photochemical smog
- Asthmatic diseases

These listed adverse health and environmental risks are not exclusive. Many ethical, legal and human barriers exist when conducting health effect studies, which makes scientists stick to the observational methodology and not the experimental. The former requires a long term observation of the case, health and environment, under a persistent factor.

It is true that health damage and environmental risk are of value that could not be quantified or monetized, but it is important to shed light on the volume of health spending related to damages that may be caused by these emitted pollutants. In order to internalize the economic social loss. The SCC, the social cost of Carbon, is the estimated cost of the environmental and health damage that a society pays due to the pollutant released in the atmosphere.

Year 2010, the US interagency task force determined that regulatory impact analyses use \$21 as a central value to estimate the social incremental cost of a metric ton of CO<sub>2</sub> emitted by assuming 2.5%, 3% and 5% as discount rate (US government, 2010). SCC is pretty sensitive to the value of the assumed discount rate estimated. Adopting a higher discount rate is a medium to discount the value and volume of harm caused by emitted pollutants in the future. Year 2012, An adverse study that criticizes the estimation mentioned above, by Johnson and Hope, suggested that this value, \$21, is tremendously distorted due to relatively high discounting assumptions; The study assumed a relatively lower discount rates 1 and 1.5% which shift the SCC to be between \$55 and \$266 (Hope & Johnson, 2012). At lower discount rate and due to Social cost internalization, the Renewable Energies technologies are having a competitive advantage over conventional pollutant technologies.

Many studies were conducted in order to quantify and monetize the harm caused by CO<sub>2</sub> as a greenhouse gas, but there is very limited concern to estimate the damages caused by

other Non-CO<sub>2</sub> emissions. One of the main reasons is the assumption that the damage caused by the Non-CO<sub>2</sub> emissions is not constant overtime as they differ in their radiative forces and their lifetime once compared to CO<sub>2</sub>. Having relatively short lifetime, the Non-CO<sub>2</sub> emissions impact is considered to occur primarily in the short term which makes their effect not discounted as severely as long lasting emissions ( US government, 2010). However, this argument doesn't take into consideration the environmental and health damage which may have occurred due to persistent low exposure to perpetually emitted Non-CO<sub>2</sub> pollutants.

Lebanon can significantly decrease its share of CO<sub>2</sub> emissions through fuel shifts, power portfolio diversification and plant rehabilitation. The simple shift from diesel to natural gas would decrease CO<sub>2</sub> emissions by 60%. The reduction of health and environmental health damages for the period 2005-2020, from the simple shift from diesel to Carbon in the electricity sector, was estimated by the hydrocarbon strategy study (HCSS) to be between US\$740 million and US\$1800 million.(Abi Said, 2008)

Moreover, the inclusion of Renewable Energies in the Lebanese electricity portfolio would be a serious turn toward decreasing the overall level of pollutants. Renewable energies as solar, Hydro, wind, Landfill gas, and Geothermal, are clean green energy sources with negligible emissions. These clean opportunities to generate electricity have many competitive advantages:

- Renewable Energies are offered by natural sources that are persistently and sustainably replenished.
- Renewable energies are becoming everyday more viable due to the cost decrease of technology and to the technological advances.
- Renewable energies turn to be highly cost competitive when the cost of negative externalities related to conventional fuel technologies, for example SCC, are internalized in the cost-benefit analysis.

Also, the physical decay of the plant decreases its generation efficiency in terms of fuel /KWh which makes the system require more units of fuel in order to produce a unit of electricity. CO<sub>2</sub> emission is positively related to the quantity of fuel burnt during the generation process. Due to non-appropriate maintenance, the efficiency is inclined from that of the initial plant design; this technical distortion requires the plant to burn more fuel as input to generate a MWh unit which increases the CO<sub>2</sub> emitted. The increase of fuel intake, associated with a drop of generation efficiency, increases the emission factor tons of CO<sub>2</sub>/MWh.

For example, Zouk plant the largest thermal plant in Lebanon with 4 turbines of total capacity of around 590 MW is operating at an efficiency of 15-25% lower than the design level. The fuel consumption required by the initial design of its turbine 1 (140MW) is 224.8 gr/KWh whereas the actual fuel consumption is 267.4 gr/KWh (World Bank, 2008). It requires burning more fuel to generate an electricity unit which means emitting more CO<sub>2</sub> per electricity unit.

Plant rehabilitation, would not just reduce the generation cost per unit but also it will reduce the SCC associated with the estimated value of extra environmental and health damages caused by further CO<sub>2</sub> emissions per MWh generated.

Thus, the path toward lessening the volume of emitted pollutants in Lebanon is strictly linked with a sustainable development of renewable energies, an immediate plant renovation and rehabilitation and a shift from fuel oil use to natural gas use.

## **Closing up the Energy Gap**

Electricity investment potential in Lebanon should be able to satisfy progressively increasing demand. The key is to estimate approximately the real demand for electricity in the long term, year 2030 for example. Forecasted electricity demand is significantly dependent on the GDP growth rate, forecasted electricity prices, and on the GDP elasticity of the demand.

According to World Bank study, demand is forecasted based on two different assumptions concerning Growth rate. The first is a low base scenario assuming the growth to be on an average of 3% after 2011. The second is a high case scenario assuming an average growth rate of 5.5% after year 2010 and onward (World Bank, 2008)

GDP elasticity or income elasticity of electricity demand is the increase in electricity demanded in response to one unit increase in income level. As being driven by service-based activity rather than energy intensive industry, Lebanon is assumed to have income elasticity of electricity demand ranging between 1.1 and 1.2.

Price elasticity of electricity demand is the percentage change in electricity demanded in response to a one unit percentage change in electricity prices. The previously mentioned low case of 3% and high case of 5.5% drafted by the World Bank study did not take into consideration any future fluctuations of electricity prices. Both scenarios assume a perpetually pegged tariff on an average of US\$ 0.09. This is implicitly assuming that EDL remains the sole market player in the electricity market with any foreseen rivalry, and that the tariff will continue to be far below the real cost paid for electricity generation.

Moreover, any attempt to forecast the future demand for electricity without an inclusion of backup energy and self-generation units would come up with tremendously distorted figures. The total capacity of self-generation in Lebanon was estimated to reach around 900MW which is actually around 60% of the electricity offered by EDL.

Thus, first, it is highly recommended to achieve a relatively real forecast of figures taking into account the prospective shift of tariff into more cost reflecting figures, and ,at later stage, the potential of future tariff to reflect higher generation efficiency in a prospective competitive electricity market. Also, to have a genuine demand forecast, the demand currently met by self-generation and backup energy should be captured and be subject to long term growth.

A World Bank study in 2007 assumes a tariff increase scenario reflecting the real generation cost and covering electricity subsidies. One of the scenarios presumes a gradual tariff increase of 26.5% in 2009, 26.5% in 2010 and 24.5% in 2011. As a result, the scenario shows a prospective 14.8% decrease in the electricity demand. Unfortunately, this study of the change in tariff effect did not take into consideration the downward possible change of a cost reflective tariff due to a better maintained efficiency in a prospective competitive market.

Concerning self-generation capture, the same previously mentioned World Bank study assumes that the portion of self-generation in the market compared to electricity met by EDL is 67%, 11%, and 11% , of the needs of the industrial sector , the low voltage user and the government respectively. If a strategy is adopted by EDL to progressively decrease backup generation to 50% of the industrial sector, to 8% of low voltage needs and to 9% of government need for electricity, the forecasted electricity demand into 2015 would reach around 3339MW which is between 6% and 9% increase each year.

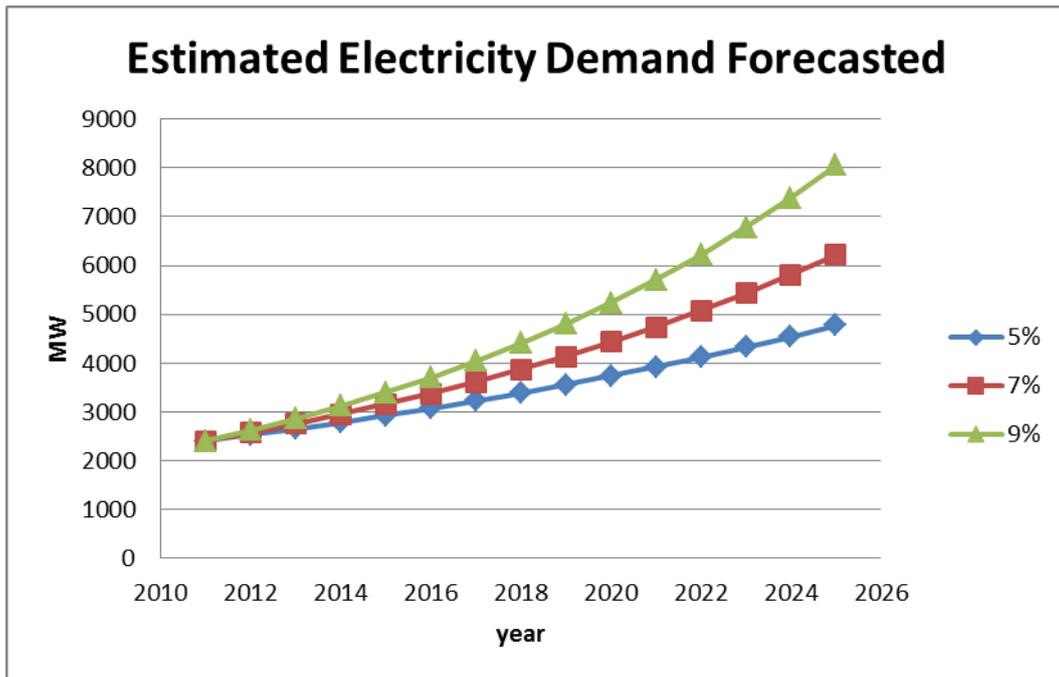
Besides, in his electricity policy paper 2011, Raymond Ghajar estimated a demand growth rate of 7% annually which projects the electricity need to be around 3500 MW in 2015.

With Electricity demand forecast it is important to note that the real and actual demand forecast would not be possible without taking into consideration the effect of the availability of electricity in the market; as electricity is widely available with no frequent and

severe interruptions and outages, the end user tends to increase its electricity consumption directly from the grid. This possible increase in electricity demand is due not just to a shift from self- generation to grid electricity but also to the development of new electricity consumption trend related to availability.

### **3 Possible scenarios for long-term electricity demand projection.**

By assuming three different electricity demand growth scenarios, the electricity demand in Lebanon would be forecasted for 2025. The growth rate of electricity demand is estimated to be for the first scenario 5%, for the second 7%, and for the third 9% using 2011 as a base year for the projection. According to data collected from EDL which estimated the monthly electricity demand in Lebanon, the average demand for electricity in year 2011 is calculated to be around 2410 MW. By projecting this figure using 3 different growth scenarios 5%, 7%, and 9% until reaching year 2025, the electricity demand growth reached 4772 MW, 6214MW, and 8054 MW respectively. (See Figure 10 for Estimated Electricity Demand Forecasted).



**Figure 10: Estimated Electricity Demand Forecasted**

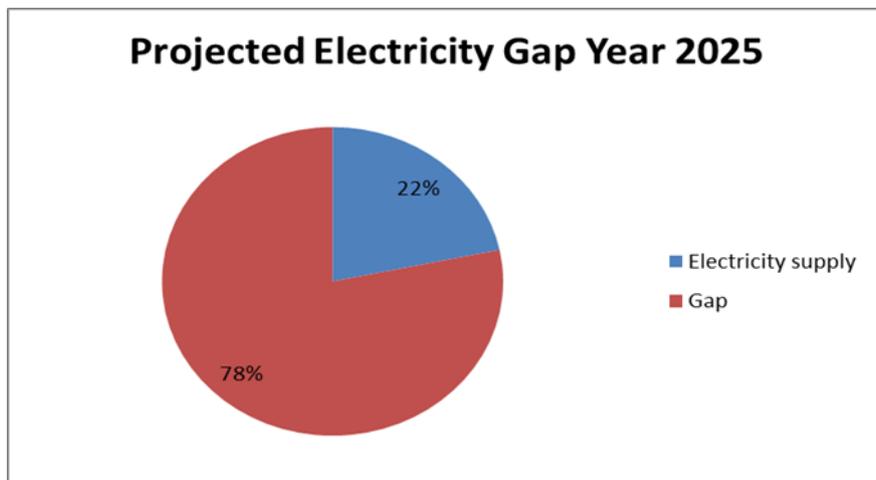
Note that the 2410 MW projected is the maximum monthly demand, but as it is mentioned previously it is without self-generation being captured. Moreover the projection did not take into account neither the change in consumption trend once electricity is generously available nor the prospective change in tariff. The World Bank case- study forecasting demand, while capturing a modest amount of self-generation, suggested a reserved reduction in self-generation and backup energy that would be met by EDL. However, the demand growth rate with this very slight capture was estimated to be between 6% and 9%. Thus, if a bigger portion or even all the self-generated electricity is captured the electricity demand growth rate will soar way above 9%.

Assuming a relatively conservative electricity demand growth scenario of 7%, the electricity demanded in year 2025 is forecasted to be 6214 MW. It is impossible to meet this figure and to satisfy this growing demand with a stagnant supply growth of 1400 MW<sup>16</sup> that

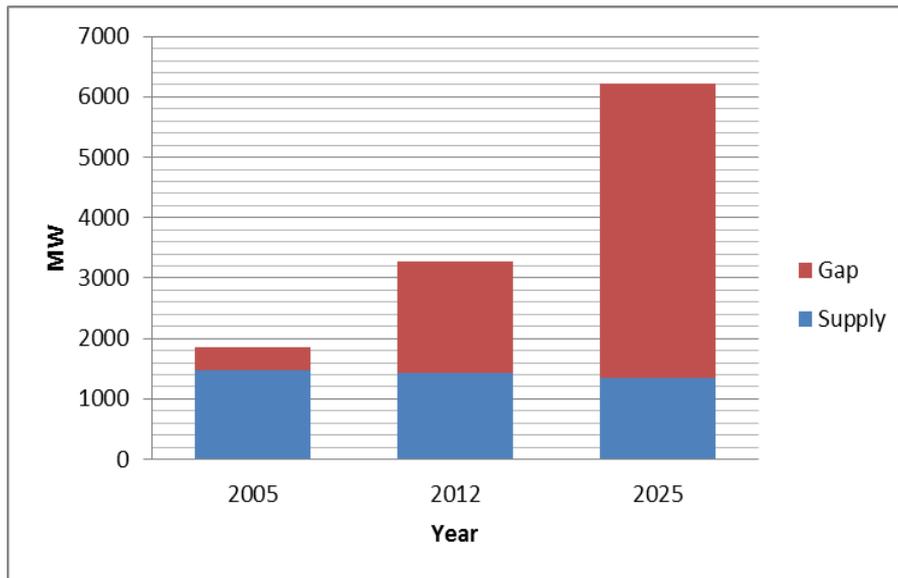
<sup>16</sup> 2012 supply with no consideration for electricity imports.

is subject to a 3% drop overall each year due to decay. Rehabilitation of existing plants and New investment projects in the electricity sector are obviously an exigent necessity. If any development or maintenance occurs, this capacity would reach 1350 MW year 2025 while dropping 3% every year . (Due to it is inconsistency in volume and frequency, the electricity imported from Syria and Egypt is not internalized in the supply projection analysis).

In 2025, with a projected electricity demand of 6214MW using an estimation of 9% electricity demand growth and a projected electricity supply of 1350 due to progressive decay at a rate of 3% ,the gap would be 4864 MW. The projected electricity gap for 2025, if any development action is taken, would be 78% of the total electricity demanded in that year.(See Figure 11 for Projected Electricity Gap year 2025). With the assumed increasing rate of demand, 9%, and the perpetual decreasing rate of electricity supply, the gap would increase dramatically between year 2005 and 2025 by around 92%. (See Figure 12 for the percentage of Gap increase.)



**Figure 11: Projected Electricity Gap Year 2025**



**Figure 12: The increasing Electricity Gap Projected**

Electricity demand growth is significantly surpassing the capacity offered by a stagnant deteriorating electricity sector. This gap would result in chronic and severe power outages undermining standards of living and curbing Lebanese economic growth.

The path toward sustainable development in the electricity sector begins with a serious attempt to rehabilitate existing plants and networks and willingness to launch new projects in the sector to feed this Lebanese electricity need.

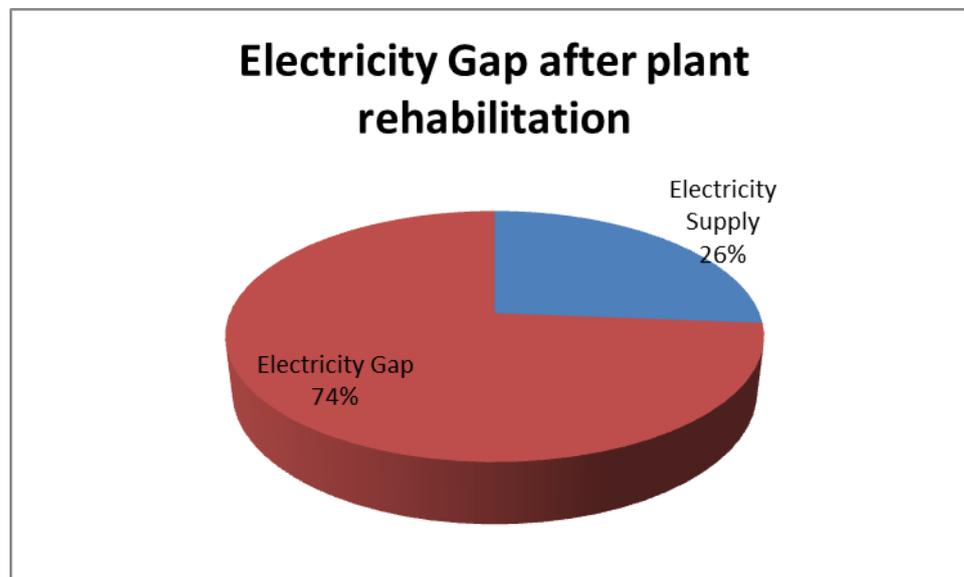
If EDL is not able to found any new project, due to severe administrative and financial failure, it should at least maintain the existing plants and open the door for other electricity players to enter the market and to invest in the sector.

Besides financial, technical and administrative decay, EDL decision making into development is always subject to political and governmental sterile debate. Privatization of the electricity sector, the activation of law 462, and open up opportunities for private investment were always subject to disapproval between governmental parties.

However, the security of electricity supply as a way to satisfy the growing electricity demand should be a priority over any political issue. New comers in the market would come

up with new needed electricity capacity and with new technological diversification than thermal energy which procure a higher level of overall supply and ease the need to lessen pollutant emissions. This potential reduction in pollutants due to green investments is a way to conform to Kyoto protocol in which Lebanon committed to increase renewable power capacity in order to reach 12% of its total national energy capacity by 2020.

If existing plants are appropriately rehabilitated and maintained, an extra of 245 MW will be provided which makes the actual capacity to be extended into 1645 MW leaving a gap of 4619 MW (see Figure 13 for Electricity Gap after plant rehabilitation). This gap should be filled by new investment in a competitive market where all new comers are welcomed with their various technologies which reflect cost efficiency, reliability of supply, and a cleaner environment.

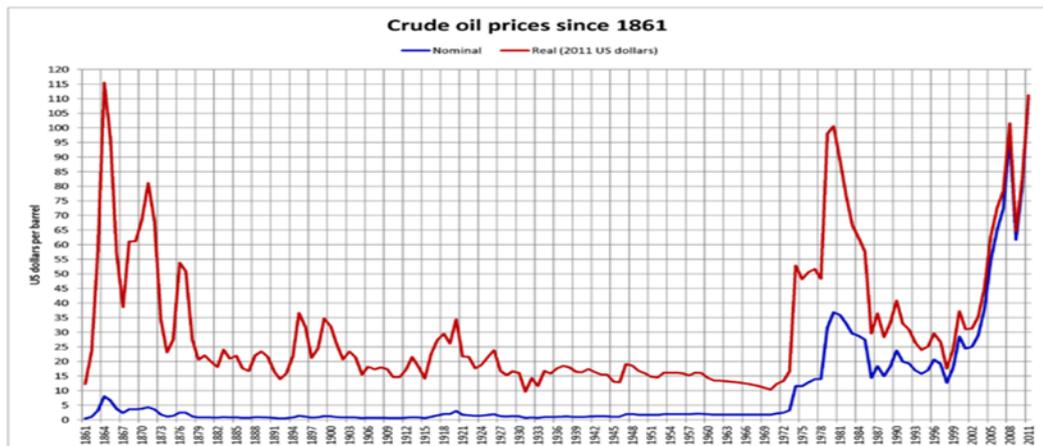


**Figure 13: Electricity Gap after plant rehabilitation**

## Chapter II

# Introduction of new power sources in Lebanon: Economic cost Analysis.

The nature of our electricity sector dependency on fuel oil and diesel, the increasing uncertainty in the fuel market, and its price volatility, an insecurity of decreasing power supply and an increasing electricity demand, an increasing financial national burden due to excessive subsidies are all creating a must to shift our energy system toward new perspectives. (See Figure 14 for crude oil prices since 1861).



**Figure 14: Crude oil prices since 1861**

The major concern in this chapter is to study the economic and environmental feasibility of various alternative electricity system. First, it is important to examine closely the economic cost function of the major type of conventional models operating in Lebanon

as a source of energy generation; diesel with 3 other sources of energy; Gas energy, wind energy and CSP.

The comparison platform is the marginal cost curve of each power plant. The marginal cost of electricity is the additional dollar value spent in order to generate additional GWh as electricity unit. It is the dollar value spent per each generated unit above the fixed cost associated with the initial capital cost of the plant.

If the concern is to ‘‘shrink’’ the gap between increasing electricity demand and decreasing electricity supply, by allocating new power plant system with least possible cost, adopting the power plant system with lowest marginal cost should be considered. Moreover, the total cost of supplying energy while maintaining current technology is compared with that of the renewable energy alternative.

Then, the environmental cost of CO<sub>2</sub> is included through the inclusion of the dollar value of the Carbon emitted per each electricity unit generated from the various electricity systems compared. This dollar value of Carbon emission per each generated unit of electricity is going to be part of the marginal cost curve of each electricity system. Finally, by taking into consideration the economic marginal cost of each examined electricity system, our objective is to build the most efficient energy mix using both scenarios the inclusion of Carbon as externality and its exclusion.

In this comparison model there are:

- Diesel energy
- Natural gas energy
- Wind energy
- Concentrating solar energy

In order to build the marginal cost curve of these various electricity plants, the cost components of each system are “dissected” into Initial cost, Variable O&M cost, Fixed O&M cost and fuel cost.

**Initial cost** of a plant is the cost of physical equipment, the interconnection to the grid cost and the establishment fees. This also known as capital cost and it may include the dollar value of the land over which the plant is built. In our study, we assume that the value of the land is remained constant with different plant type. And this assumption is done due to major land values discrepancy between various Lebanese areas and due to the wide investor’s choice concerning the location of the various plants compared.

In this study the initial cost is depreciated over the **lifespan** of the power plant.

**Fixed O&M cost** are the costs that arise irrespectively of the size of the plant unit generation. These costs are usually including staffing, overhead and equipment (including leasing), regulatory filings, and miscellaneous direct costs (California Energy Commission (CEC), 2009).

**Variable O&M cost** are the costs occurred as a function of electricity produced or operating hours of the plant. It consists of annual maintenance and overhauls, of non-fuel consumables and water supply, and yearly repairs for forced generation interruption.

The initial cost is directly linked to the initial **capacity** of the power plant. The initial capacity is the **rated capacity** of the plant. It is the maximum plant capacity designed by the manufacturer and it is expressed in terms of the electricity output generated per unit time. The rated capacity is what is expected to be achievable under perfect conditions, but, in reality, there is no perfect conditions reached. The most frequent term used to determine the plant generating capacity is Electric Megawatt (MW or MWe) (Dalhousie, 2012).

Because there is no perfect operating conditions the plant cannot achieve its rated capacity. The **capacity factor** of a plant is its average percentage of the plant’s full capacity

when operating at a given period of time (Energy Vortex). To calculate the capacity factor we have to take the average generated power at a given period of time and divided by the theoretical generating value that the plant would generate at full capacity up to its designed rated capacity.

So it is the ratio between the average load of a plant and its rated load for a period of time and can be expressed as

$$\mu_{cf} = (100) P_{al} / P_{rl}$$

This capacity ratio is varied widely due to the type of fuel used, to the plant design, and due to environmental conditions.

In our model the diesel plants and natural gas plants technology is a combined cycle which more power production efficient than the open cycle system. (The Engineering Toolbox). The thermal efficiency in an open cycle plant is around 35% whereas in the combined cycle gas turbine is about 60%. And this efficiency is tending to be higher by year 2020 reaching around 65% due to expected technological improvement (Energy Technology System Analysis Program (ETSAP), April 2010 a).

**Economic efficiency** of a plant is the ratio between production and operational costs, and the energy generated as output from the power plant at a period of time. Economic efficiency can be stated as

$$\Phi_{ee} = C / E$$

Where

$\Phi_{ee}$  = economic efficiency (Money value in a specific currency over unit of production; \$/KWh, €/KWh)

$C$  = production costs for a period (cents, euro,)

$E$  = energy output from the power plant in the period (KWh)

The **heat rate** is the efficiency of a power plant converting heat into electricity. It is measured through dividing the total energy supplied in the turbines as inputs in British Thermal Unit (BTU) by the total electricity outputs in KWh. So, It is a comparison between what is consumed in BTU and what is produced in KWh (See Table 2). The heart rate of a plant is directly related to the **heat content** or the **energy content** of the fuel. It is important to note that the lower the heating rate the more efficient the plant is; it needs less BTU to produce more KWh.

The heat content of a fuel is the heat energy obtained and expressed in British Thermal Unit or one thousand British Thermal Unit (btu, mbtu) when a certain quantity of a specific fuel is burned (Gallon, Liter, Kg). So, the type of combustible fuel is an important factor of the power plant efficiency.

Some accepted heating contents:

- 1028 Btu per cubic foot of natural gas
- 10,157 Btu per pound of coal
- 128,000 Btu per gallon of diesel fuel

To measure the efficiency of a plant as a percentage, divide the equivalent Btu content of a KWh of electricity (which is 3,412 Btu) by the heat rate of the plant. So, if its heat rate is 10800 Btu, its efficiency is 31%; if the heat rate is 7,000 Btu, the efficiency is 48%. ( See Table 2 for the average operating heat rate for selected energy sources, 2001 through 2011).

**Table 2: Average Operating Heat Rate for Selected Energy Sources, 2001 through 2011**

(Btu per KWh) (Source: EIA, 2013)

	<b>Coal</b>	<b>Petroleum</b>	<b>Natural Gas</b>
<b>2001</b>	<b>10,378</b>	<b>10,742</b>	<b>10,051</b>
<b>2002</b>	<b>10,314</b>	<b>10,641</b>	<b>9,533</b>
<b>2003</b>	<b>10,297</b>	<b>10,610</b>	<b>9,207</b>
<b>2004</b>	<b>10,331</b>	<b>10,571</b>	<b>8,647</b>
<b>2005</b>	<b>10,373</b>	<b>10,631</b>	<b>8,551</b>
<b>2006</b>	<b>10,351</b>	<b>10,809</b>	<b>8,471</b>
<b>2007</b>	<b>10,375</b>	<b>10,794</b>	<b>8,403</b>
<b>2008</b>	<b>10,378</b>	<b>11,015</b>	<b>8,305</b>
<b>2009</b>	<b>10,414</b>	<b>10,923</b>	<b>8,160</b>
<b>2010</b>	<b>10,415</b>	<b>10,984</b>	<b>8,185</b>

## **Wind**

The wind turbine energy is a capital intensive technology, 75% of the total cost of energy is a factor of the cost of wind turbine, the cost of physical electrical equipment, grid connection cost, and establishment cost<sup>17</sup>( The European Wind Energy Association (EWEA) 2009) (ETSAP, May 2010 b)

<sup>17</sup> In Lebanon Zahrani and Beddawi plants are combined cycle and they are operating on diesel.

The wind turbine **initial cost** differs due to its technology and due to its generator capacity factor that lies between 20% and 50%. But, Several parameters affect the capacity factor of the turbine including The size of the wind turbine generator, the wind speed in a specific area, the slope of the local terrain, the wind density, and altitude. It is important to explain that these parameters are not homogenously positive. For example let us examine the two parameters, the size of the turbine generator and the wind speed together. The small turbine generator is cheaper and more capacity sufficient than the large turbine generator, but at high wind speed it will produce less energy. On the contrary, the large generator is able to produce a little extra energy more than the small one but the problem may occur when the wind speed decrease, it may stall out. In our study we are considering the optimum **capacity factor** of the wind energy system which is around 40%.

The electricity generated from a given turbine is a factor of the capacity factor and the rated capacity of the turbine.

$$\text{Electricity Generated} = \text{capacity factor} * \text{turbine rated capacity} * 8760^{18}$$

As an example having a capacity factor of 40%, an operating 10MW turbine can produce about 350000MWh/year.

Moreover our wind turbine electricity system is assumed to have a **lifespan** of 20 years. Thus its initial cost would be depreciated over its life span on yearly basis. And, the energy generated from the wind turbine system is compared with energy generated from other systems on yearly basis.

The initial cost of our wind energy system is assumed to be around 1.95 \$/MW<sup>19</sup> (Albert Khouri, personnel communication, July 2012). The fixed operating and maintenance yearly cost is 13.7 \$/KW whereas the variable operating cost of generation is 5.5\$/MWh (CEC,2009). Concerning land leasing cost, 100MW turbines needs a land of around 990m<sup>2</sup>

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<sup>18</sup> Hours per year.

<sup>19</sup> Hawa Akkar case, wind turbine plant, North Lebanon.

where 20m<sup>2</sup> is needed per each 3 MW turbine. Also, The estimated land leasing cost per 20 years is supposed to be 5% of the land value which is estimated to be as an average of \$40 in rural areas. Based on these givens, the total leasing cost for 100 MW over 20 years would be around \$M 0.0528 .

At a capacity factor of 40%, our wind turbine electricity system is expected to produce around 350000MWh/per year. Assuming that this is the annual generation derived from the designed rated capacity, the annual running cost of our turbine plant is equal to the total MWh generated multiplied by the average variable O&M cost which is \$5.5/MWh. Thus, the Annual running cost is \$1925000.

Which is;

$$\text{Variable O\&M cost} * 350000 \text{ MWh} = \$5.5/\text{MWh} * 350000 = 1925000$$

In order to figure out the yearly total cost of the turbine plant, the fixed including initial and the variable, we have to find the annual fixed initial cost which is the initial value depreciated over the system life span:

The annual fixed initial cost= (initial cost per MW\* rated capacity)/life span + the annual fixed cost of maintenance and operation + 20 years land leasing fees/20 cost

In this case:

$$\begin{aligned} \text{The annual fixed cost} &= (1.95\$M/\text{MW} * 100\text{MW})/20 + \$M1.370 + 0.0528/20 \\ &= \$M 11.12264 \end{aligned}$$

The annual variable cost is the cost related to the generated units of KWh over one year it is: the variable cost of generating one MWh \* the generated MWh per year

$$5.5\$/\text{MWh} * 350000 \text{ MWh} = M\$ 1.925$$

The total annual cost = fixed annual cost + Variable operating cost

$$= \$M 11.12264 + \$M 1.925 = \$M 13.04764$$

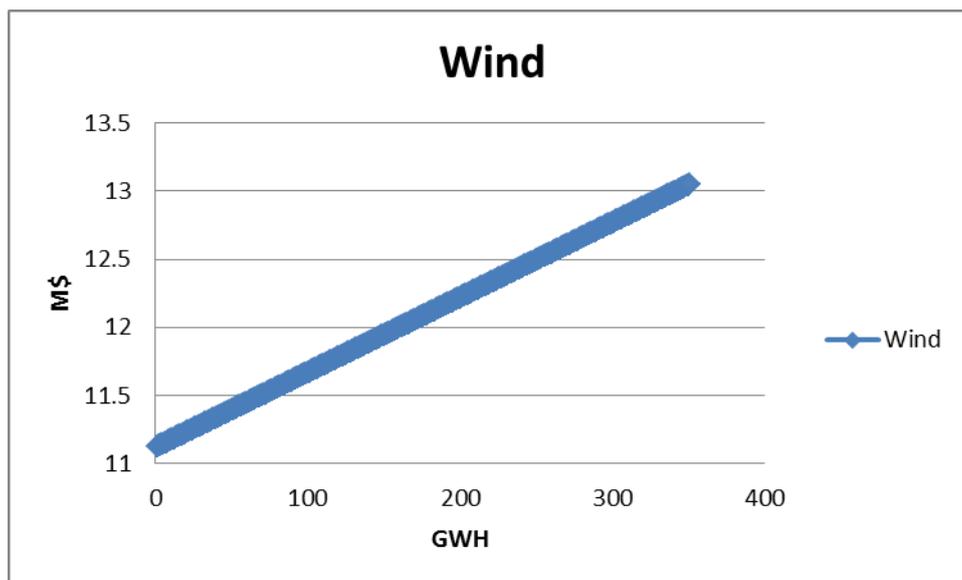
This absolute value is an acceptable comparison platform to examine the cost of energy but it is not the ideal one. To be effective our cost comparison should be observed in term of the relative electricity generated. Thus, we have to compare the total running cost over the generation over a period of time. The total running cost is the variable cost over one year which is \$M 1.925

As a result, The wind economic efficiency is:  $\$M 1.925/350GWh \approx 0.0055$

This could be explained as the marginal cost of every additional unit generated by the wind turbine electricity system. Each year and along the system life span 20 years, our annual fixed cost is the Initial cost of the wind turbine plant/ life span, the cost of leasing land, and the fixed cost of O&M. Thus, it is \$M 11.12264 and by each unit, KWh, generated an additional cost of \$0.0055 is added as marginal cost per unit, until reaching the expected generation potential of the plant relative to its power capacity factor. Therefore, the total annual cost of the wind electricity system of 100 MW of initial capacity is

$$Total\ annual\ cost\ (Wind) = \$M\ 11.12264 + 0.0055 * GWh\ generated\ per\ year$$

(See Figure 15 for Wind energy cost graph).



**Figure 15: Wind energy cost graph.**

## **Concentrating Solar Energy**

The concentrated solar energy is also named **Solar Thermal**. It consists in converting a large concentrated sunlight into electricity through the use of mirrors or lenses. Actually, it sounds like the photovoltaic energy but there is a main difference between this one and the latter. In the photovoltaic system the concentrated sunlight is converted directly into electricity through the photovoltaic effect, whereas in the CSP system it is converted into heat that is converted at later stage to electricity ( O'Shea,n.d). First, The CSP system concentrates the sun onto relatively one small point that heats a medium. Then this heat is either used as thermal energy through heating a specific target such as water containers or it is converted into electricity through generator connection. (IEA/ Solar Paces, 2013).

CSP systems are able to store energy to be used at night or at time of low sunlight through Thermal Energy Storage technologies, TES in order to generate electricity. This storage ability creates a significant advantage for CSP over other RES, and it resolves the perpetual intermittency problem strongly correlated with the REs (Green,2011).

There are many types of CSP systems:

- The parabolic trough collector
- The Linear Fresnel Collector
- The Solar Tower Collector
- The linear Dish Collector

This study examines closely the Parabolic trough collector system in which sunlight is reflected by the mirror and concentrated along a tube. The trough is usually aligned on a north-south axis, The trough rotates along the day to track the sun moving from east to west along the sky. The parabolic shaped mirrors catch the sunlight and reflect it in a concentrated mode onto one central receiver which contains the absorber tube, usually stainless steel coated, inside an evacuated glass envelope which helps to reduce heat losses. This tube

absorbs the short wave solar irradiation but reflects an insignificant long wave infrared which help minimizing heat loss. Then, a heat transfer fluid circulates through the tubes and conveys the sun energy either to the steam generator to be converted into electricity or into the heat storage system for later usage. The heat transfer fluid is usually synthetic oil at a constant temperature of 400°C or a molten salt at constant temperature of 540°C. Higher fluid temperature helps significantly the heat storage capacity which increases the overall capacity factor of the system.

The capacity factor of the plant is a factor of:

- Trough sunlight exposure (insolation)
- The heating storage system capacity
- The solar multiple
- The sunlight capture efficiency
- Tracking system

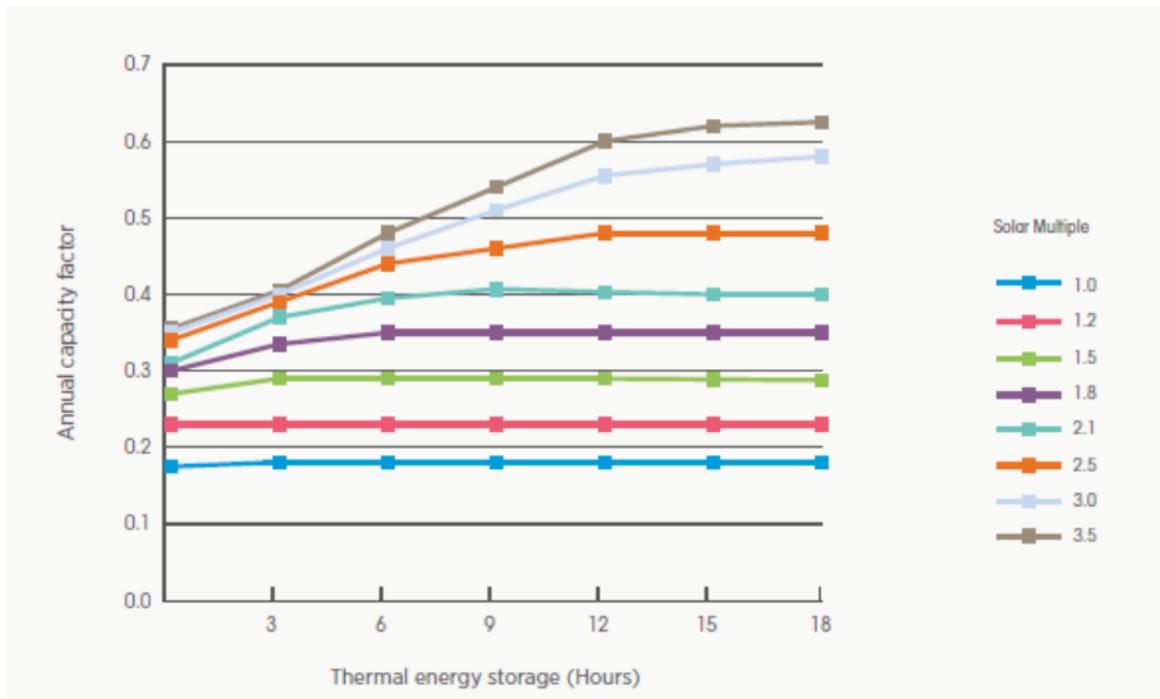
The **thermal capacity storage** in the solar trough system increases the Initial cost by about 12% to 20%<sup>20</sup>, but it increases the capacity factor of the CSP system by at least 20% if it is equipped with 6 hours storage capacity (US Department of Energy, 2010). The salt used in such system is a substantial part of the capacity storage system in Andasol plant case it costs €0.7 per one kilogram (EASAC,2011).

The **solar multiple** is an important factor to increase the CSP capacity factor. It is the actual size of the solar field relative to what is required to attain the rated (designed) electricity capacity of the CSP system. In order to reach a satisfying efficiency, the solar multiple should normally be larger than 1 and preferably between 1.3 and 1.4. In case of more than 6 hours of storage the solar multiple can be higher than 2.0 (IRENA, 2012). The figure below illustrates the correlation between the annual energy storage (hours) and

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<sup>20</sup> Andasol case thermal storage is estimated to be around 10-12% of the total cost.

between the capacity factor of CSP systems ranging between 20% to 60% for different solar multiples.(see Appendix for solar multiple graph.)



**Figure 16: Solar multiple graph (Source: IRENA, June 2012. Concentrating solar energy.)**

The thermal storage accounts as a significant percentage of the CSP plant. For example, collected data and figures from the 50 MW Spanish Andasol, indicated that the storage capacity of 7.5 hours increased the initial cost from € 210 million to € 320 million, just € 40 million of this cost rise and the rest is associated with a 70% increase in the solar field which result to 70% increase in the solar field of the plant which increase the generation output about 70% (EASAC,2011). Thermal storage is economically feasible; studies shows that a generating cost is cut by 10% due to such increase in operating hours (IRENA, 2012).

The rated capacity of Andasol1 is about 50MW. It is **initial cost** is estimated to be about \$M 380. Due to its capacity factor of 41% this plant generates around 180 GWh per year (Solar Millennium, 2008) (NREL,2013). The actual cost of Andasol is not publicly

disclosed especially concerning the fixed and variable operating and maintenance cost (US Department of Energy, 2012). However, they are estimated to be 0.04 \$/KWh and this cost is subject to drop due to the long run potential automation until reaching 0.025\$/KWh. Actually, the personnel cost in the US CSP parabolic trough plants of 100MW is 45% of the total variable cost of operating and maintenance ( O&M), whereas in South Africa it is about 23% in similar plant capacity (Turshi, 2010). For the composition of this cost, it was estimated that the variable O&M cost constitutes just 8% of the total O&M cost (Cohen, Kearney & Kolb,1999).

The examined CSP plant system adopted to be included in the comparison study is a parabolic trough with a rated capacity of 100 MW. It has a solar multiple of 2.5 and nine hours of storage and a capacity factor of 56%. Its **initial cost** is around 7550 \$/kw and it costs yearly \$14.6 million as total O&M cost from which 92% are fixed operating cost (Fichtner 2010). The annual variable O&M cost of the CSP is 8% of the total O&M cost which is around \$ 0.0025 per each KWh generated.

The expected electricity generated from this plant at yearly basis is:

$$100 \text{ MW} * 8760 * 56/100 \approx 490 \text{ GWh}$$

Annual fixed cost is equal to the initial cost depreciated over the plant life span, the annual fixed cost of maintenance and operation and the cost of land depreciated over 35 years.

The total fixed cost of the CSP is the initial cost of the plant and the cost of land.

For a 100 MW plant the initial cost is:  $7550 * 100\,000 \text{ KW} = \$ 755 \text{ million}$ .

Based on the above estimations of fixed and variable operating cost, The annual fixed operating and maintenance cost for a 100 MW CSP plant is around M\$13.43.

For a 100 MW CSP plant the land needed is around  $1020000 \text{ m}^2$  if an average \$40 is associated per each squared meter in rural areas the cost of land would be M\$ 40.8.

Concerning the lifespan of our CSP solar trough, its operating lifetime lies between 25 and 30 years (BMU, 2003). And in some systems, as Andasol, plant life expectancy is estimated to be between 30 and 40 years. In this examined system the lifespan is assumed to be around 35 years.

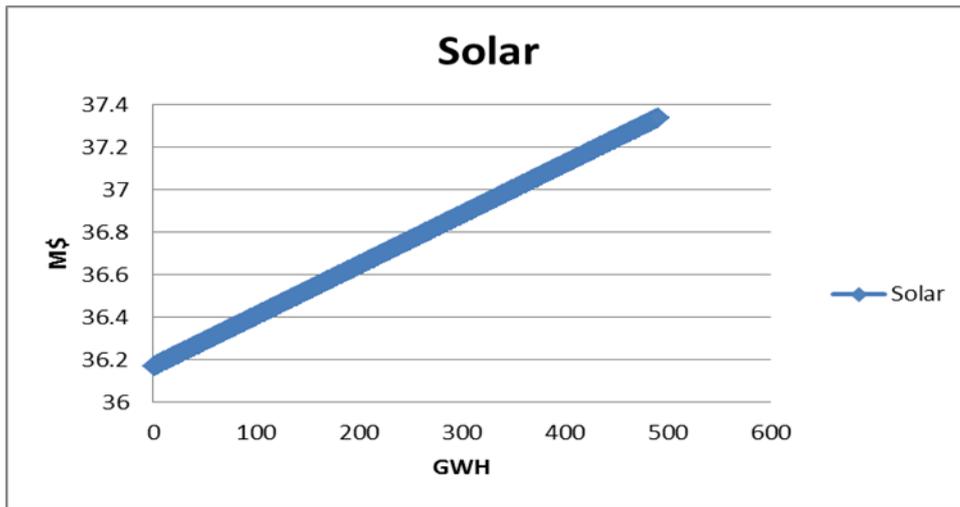
Thus, the total Annual fixed cost is around  $M\$ 755 / \text{lifespan} + M\$13.43 + M\$ 40.8 / \text{lifespan} \approx M\$ 36.2$

The total running cost = total variable cost + fuel cost  
 $= \$M1.168 + 0 \text{ fuel cost}$

As mentioned in the wind turbine system analysis, this absolute value helps the decision makers to figure out the annual cost of the system but it does not reflect the efficiency of the system in terms of the generation. The real efficiency of the system is reflected through the additional cost spent per each GWh generated, which is the marginal cost, the additional \$ amount spent over the annual initial cost in order to generate an additional GWh from the CSP system. In this CSP energy system the marginal cost is the annual running cost over the units of GWh generated over one year (or the lifetime expected running cost over the lifetime expected GWh generated). The marginal cost is the dollar value added cumulatively with the generation of each CSP GWh above the annual capital cost until reaching the expected annual generation and the total annual cost. Thus, In this case the marginal cost of each unit generated is  $\$M1.168 / 490 \text{GWh} = 0.002$ . Therefore, the 100MW CSP plant cost equation is:

$$\textit{Total annual cost (CSP)} = 36.169 + 0.002 * \textit{annual GWh generated}$$

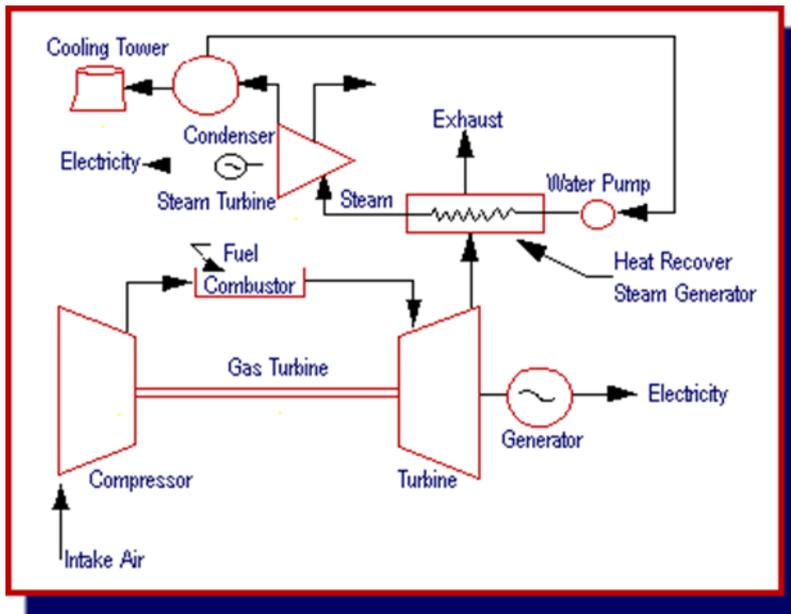
The marginal cost of the CSP plant is  $\$M 1.168 / 460 \text{ GWh} \approx 0.002$  (See Figure 17 for CSP cost function)



**Figure 17: CSP cost function graph.**

### **Combined Cycle Power Plant**

The combined cycle power plant combines a steam turbine and a gas turbine. The principle of this system is to reuse the heat of the first engine and convert it into mechanical energy that drives at its turn the power generators. It consists in using waste heat recovery boilers to transmit the heat fired in the gas turbine exhaust into steam energy to supply and drive a steam turbine. (See figure 19 for the combined cycle plant) . In a regular (non-combined cycle) heat engine is not used in the system and it remains a waste. Also it is important to know that the fuel turbine is not consuming efficiently the total fuel input, in combined cycle efficiency is increased significantly due to the extraction of substitute energy from heat. The combined cycle efficiency is relatively higher than that of the open cycle system because the same source of fuel is powering the different plant cycles.



**Figure 18: Combined Cycle Gas Turbine design. Source: Cogeneration.net**

The plant **efficiency** is the overall output as energy extracted from the input as fuel. It is a factor of the fuel turbine efficiency in converting fuel into energy, the steam turbine efficiency in converting steam into energy, the waste heat boiler efficiency and the mechanical drive shaft and clutch efficiency. Usually the overall combined cycle plant efficiency is around 55% and this percentage is subject to further increase with further and technical improvement of each part of the plant.(EnergyCentral,2009). The efficiency of the plant is not a comparison reference for different plant systems with different technology. We can refer to the efficiency percentage in order to compare the mechanism and the performance of the plant to another plant of same technology, over here Combined cycle power plants. Whereas the **Capacity factor** could be used to compare different power plant systems of same rated capacity. The capacity factor is calculated by taking the total amount of energy produced over a period of time and dividing it by the total amount of energy that a plant would have produce in a perfect condition at full capacity. It is variation depends impressively on the **type of fuel** used as a source of energy, and on the **plant design**. In a

combined cycle power plant, the type of fuel used to drive the turbines is the main factor in the alteration of the capacity factor of the plant. Usually the capacity factor of a combined cycle plant lies between 72% and 82% (Environmental Protection Agency (EPA), 2010).

Taking one plant technology and design, the combined cycle gas turbine (CCGT), the fuel efficiency, natural gas and diesel are to be compared on the bases of to be electricity conversion, their heating content and the related cost of MBTU derived from each.

Despite using the same plant specifications, different combustibles have different heating contents which affect the plant generation efficiency. In this part, the nature of each of selected combustibles and the effect of their heating content are examined closely :

- 1028 Btu per cubic foot of natural gas
- 128,000 Btu per gallon of diesel fuel

The amount of energy in MBTU generated from each of these combustibles differs; the gallon of diesel has 128000 BTU as energy content, and each US gallon of diesel is about 3175.15gram whereas the natural gas cubic foot containing a 1028 BTU is measured to be about 20.4 grams. The related amount of gram to generate one unit of energy BTU energy for each of these different fuel is:

$$(3175.15 \text{ g/ gallon}) / (128000 \text{ BTU/gallon}) \approx 0.025\text{g/BTU} \text{ For diesel}$$

$$\text{And, } (20.4\text{g/cubic foot}) / (1028 \text{ BTU/foot}) \approx 0.189\text{g/BTU} \text{ for Gas}$$

But this figure in itself is a perfect combustible efficiency indicator, to measure the economic efficiency of these fuels, it is important to examine the energy generated in terms of dollar \$ value. For this purpose we take the average industrial price for each substance over a period of the 10 months<sup>21</sup>; from January 2012 until October 2012. The average price for diesel is about \$US 3.11 per US Gallon of diesel, and \$US 91.713 per thousand of cubic meter of natural gas (Index Mundi, 2013).

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<sup>21</sup> The latest 10 consecutive months of year 2012 relatively to the period this paper is written.

The \$ value of one MBTU generated from diesel is

$$(3.11 \text{ \$/gallon})/(128 \text{ mbtu/gallon})= 0.02430469 \text{ \$/mbtu.}$$

Whereas the \$ value of one MBTU generated from natural gas is

$$91.7/ 35.146^{22}/1000/1.028^{23}= 0.00253841 \text{ \$/mbtu.}$$

Thus, the one thousand British thermal units generated from the natural gas source is cheaper than the one thousand British Thermal Unit generated from the diesel source by about 89%. So relying on this \$ value per MBTU generated we can conclude that relatively to diesel, natural gas is highly economically efficient for the operation of our combined cycle plant.

Now, in this part, the overall combined cycle system is examined in order to derive the marginal cost of each GWh generated, at a period of time. The fuel cost is included in the total operating cost, and this latter is observed with the variation between two variables; diesel use or natural gas use.

Combined cycle power plant is represented by a 100 MW plant. This plant is a capacity relative cost replica of a power plant of 500MW. It consists of two combustion turbines and one steam turbine. The **initial cost** varies due to the efficiency of the system. A report prepared by the IEA Energy technology system, in May 2010, stated that the initial cost of a CCGT is typically between \$1100/kw and \$1800/KW (IEA,2010).Whereas the National Renewable Energy Laboratory (NREL) cost report shows that the CCGT initial cost for year 2010 is \$1230 per KW installed (NREL, 2012). Moreover, the comparative cost of energy prepared at the end of year 2009 explained that the initial capital cost is around \$1044 per KW (California Energy Commission (CEC), 2009)

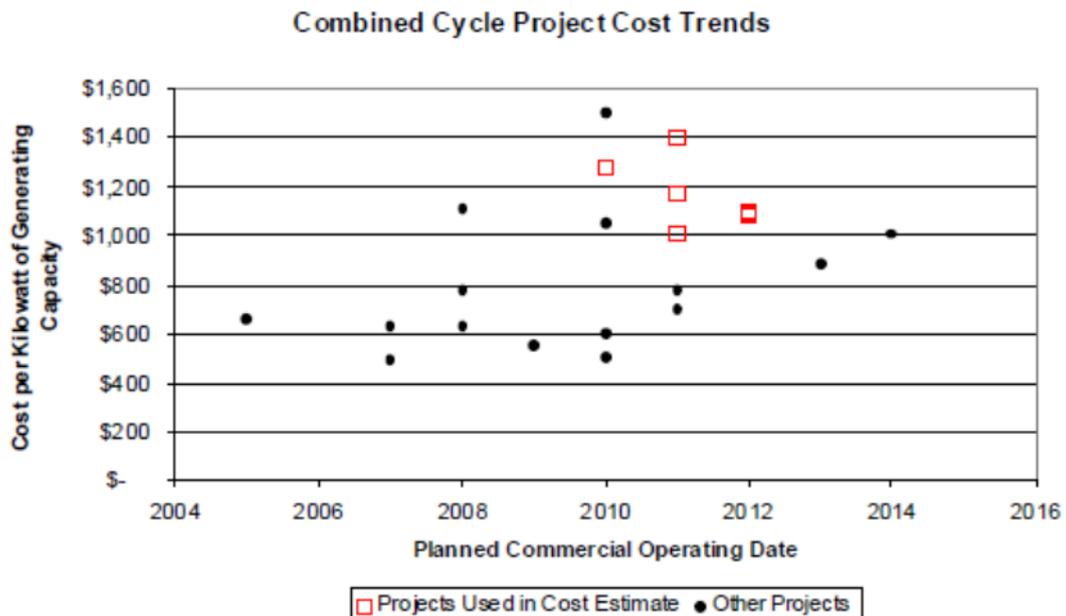
As the cost differences between these different sources are not significantly deviated from the average, we are going to assume the initial cost of the CCGT plant represented to be

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<sup>22</sup> Natural Gas cubic meter is equal to 35.146 cubic feet

<sup>23</sup> There is 1.028 MBTU in one cubic feet of Natural Gas

around the average of the figures offered, thus, around \$1200/KW. Also \$ 1200/KW is the rounded average of 8 combined cycle power plants at various areas in the United States of America (Kaplan, 2008). (See Figure 19 for combined cycle project cost trend.)



**Figure 19: Combined cycle project cost trend. (Source: Kaplan 2008, Power Plants: Characteristics and costs.)**

Concerning the Fixed and Variable operating and maintenance cost, The NREL energy cost report stated that with each MWh generated there is \$3.67 as variable cost of operation and there is an annual fixed cost related to the initial rated capacity of the plant which is \$6.31/KW (NREL, 2012). The variable and fixed costs offered in the comparative cost report, by CEC, for year 2009 was 3.19 for the former and 8.62 for the latter (CEC, 2009). The differential in the fixed cost is due to the differential in the technological measures that require more sophisticated fixed annual maintenance, whereas the differential between the variable cost is due to the differential in the operating efficiency.

The CCGT sample plant is assumed to be a 435MW as rated capacity<sup>24</sup>, with a **variable cost** around \$3.67 per MWh generated and an annual **fixed cost** around \$6.31/kw installed. Its capacity factor when operated on diesel is 74% while when operated on natural gas it is more than 80%. **Fuel cost** and capacity factors are the only two variables in the represented combined cycle that change up to the type of fuel driving the plant; diesel or natural gas.

The fuel cost is directly affected by the **fuel prices** and by the **fuel consumption** rate of the plant. In this comparison model the price of the driving fuel, diesel or natural gas, for ten consecutive months of the year 2012 is included and an average industrial price for each is derived;

- Diesel: \$3.111 per Gallon which is \$888 per ton<sup>25</sup>
- Natural gas: \$91.713 per thousand cubic meter which is \$2.54 per mmbtu (Thousand Thousand of BTU) <sup>26</sup>

The average of fuel consumption of the CCGT is 166 gram of diesel per KWh generated,<sup>27</sup> where the average consumption of Natural gas is 6.5 mmbtu per each MWh.

**CCGT operating on diesel.** In the represented CCGT power plant the life span is 20 years. The related capacity factor when run by diesel is around 74-75%. So the yearly electricity generation from the 435 MW is;

$$435 \text{ MW} * 8670 * 75/100 \approx 2\,858\,000 \text{ MWh}$$

The initial cost of the plant is \$1200 per KW installed. So the total initial cost is;

$$435 \text{ MW} * 1200 * 1000 = \text{M\$ } 522$$

The total annual fixed operating and maintenance cost is;

---

<sup>24</sup> This plant sample is similar to the Lebanese CCGT Zahrani and Deir Ammar plants capacity.

<sup>25</sup> Each US Gallon of diesel is about 3175.15g

<sup>26</sup> The cubic feet of natural Gas generates an average of 1028 BTU

<sup>27</sup> Due to plant aging, Lebanese combined cycle Zahrani and Deir Amar are consuming 180grams of diesel to generate one KWh.

$$\text{\$ } 6.31 * 435 * 1000 = \text{M\$ } 2.74485$$

The variable operating and maintenance cost is \\$3.67/MWh so the total annual is;

$$3.67 * 2\,858\,000 \text{ MWh} = \text{M\$ } 10.48886$$

The annual fuel cost as Diesel is;

$$166 \text{ g/KWh} * 2\,858\,000 \text{ MWh} * \$888/\text{ton} / 1000000 * 1000 = \$ 421\,292\,064$$

The annual total operating cost is;

$$10\,488\,860 + 421\,292\,064 = \$ 431\,780\,924$$

The yearly fixed cost and initial cost depreciated is<sup>28</sup>:

Initial cost/20 years + yearly fixed M & O cost:

$$\text{\$M } 522 / 20 \text{ years} + \text{\$ M } 2.74485 = \text{\$M } 28.84485$$

To calculate the economic efficiency of the GCCT operating on Diesel, the total annual operating cost is divided over the total yearly electricity generated which is;

$$\text{\$ } 431.780924 / 2858 \text{ GWh} = 0.151$$

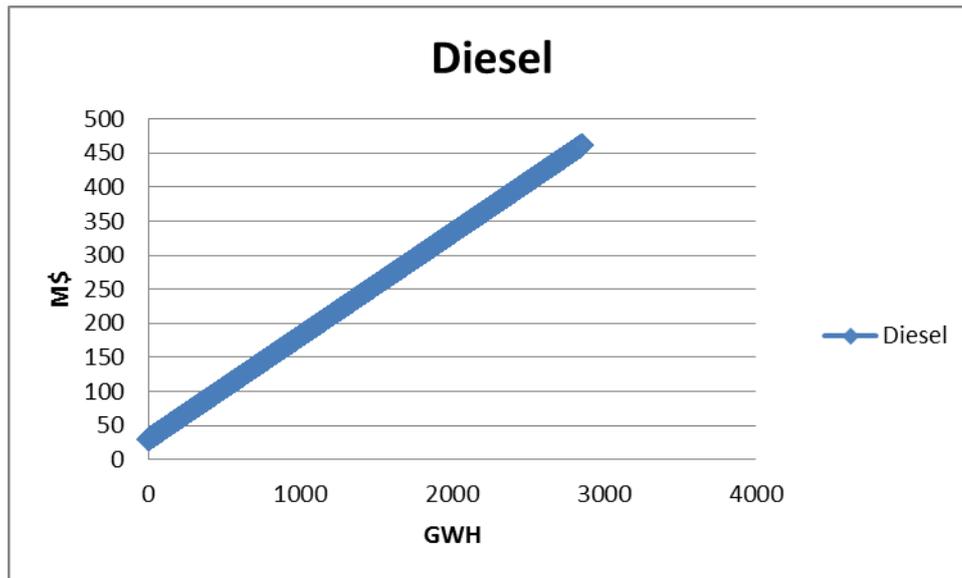
This value is interpreted as the additional operating cost spent with each additional electricity unit generated, so at yearly basis and over the \\$M 28.84485 as initial and fixed cost, the generation of each GWh results in spending a M\\$ 0.152 as marginal cost or to be simplified the generation of each KWh costs \\$0.152 above the initial and fixed value. (See Figure 20 for diesel cost curve).

Thus, the cost equation for the CCGT plant operated using diesel as fuel is:

$$\begin{aligned} \textit{Total annual cost (CCGT diesel)} \\ = \text{\$M } 28.84485 + \text{M\$ } 0.152 * \textit{GWh generated annually} \end{aligned}$$

---

<sup>28</sup> The land cost in thermal technology is supposed to be insignificant.



**Figure 20: Diesel cost curve.**

**CCGT Operating on Natural Gas.** In the represented CCGT power plant the life span is 20 years. The related capacity factor when run by diesel is around 80-81%. So the annual electricity generation from the 435 MW is;

$$435 \text{ MW} * 8670 * 81/100 \approx 3\,704\,000 \text{ MWh}$$

The initial cost, and the annual fixed operating and maintenance cost are the same as the GCCT when driven by diesel which are respectively M\$ 522 and M\$ 2.74485.

The variable operating and maintenance cost is \$3.67/MWH so the total annual is;

$$3.67 * 3\,704\,000 \text{ MWh} = \text{M\$ } 13.59368$$

The annual fuel cost as natural gas is;

$$6.5 \text{ mmbtu/MWh} * 3\,704\,000 \text{ MWh} * \$2.54/\text{mmbtu} = \$ 61\,153\,040$$

The annual total operating cost is;

$$\$ 13.59368 + \$ 61\,153\,040 = \$\text{M } 74.74672$$

The yearly fixed cost is equal to the initial cost depreciated over 20 years, the annual fixed cost which is<sup>29</sup>;

$$(\$M 522 / 20 \text{ years}) + M\$2.74485 = \$M 28.84485$$

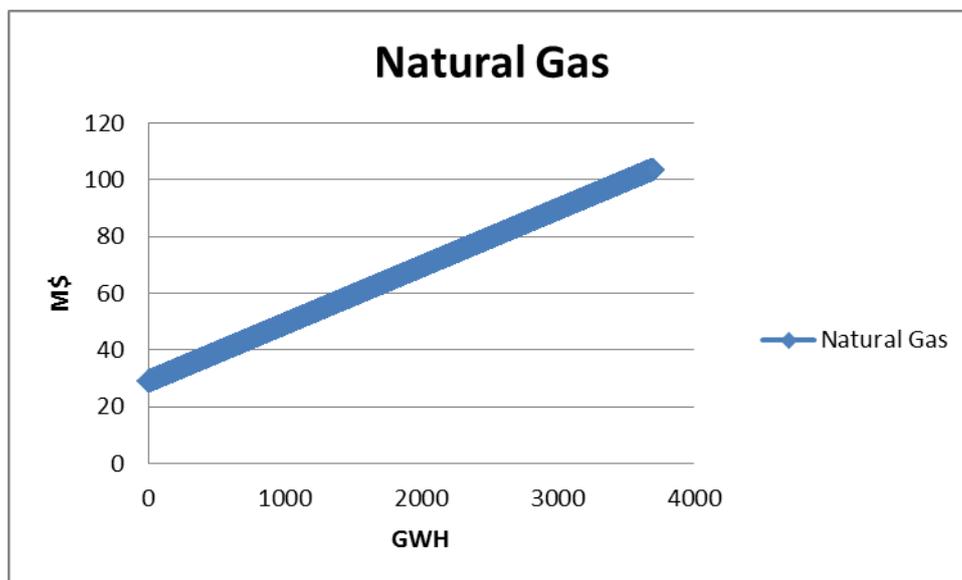
To calculate the economic efficiency of the GCCT operating on natural gas, the total annual operating variable cost, fuel cost and variable cost are divided over the total yearly electricity generated which is;

$$(\$ 13.59368 + \$ 61 153 040) / 3704 \text{ GWh} = 0.02018$$

This value is interpreted as the marginal cost per each unit of electricity generated and it is spent above the initial and fixed operating cost of the plant. Therefore, on yearly basis and over the initial and fixed cost \$M 28.84485 , the cost will arise \$0.02018 with the generation of an extra KWh ( or M\$ 0.02018 per each GWh generated.)(See Figure 21 for natural gas cost curve).

The annual total cost of the electricity generated from a CCGT operating on gas is:

$$\text{Annual total cost (CCGT NG)} = M\$ 28.84485 + 0.02018 * \text{GWh generated}$$



**Figure 21: Natural Gas cost curve.**

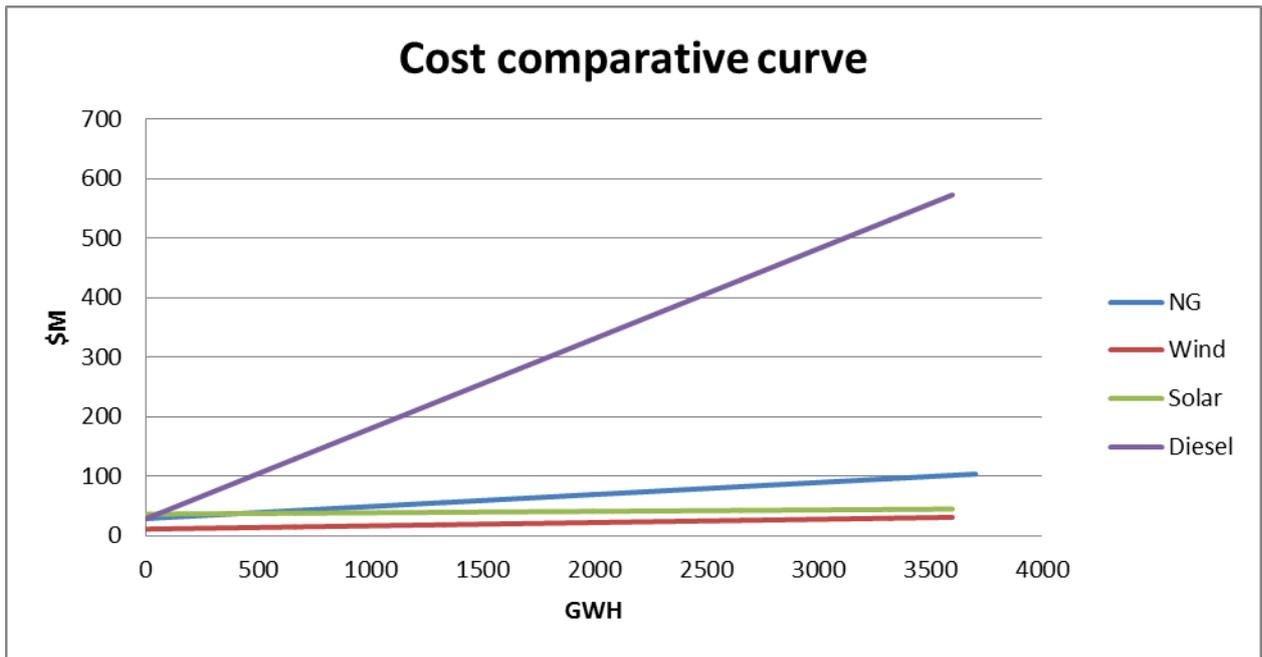
<sup>29</sup> The cost of land is supposed to be insignificant in the thermal plant cost estimation.

The marginal cost of each electricity system is the extra dollar over and above its related fixed initial cost of investment and operation . When the electricity system is fuel independent this will drop the extra value of money spent with each unit of electricity generated. When considering which electricity system to include in the Lebanese Energy mix, Systems with the lowest marginal costs should be given priority, which contribute to decrease the overall cost of electricity supply.

To build an efficient electricity supply sector, to increase the generation at minimal cost escalation and to meet the potential surge in demand in the Lebanese electricity market, the electricity gap should be bridged by using the most efficient electricity systems. This model shows that the dollar marginal cost curve of KWh produced from renewable energies is dropping within generation, whereas the marginal cost curve of conventional energies is going up slightly with the use of natural gas and more aggressively with that of oil (diesel). (See Figure 22 for comparative cost curve.)The graph shows that the 300<sup>th</sup> GWh produced by oil, natural gas, wind, and CSP costs respectively M\$ 74.16825, M\$ 34.898, M\$ 12.772, and M\$ 36.884.

By projecting the electricity demand in Lebanon at an Average of 7%, The electricity needed to be supplied is around 27388 GWh. By adopting a scenario in which the electricity demanded per year 2015 for example is fully offered by CCGT plants operating on diesel, 10 CCGT diesel plants of 435MW are needed and the total annual cost of the electricity in Lebanon would be:

$$\begin{aligned} \text{Annual total cost} &= \$M 28.84485 * 10 + M\$ 0.151078 * \text{GWh generated annually} \\ &= \$M 4426.172764 \end{aligned}$$



**Figure 22: Cost Comparative Curve.**

Whereas, if the energy system is operated by adopting a scenario in which 80 %, 10% and 10% of the electricity demand are provided from a CCGT operating on natural gas Wind energy and CSP energy respectively, a mix of 6 CCGT NG plants, 8 wind plants of 100MW, and 6 CSP plants of 100MW. The total annual cost of electricity supply would be the annual total cost of the 80% of electricity demand supplied by natural gas CCGT plus the annual total cost of the 10% of electricity demand year 2015 supplied by Wind energy plus the annual total cost of the remaining 10% of electricity demand supplied by the CSP technology.

*Annual Total cost of electricity from natural gas CCGT = Type equation here.*

$$28.84485 + 0.02018(80\% \text{ total electricity demand})$$

$$= 28.84485 * 6 + 0.02018 * 21910.4 \text{ GWh}$$

$$= \$M 615.220972$$

*Annual total cost of electricity from Wind energy =*

$$11.12264 * 8 + 0.0055 \text{ (10\% total electricity demand)}$$

$$= 88.98112 + 0.0055 * 2738.8 \text{ GWh}$$

$$= \text{M\$ } 104.04452$$

*Annual total cost of electricity from CSP =*

$$36.16914286 * 6 + 0.002383673 \text{ (10\% total electricity demand)}$$

$$= 217.0148571 + 0.002383673 * 2738.8 \text{ GWh}$$

$$= \text{\$M } 223.543262$$

*Annual total cost with ( 80% from natural gas, 10% from wind and 10% CSP) =*

$$\text{\$M } 615.220972 + \text{M\$ } 104.04452 + \text{\$M } 223.543262$$

$$= \text{M\$ } 942.808754$$

Hence, The operation of the electricity system by purely using Diesel as a source of energy in order to provide the electricity demand for the year 2015 will cost the economy around \$M 4426.172764 whereas a shift to a diversified electricity profile by using natural gas , wind and CSP as sources of energy would be significantly cheaper and more efficient with approximately a total annual cost of M\$ 942.808754 . Substituting the conventional energy source with a mixed green and natural gas sources would have drop the cost of providing electricity demand by around 79%.

The electricity generating system purely using Diesel sources is inflicting direct accumulated losses on the whole economy. Including the opportunity cost forgone due to the use of diesel and the abstention from using a green/NG system would shift the losses upward. Moreover if the CO<sub>2</sub> cost is included in this study, the substitution of diesel with a mix of Green/NG would be even more justified.

## CO<sub>2</sub> Cost Inclusion

In this Part, the model above is going to internalize the cost of CO<sub>2</sub> emitted from each power plant system in the study. The green energy systems in our models, CSP and Wind, have zero CO<sub>2</sub> emissions<sup>30</sup>. The Conventional energy systems natural gas and Diesel have a significant toxic discharge of CO<sub>2</sub>.

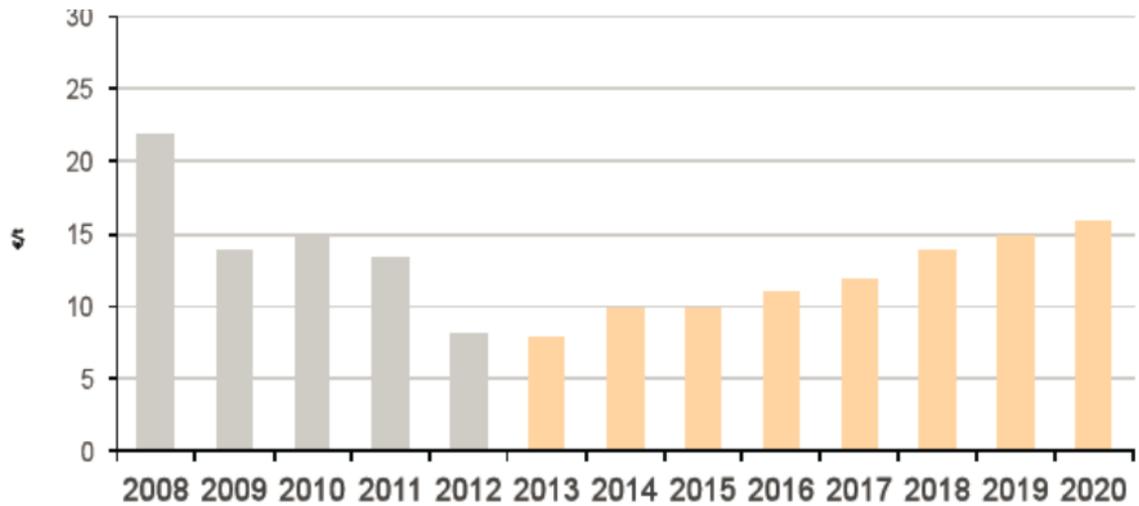
With the inclusion of CO<sub>2</sub> pricing in our cost function model, the running cost of conventional technologies is going to increase. These technologies are paying the cost of contribution in the greenhouse effect. Through generation, each MWh by combusting NG or Diesel, a specific amount of CO<sub>2</sub> is emitted. Thus, CO<sub>2</sub> discharge is a direct result of MWh generation. With regard to the fuel type and to the size of the generation, there is a related CO<sub>2</sub> discharge. The cost of Carbon is a composite of the operating variable cost. So, the increase of MWh generated, will increase Carbon emission, which increases the yearly total cost paid for Carbon emitted.

Carbon pricing is the government adoption of Carbon offset policy by either using subsidies, emissions trading or Carbon tax. Assuming that the government is embracing the emission trading policy, our model will include the cost paid for polluting the environment which is the price paid to get the Carbon allowances or the Carbon credits up to the energy firms emissions volume. The cost of Carbon is specified by a monetary value versus the mass of the Carbon emitted. The average cost of Carbon trading for year 2012 and 2011 is around €8 /Ton (point Carbon, 2012), which is around USD\$ 10.2/ton of Carbon.<sup>31</sup>(See Figure 23 for the Carbon average cost trend.)

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<sup>30</sup> No hybrid technology used.

<sup>31</sup> The average exchange rate between 12/2011 and 12/2012 is USD\$1.2856/€



**Figure 23: The Carbon average cost trend. (Source: Point Carbone, 2012)**

As it is mentioned previously the volume of Carbon emitted is strongly related to the combustible nature. In our study model there are two conventional combined cycle plants operating on natural gas and on Diesel (oil). Note that the volume of Carbon emitted from combined cycle technology is less than that emitted from an open cycle technology by about 30% (IEA, 2010).

The light Fuel oil, diesel, CO<sub>2</sub> emissions are estimated to be around 683KG/KWh when turned in a combined cycle power plant. (Schock, 2007).<sup>32</sup> However, the CO<sub>2</sub> emission rate of a combined cycle plant operated on natural gas in is around 390 kg of CO<sub>2</sub>/KWh. (IEA ETSAP, April 2010 a) (GHG institute).

As the annual Generation is 2858 GWh from the combined cycle power plant rated 435 MW and operated on diesel, The annual CO<sub>2</sub> emissions are;

$$0.683 \text{ CO}_2 \text{ Tons/MWh} * 2858 \text{ 000MWh} \approx 1952014 \text{ tons of CO}_2$$

The trading cost of the CO<sub>2</sub> emitted is to be included in the annual operating cost of the plant is;

<sup>32</sup> In the Lebanese Zahrani plant, combined cycle and operated on Diesel the CO<sub>2</sub> emissions are more than 734 tons/MWh due to aging factors( Carma Carbone monitor )

$$1952014 * \$10.2/t$$

$$= \text{M\$ } 19.9105428$$

$$\approx \text{M\$ } 20 \text{ per year}$$

The marginal cost of Carbon associated with each GWh generated by a diesel CCGT system is

$$\text{M\$ } 19.9105428 / 2858 \text{ GWh} = 0.0069666$$

When this externality cost is included in the total operating annual cost of the plant, the economic efficiency of the plant is negatively affected and the marginal cost will go up;

$$\text{M\$ } 431.780924 + \text{M\$ } 19.9105428 = \text{M\$ } 451.6914668$$

With externality inclusion, the marginal cost of the electricity unit generated from a diesel CCGT plant is,

$$\text{\$M } 451.6914668 / 2858 \text{ GWh} = 0.1580446$$

This figure 0.1580446 is the incremental cost in dollar value per each electricity unit generated when a combined cycle power plant is operated on diesel and when the CO<sub>2</sub> emitted are traded per \$10.2 per each ton. Thus, each GWh will cost 0.158 above the annual initial and fixed cost.

The annual total cost of the electricity system purely operating on diesel and with the inclusion of the incremental cost Carbon would be:

$$\textit{total annual cost (diesel CCGT with CO}_2) =$$

$$28.84485 + 0.1580446 * \textit{GWh generated over one year}$$

Moreover, the Carbon inclusion trading cost will affect the annual operating cost of the combined cycle plant rated 435 MW and operated on natural gas as fuel. The annual CO<sub>2</sub> emissions are;

$$0.39 \text{ CO}_2 \text{ tons/ MWh} * 3704 \text{ 000 MWh} \approx 1444560 \text{ tons of CO}_2$$

The trading cost of CO<sub>2</sub> is:

$$1444560 \text{ tons of CO}_2 * \$10.2 = \$ 14\,734\,512$$

The marginal cost of Carbon per each unit of GWh generated from a natural gas CCGT is  $\text{M\$ } 14.734512 / 3704 = 0.003978$

When CO<sub>2</sub> externality is included in the total annual operational cost through trading Carbon policy ;

$$\text{M\$}74.74672 + \text{M\$ } 14.734512 \approx \text{M\$ } 89.481232$$

The economic efficiency of the plant would be:

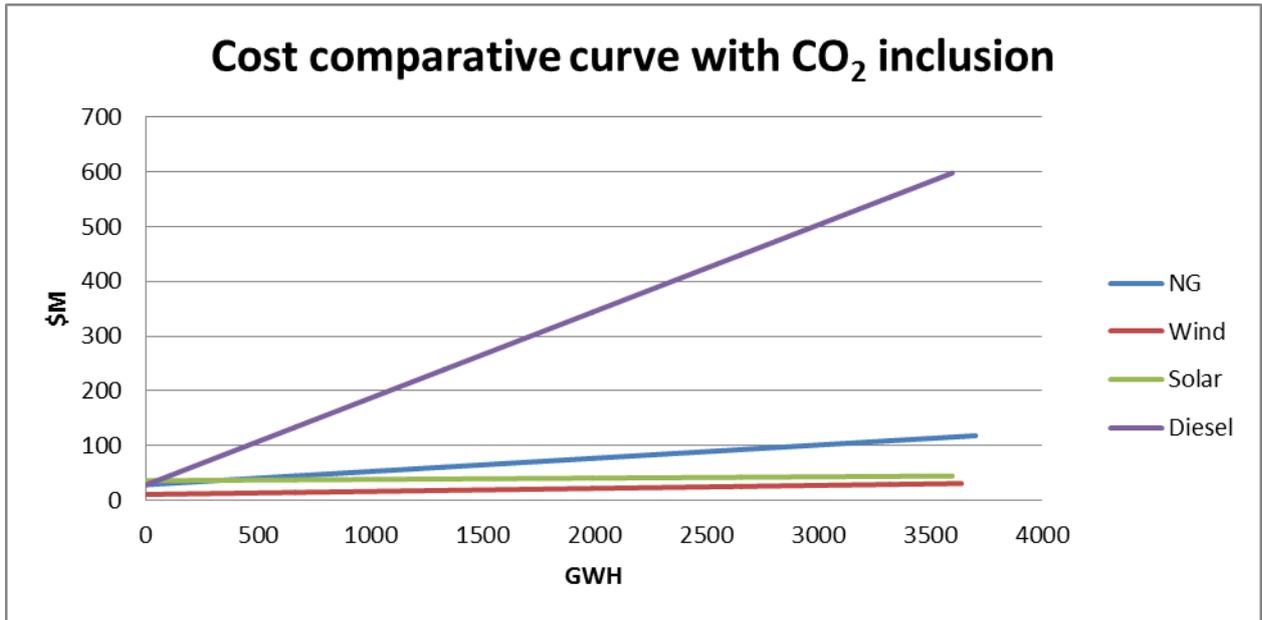
$$\text{M\$ } 89.481232 / 3704 \text{ GWh} = 0.024158$$

This value is the incremental cost paid per additional unit of generation above the initial and fixed annual cost with the inclusion of CO<sub>2</sub> cost.

The total annual cost of the electricity generated from a CCGT system operated on natural gas while considering the CO<sub>2</sub> cost is:

$$\begin{aligned} & \textit{Total annual cost (CCGT NG with CO}_2 \textit{ inclusion)} \\ & = 28.84485 + 0.024158 * \textit{GWh generated per year} \end{aligned}$$

While It is obvious that the incremental cost per each of the combined cycle power plant operated either on diesel or on natural gas is “amplified” due to the CO<sub>2</sub> inclusion. However, due to insignificant CO<sub>2</sub> emissions from the green energy system wind and CSP, there is any additional cost associated with CO<sub>2</sub> to be included as an incremental cost of unit of electricity generated.(See Figure 24 for Annual electricity cost curve with CO<sub>2</sub> inclusion.)



**Figure 24: Cost comparative curve with CO<sub>2</sub> inclusion**

Under the Carbon inclusion ceiling, the diesel use as fuel to operate CCGT plant and provide the demanded electricity in Lebanon, would inflict deeper losses and result into inefficient spending.

To supply for the estimated electricity demand in Lebanon year 2015 of 27388 GWh, a couple of scenarios are to be assumed under Carbon cost inclusion. The first scenario is the adoption of a pure diesel energy system of around 10 CCGT diesel plants of 435MW each, whereas the second is the previously assumed mix of 80%, 10%, and 10% from different sources as natural gas, Wind and CSP respectively in which there are 6 CCGT NG plants of 435 MW, 8 Wind plants of 100MW, and 6 CSP plants of 100MW each.

In the first scenario, the total annual cost would be:

$$\text{Total annual cost (Scenario 1)} = 28.84485 * 10 + 0.1580446 * 27388$$

*Which is M\$ 4616.974005*

The Annual cost of electricity generated with Cost inclusion in an exclusive diesel energy system is 4.13% higher than a similar system with no CO<sub>2</sub> cost inclusion.

While in the second scenario, with CO<sub>2</sub> cost inclusion, the total annual cost would be the total cost of supplying 80% of the electricity demand year 2015 from natural gas CCGT system while including the social environmental cost of CO<sub>2</sub> plus the cost of supplying the remaining demand of 20% with equal share 10/10 from wind and CSP energy sources.

$$\text{Total cost from NG} = \text{M\$ } 28.84485 * 6 + 0.024158 * (80\% * 27388)$$

$$= \text{M\$ } 702.3805432$$

$$\text{Total cost from Wind energy} = \text{M\$ } 11.12264 * 8 + 0.0055 * (10\% * 27388)$$

$$= \text{M\$ } 104.04452$$

$$\text{Total cost from CSP} = \text{M\$ } 36.16914286 * 6 + 0.002383673 * (10\% * 27388)$$

$$= \text{M\$ } 223.543262$$

Thus, under CO<sub>2</sub> cost inclusion, the annual total cost of the 80%,10%,10% natural gas and green energy mix is M\$ 1029.968325 which is higher by 8.46% than a scenario neglecting CO<sub>2</sub> as social externality. Therefore, by exclusively adopting the first scenario and neglecting any substitution and by including the CO<sub>2</sub> environmental and health externalities, the economy would have an additional cost burden of M\$3587.00568 while supplying annual electricity demand for year 2015 for example . However, with cost CO<sub>2</sub> cost internalization and with an energy mix of 80% generated thru a CCGT natural gas and of 20% of green renewable energies equally shared by wind and CSP, the annual cost of generating electricity for the sample year 2015, would drop by around 77.7% compared to an electricity system fully operated on diesel use.

The Carbon cost inclusion increases the cost of electricity supply by about 4.13% in an exclusive diesel system and 8.46% in a natural gas/ green energy mix system. While the carbon emissions are relatively higher per MWh generated by CCGT diesel system by

around 42.8% than those generated by a CCGT natural gas electricity system, the percentage of change of the cost before and after Carbon cost inclusion in the Diesel system is relatively lower than that of the NG/Green. This is because the main cost component that is significantly driving the marginal cost upward in a diesel CCGT plant is the diesel price itself and the diesel generation efficiency in terms of dollar which is 0.02430469 \$/mbtu compared to natural gas of 0.00253841 \$/mbtu (for the average prices of year 2012).

However, a shift to a natural gas/ green energy mix of 80-10-10 in order to supply for the electricity demand in Lebanon, for year 2015 for example of 27388 GWh, would save the economy about M\$ 3730. Year 2011, around billion \$1.57 were transferred to EDL as electricity subsidies and 93% of these subsidies are paid as oil bills (Carboon, May 2012). However, during the same year the electricity supply was around 12396.4 GWh with a gap of 40%.(EDL Data,2012). A natural gas/ green mix of 80-10-10 would secure the supply and fully procure the electricity demanded of 27388 GWh for around billion \$0.942 a year, which is less than the subsidies paid for the inconsistent supply of 60% of the electricity demand in Lebanon year 2011 as an example. Moreover, besides economic cost, the shifting from a homogeneous diesel energy system to a more diversified energy mix based on natural gas would be an environmentally friendly option with substantive decrease in CO<sub>2</sub> and other harmful emissions. An electricity volume of 27388 GWh purely generated from diesel will result in

$$683 \text{ tons CO}_2/\text{GWh} * 27388 = 18\,706\,004 \text{ tons of CO}_2 \text{ per each year}$$

While the CO<sub>2</sub> emissions from the NG/green mix 80-10-10 per year are:

$$390 \text{ tons CO}_2/\text{GWh} * 21910.4 = 8\,545\,056 \text{ tons of CO}_2$$

With this latter amount of CO<sub>2</sub> internalized, the annual cost for electricity would reach billion \$ 1.023 and would still cheaper than the subsidies paid year 2011 to supply for 60% of the electricity demand for the same year.

Thus, in order to secure reliable electricity supply, to decrease cost of supply and to maintain lower harmful emissions level ,shifting to a diversified energy mix based on green and natural gas is the key proven to be a feasible environmental and economic option.

## **Chapter III**

### **The natural gas and the green potential in Lebanon: availability and technology assessment.**

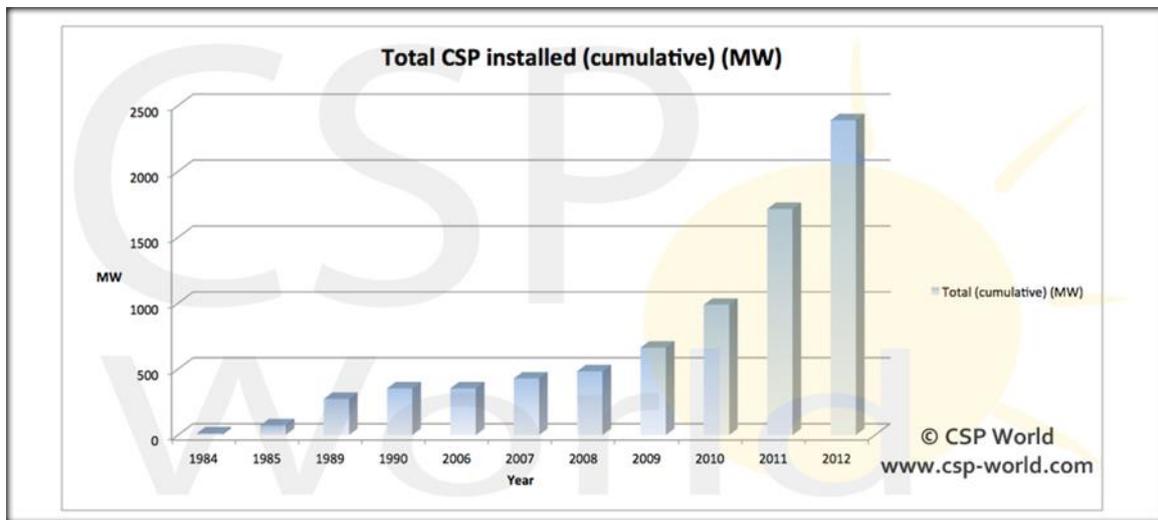
The use of natural gas combined cycle proved to be environmentally and economically feasible relatively to the diesel technology. Also CSP and wind energy prove to be the leading worldwide technologies adopted concerning renewable clean energy.

In the previous chapter, a general economic and environmental assessment of each system is covered. In this chapter, a close examination of the potential of natural gas, wind and CSP would be held in order to disclose the real opportunity behind these technologies in the Lebanese context.

#### **Concentrating Solar Power**

This technology is first installed in the 1984 with the SEGS in California, USA. This technology has known major development and expansion globally until reaching 1.6 GW of operating installed capacity by year 2011, from which Spain is endorsing 0.58 GW, USA 0.507 GW and Iran 0.06 GW (Wang, 2011). Furthermore, it is estimated that it has reached about 2.3 GW at the end of year 2012. (see Figure 25 for the CSP installed capacity world widely.) About 17 GW of CSP projects are under construction worldwide from which the USA has a share of about 8 GW. Then, there are 4.46 GW plants in development in Spain and 2.5 GW CSP power plants under construction in China. This technology is even expanding in MENA where Morocco is planning to develop a CSP plant of a capacity of 2 GW in Ouwarzazat area, whereas Israeli government will have completed by 2013 a plant in Negev desert of a capacity 0.25 GW, and it is planning to build another plant of 60 MW in

the same area and 120 MW in Tze'elim (Mahdi, W. 2013) (Siani, J, 2012) (CDM UNFCCC, 2006).



**Figure 25: the worldwide CSP capacity installed (Source: CSP World.)**

In general, CSP has many technology advantages that make it one of the most expanded renewable energies. These advantages are mainly due to dispatchability, predictability of production, fuel independence, and a relative higher capacity of production. The technological efficiency and its maturity lead towards lower cost- quantity ratios which increase its competitive advantage when compared with other conventional technologies. There is a perfectly positive correlation between enhanced technology and enhanced capacity factor.

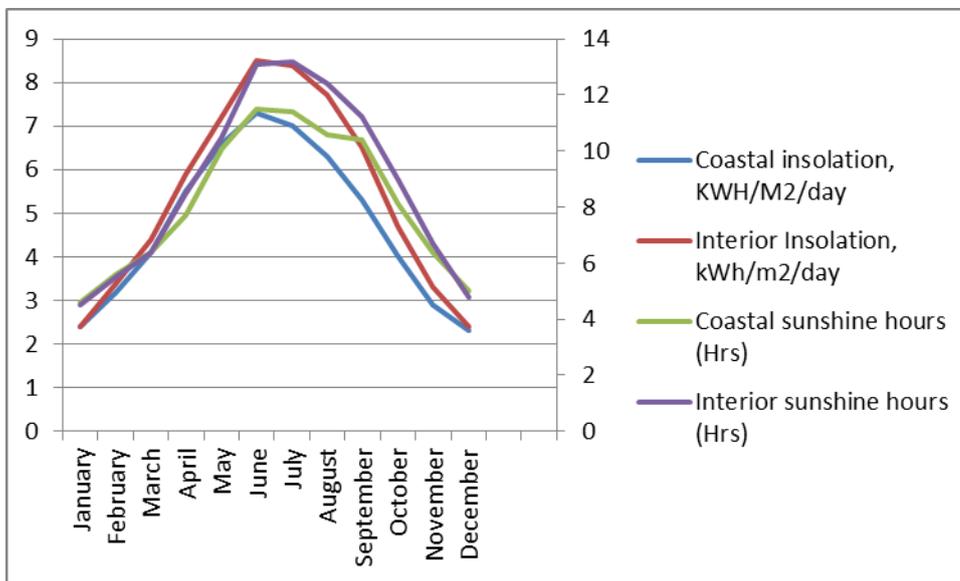
**CSP in the Lebanese context.** There are many factors dictating the success of CSP and increasing its capacity factor. First, it is dependent on the solar multiple of the plant and the storage capacity, directly related to the plant design, and to the degree of insolation directly related to the location of the plant. The multiple solar is the amount of solar energy measured by the size of the solar field, which is the concentrators focusing sun thermal energy onto the heat-transfer fluid relative to the size of power block which is the steam turbine converting the thermal energy into electricity (Denhlom & Sioshansi, 2010.) To

assure an effective and efficient operation of power blocks, the multiple solar should be typically more than a unity and preferably between 1.3 and 1.4 (IRENA, 2012). Also, the increase in storage capacity requires the increase in solar multiple, for example a CSP plant may have a solar multiple of 2 if six hours of thermal storage are added. Moreover, the storage thermal capacity is a crucial element in increasing the annual generation capacity of the plant. It is true that the initial cost of adding storage capacity is relatively and significantly higher than a plant with zero thermal capacity by about 30%, but this additional cost increase is totally justifiable due to the substantial increase in generation (NREL, 2012). The operational variable cost per unit of generation of a CSP plant tends to be lower with plant size increase, so a CSP with storage capacity has a similar or lower Levelized cost of energy (LCEO), which is an economic valuation of the cost of the electricity system with the inclusion of all the costs over its lifetime given in a value of currency per unit of energy generated. “It is the constant unit cost (per KWh or MWh) of a payment stream that has the same present value as the total cost of building and operating a generating plant over its life” (Black & Veatch, 2013). The storage and solar multiple are key elements in the determination of the generation capacity of the plant (See Figure 16 for the solar multiple graph).

In addition, insolation, the intensity and amount of solar radiation energy received on an object or on specific surface area and recorded during a given time is an influential factor in determining the size of the plant, its solar multiple and its thermal storage capacity in order to achieve a target generation (UCSB). Also, for a same plant size, the increase in insolation level or in the Direct Normal Irradiance (DNI), has respectively a direct effect in increasing the generation size for a given period and in decreasing the LCOE. For example, an increase of DNI from 2000 KWh/m<sup>2</sup>/year to a figure between 2300 and 2700 would decrease the LCOE per about 25% to 35% (Cedro, 2012). Moreover the latitude of the surface area is an important factor in increasing the sun irradiation, the higher leads to higher generation from

solar concentration power process. The parabolic trough technology is most efficient in the areas of latitude around 35 degree or more.

According to a study directed by Karaki and Chedid at the American University of Beirut (AUB), The Renewable Energy Country profile for Lebanon, it is observed that the solar sunshine is relatively highly concentrated in the interior Lebanese zones<sup>33</sup>(Karaki & Chedid, 2009). Table 2 shows the averaged values of the total solar insolation, coastal and internal, on a horizontal surface. The coastal data are collected from the Airport station and are related to the years between 1965 and 1975, whereas the internal data are collected from the internal station in Bekaa Valley, Ksara, between 1956 and 1965. Based on these data, it is concluded that the highest DNI in Lebanon is found in the internal areas. The average interior insolation in Lebanon per year is 5.4 KWh/m<sup>2</sup>/ day, so per year the DNI is around 1980 KWh/m<sup>2</sup>/year with the average sunshine hours of 8.8 over the year. (See Figure 26 for Insolation ratio in Lebanon table)



**Figure 26: Insolation ratio in Lebanon. (Source: Karaki and Chedid, 2009 ( in Beheshti, 2010.)**

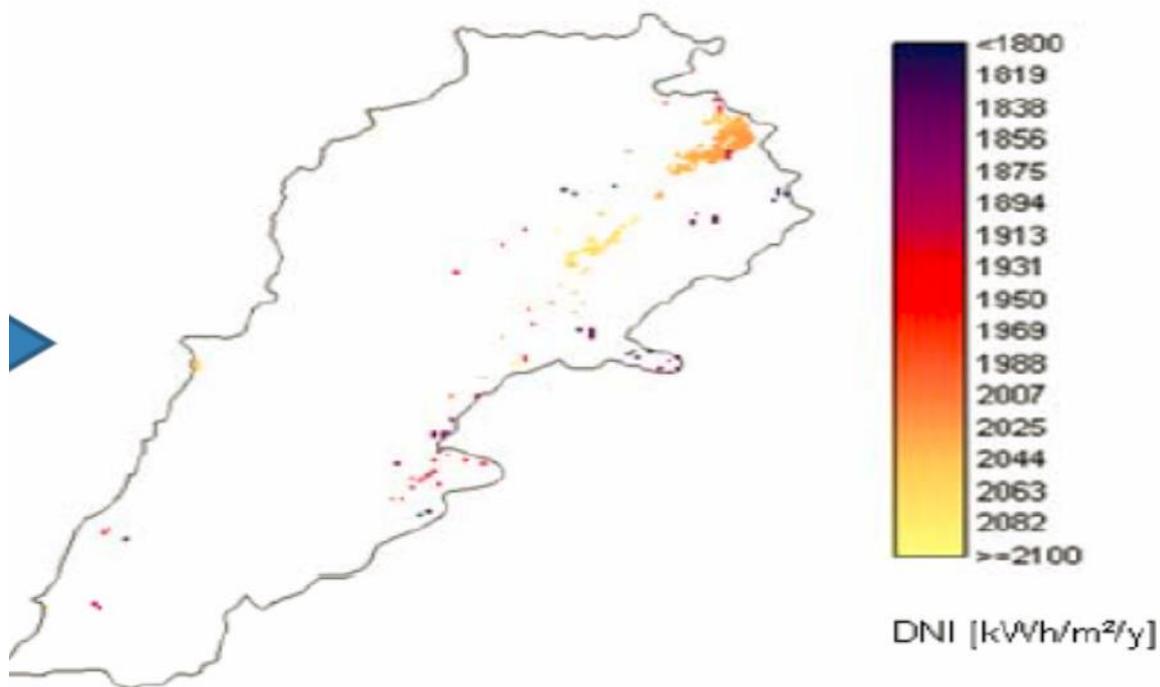
<sup>33</sup> The Renewable Energy Country profile for Lebanon, Chedid and Karaki, AUB.

An internal Lebanese area located in Bekaa Valley, was assumed to be a suitable location to develop CSP plant; this area is Hirmel. It was selected by The Country Energy efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon (CEDRO) due to a relatively great yearly Solar resources that makes it one of the ‘fittest’ areas for CSP requirements and feasibility in Lebanon (Cedro, 2012). With a specific CSP technology and a given rated capacity, the higher the DNI the more actual generation is. In Hirmel the average DNI is approximately 2400 KWh/m<sup>2</sup>/year( higher than the average of internal Lebanese areas) See Appendix for the DNI map of Lebanon). In addition to the DNI advantage, the suggested Hirmel plant would have a latitude around 34.39 degree which is suitable for parabolic technology.

A study directed by CEDRO, suggested launching a typical reference CSP plant in different areas with different DNI in order to observe technical and economic variables (Cedro, 2012). This plant is Andasol CSP plant located in Granada, Spain, with a DNI of 2201 KWh/m<sup>2</sup>/year, with an altitude of 35.6 degrees. This plant rated generation capacity is 50 MW, with 7.5 hours of storage, a solar multiple of 1.99, and a field size of 510,120 square meter (m<sup>2</sup>).

In case the same Andasol plant with its overall specifications is launched in Hirmel, it is expected that Hirmel version would be more productive due to environmental context as DNI. In Hirmel the field size would be similar to the field size of the reference plant with 509,440 m<sup>2</sup> and on a total land surface of 1.9 square kilometer ( km<sup>2</sup>) (Cedro 2012). The actual generation of the Andasol in Granada is around 157,206 MWh annually whereas it is estimated to be around 170,589 MWh annually with an annual capacity factor of 45.82% ( Aringhoff et al. 2002). If the Andasol system endorsed a hybrid technology of 15% fuel in Granada and in Hirmel, the annual generation would be 180GWh and 220GWh respectively.

Hirmel is the best ultimate location in Lebanon to launch a CSP plant due to abundant sunshine (See Figure 27 for the DNI map in Lebanon). A space around 510,000 m<sup>2</sup> is needed to build a plant of 50 MW with 7.5 hours of thermal storage a day generating yearly around 170,589 MWh. By simple calculation, a land of 4 square km (8 times bigger), for example, can be invested to generate yearly 1,337,953 MWh. This amount of electricity actually accounts to more than 8% of the average estimated demand for electricity between 2008 and 2012. By assuming that a yearly average consumption of electricity per each resident in Lebanon is 3500 KWh, this simulated plant would be a source of satisfaction for more than 48740 residents or 12185 average-size households of 4.



**Figure 27: DNI map of Lebanon (Source: Chehab, 2010)**

## Wind Energy in the Lebanese context

This part of the chapter is concerned with shedding light on the wind energy potential in the Lebanese environment. It is crucial to note that the factors examined in the generation of wind energy is directly related to the turbine design, specifically the rated capacity, the hub length, and the rotor diameter. It is also sensitive to the environment and location of the turbine, specifically the wind speed, the wind density, and the altitude. These factors determine the power generated from a specific turbine in a specific location at a specific altitude.

According to *Wind Atlas in Lebanon* and other private independent studies and observations in Lebanon and in the region, the windiest areas in Lebanon are those located in the North and the South where there are natural wind corridors. For example, a study generated by the Electricity Utility of Aley in Akkar area, North of Lebanon, stated that the minimum wind velocity is around 7m/s which makes it a prospective area for launching a wind farm and harvesting wind energy. Moreover, it was estimated that the Southern Lebanese region has one of the highest wind velocities in Lebanon especially in its central area which is a natural corridor. The regional wind records taken from the surrounding army airports along the northern areas of occupied Palestine and along the entire Syrian border indicate a prospective potential for the Lebanese Southern area with a wind velocity not less than 7 m/s at a height of 40 and 50m above the ground (Beheshti, 2010). In 1992 and just 30 Km from Khiyam, the southern Lebanese village, the Israeli government invested in the wind energy by building a wind farm in Tel Assaniyeh located inside the Golan borders. The farm was originally constituted of 10 turbines of 6 MW capacities and provided electricity for surrounding wineries and plants. It sold the remaining 20% of power generated to the electricity grid. The project success led the contractors to forecast a wind farm expansion In

the Golan heights with a potential of 380 MW, distributing the wind turbines over 140 square kilometer (Sq.km) (Bar-Eli, 2008).

In order to study the technical feasibility of wind energy in Lebanon, several technical and location assumptions should be examined:

**Location:** the ultimate location suitable for effective and efficient electricity generation from the power of the wind is the location with the highest wind **velocity** mean, the highest air density and most importantly a high frequency to maintain highest level of wind velocity and air density. The **density of air** is the mass per unit volume of the wind, expressed by  $\text{Kg/m}^3$ . It is negatively related to the increase in absolute temperature in a specific location, and positively related to the absolute pressure in the selected location. Moreover, the geographic location is important in determining the **volume of air** passing through the area of the turbine rotor.

**Velocity:** It is crucial to note that the power of the wind has a cubic positive relation with the wind velocity which makes it one of the most important factors in the wind energy potential. An increase of just 20% of wind velocity would increase the wind power by 73%. For that reason any built or natural barriers in the location negligibly affecting the velocity would dramatically affect the wind power. For that, the choice of an open location is very critical.

**Hub height:** The hub height of the wind turbine is considered an important factor affecting the air velocity at a specific location. For example, by increasing the hub height from 10 m to 45 m the velocity increases by about 26%. It is important to note that this change is within maintaining neutral stability conditions of the atmosphere which is estimated to be  $1/7$ . By applying the  $1/7$  law, the increase in hub height fivefold would result in increasing the wind power twofold. (Gipe, 2004)

Thus, the relation between the change of hub height and the change of wind velocity is:

$$V_0/V = (H_0/H)^{1/7}$$

**Rotor Diameter:** Power is directly and positively related to the area intercepting the wind. Large rotor wind turbines catch more wind than small rotor wind turbines. It is effective to double the size of the rotor area in order to double the turbine power.

Surprisingly, the increase of 20% in the blade length will result in an increase of 44% in the wind capture area. Moreover, by doubling the diameter of the rotor, the turbine will generate four times more wind electricity. According to Paul Gipe, "Nothing tells you more about a wind turbine potential than the area swept by its rotor \_\_\_ nothing." (Gipe, 2004).

$$A = \pi * r^2$$

Where A is the area of the rotor, and r is the radius of the rotor.

**Power density:** the power density is the rate at which power passes through a unit of area (Gipe 2004). The power density is effective shorthand used to measure the energy of the wind at a specific period, usually a year. In order to calculate the power density, it is expected to have measurements concerning the air density and the velocity at a specific location.

$$\text{Power density} = (P/A) = 1/2 \rho V^3$$

**The potential energy output in Lebanon:** In order to figure out the approximate amount of energy derived from a single turbine in a specific location, the indicative annual wind energy output linked for a given power density has been calculated by the National Wind Atlas of Lebanon. (See Appendix for The power density and related Annual energy output Table.)(Wind Atlas, 2011).

**Table 3: the Power density and related Annual energy output (Source: The National Wind Atlas, 2011)**

<b>Power Density (W/ m2)</b>	<b>Annual Energy Output (GWH/yr)</b>
650	2.7
600	2.6
550	2.5
500	2.5
450	2.4
400	2.3
350	2.2
300	2.1
250	1.9
200	1.7
150	1.4
100	1.1
50	0.6
0	0

The power density table assumes that the designed capacity of the turbine is around 1.5 MW with a hub height 80m. It is important to note that this turbine is not any real existing commercial turbine but it is just used as theoretical primary given to figure out the annual energy output (GWh/year) related to the power density ( $W/m^2$ ).

To study closely the wind energy potential along the Lebanese area, an examination of some prospective Lebanese geographic locations would reflect the volume of energy

expected. Marjayoun , located in the South, for example, will shed light about what is the expected energy generated related to wind power. Marjayoun, located along the wind corridors passing through the Lebanese area, is a good example to look at closely. This area is estimated to have a mean wind velocity of 7m/s and an altitude around 950 m above sea level with a 55% average humidity (Wind Atlas,2011).This area is estimated to have a power density between 500 and 550 at a hub height of 80m, which theoretically lead for a turbine of 1.5 kW of installed capacity to generate 2.5 GWh of electricity annually.

Another example to study is Qlayaat in the North. It has an approximate elevation of 50m, an annual average humidity of 57% and an average annual temperature of 21 degree Celsius. These climatic givens dictate an annual average air density around 1.17788 Kg/m<sup>3</sup>. According to the National Wind Atlas of Lebanon, 2010, the average wind velocity in Qlayaat is around 6.5Meter/second. The turbine used in this simulation is assumed to be of a rated capacity of 3 MW, having a hub length of 90m, and a rotor diameter of 90m<sup>34</sup>.

It is important to note that the average annual velocity itself is not an accurate and fair indicator of the wind potential. Some velocity figures in the time series may be widely scattered from the mean. These scattered figured and their related frequency has major effect in the wind energy decision making. In order to include the effect of distorting figures, it is important to use the Weibull distribution, a probability density function. The Weibull distribution is applied in this model which takes into account the wind velocity variation from the mean, due to climatic variation, and the frequency distribution of the wind. In order to measure the frequency of occurrence, the Weibull distribution is determined by two parameters  $K$  and  $c$  where  $K$  is the dimensionless shape factor describing the width and form of the distribution and  $c$  is the scale factor relating the wind speed to the location. In a temperate location, with mid-latitudes, as Lebanon the  $K$  is equal to 2. In moderate areas

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<sup>34</sup> This design is actually provided by Vestas for onshore and offshore wind energy. It is the V90-3.0 MW Turbine.

with a K equal to 2, a special case of Weibull function appears as an estimation of wind speed distribution; it is called the Raleigh distribution. The negative skew to the left of the distribution implies that the weight of the distribution is biased to the positive side of the mean, which indicates that there are relatively more wind velocity figures higher than the yearly average in the distribution ( Odo & Akubue ,2012).

By applying the related climatic givens for Qulayaat with the previously mentioned technical specifications of the turbine, the expected annual electricity generated from a single turbine would be around 10,165 MWh. By planting 150 turbines of 3 MW rated capacity around 1,524,750 MWh of electricity is harvested annually. Thus, around 8% of the average annual estimated demand between year 2008 and year 2012 would be satisfied.

Concerning turbine plantation, an optimal spacing between horizontally planted turbines is around 6 to 10 times the rotor diameter of the turbine. However, some large farms with large turbines initial capacity may require spacing around 15 times the rotor diameter as a medium to reach economic optimal efficiency. This spacing requirement is taking into consideration the land cost and the technical specifications of the turbine.

By assuming a spacing of 10 times the rotor diameter, the area required to build a farm of 150 turbines of 3 MW as initial capacity and a rotor diameter of 90 m is around 121 sq. Km(NREL, 2013.) The space per each turbine would be around 81000 square meter (sq. m or m<sup>2</sup>) plus the ‘‘footprint’ ’area, in which the turbine is planted, of approximately 12 sq. m<sup>35</sup>.

It is important to note that the cost of wind turbine land use is actually the cost of leasing the footprint area. Thus, what is actually leased in Qulayaat case is just the total area used as footprints for 150 turbines.

The required area to be leased is:

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<sup>35</sup> The V90-3.0MW has a hub diameter of 3.6m.

$$150 * 12 \text{ sq. m.} = 5400 \text{ sq. m.}$$

The 5400 sq. m is an area accounting for the footprints space of 150 3mw-turbines. The fragmentation of the total footprint area over an area of 121 sq.km, is a real advantage for the wind energy technology over other technologies due to the relative flexibility in land use. The remaining area of the wind farm, between turbines, is a free space that can be used for agricultural and industrial affairs, animal domestication, or even for leisure activities as hiking and ranching.

### **Natural Gas Potential in Lebanon**

For most of its history, Lebanon was fuel dependent country, and it depends mainly on the import of fuel oil in order to operate its power plants. Among these plants there are the combined cycle plants along the Lebanese shores of 450 MW each , Zahrani and Beddawi, that are designed to operate on natural gas, but unfortunately they are operated on gas oil. Moreover, there are the open cycle power plants Baalbeck and Tyr of 70 MW each which are also fired up by gas oil usage . The Lebanese government spends about \$2 billion as fuel subsidies a year due to soaring prices of fuel during the last decade (Ministry of Finance,2010).

Due to astronomical increase in gas oil (diesel) prices, extensive amount of subsidies could have been saved from the simple shift to natural gas use in both plants Zahrani and Beddawi. According to Fuel prices shown in the ‘‘short term energy outlook’’ table presented by the EIA on February 2008, Dr Shafik Abi Said declared that if these two plants were operated on natural gas, on which they are designed to run, Lebanon could have saved around \$1505 Million between Jan 2004 and Jan 2008 (Abi Said, 2008). This comparison is based on 6000 hours of operation per year and the expected savings due to natural gas replacement is from 20 till 40% even without the inclusion of the environmental savings.

There are many advantages justifying the replacement of fuel oil by natural gas:

- The natural gas has relatively higher burning capacity than Fuel Oil; it is respectively 11464 Kcal/Kg versus 10035 Kcal/Kg for fuel oil and 10350 Kcal/Kg for Gas oil.
- A plant operated on natural gas has relatively longer life span and reduced operation and maintenance frequency.
- A significant amount of pollutant gas emission is reduced when the Lebanese combined cycle plants shift to natural gas; there is a 100% reduction concerning the Carbon emissions, 60% concerning CO<sub>2</sub> and 70% concerning NO<sub>x</sub> (Abi Said, 2008).
- The Hydrocarbon Strategy Study (HCSS), held out in cooperation with the World Bank, estimated that the health and environmental damages value between 2005-2020 is to be decreased between \$740 million and \$1800 million due to natural gas (NG) shift.

Due to its economic and environmental feasibility, it was obvious that the shift from the fuel oil to natural gas is of great net benefit for Lebanon. Lebanon needs not just only to drop urgently the large cost paid for fuel but also to apply international environmental treaties imposing the necessity to lessen the pollutants emitted.

It is crucial to know that natural gas could be supplied in two different ways: First, as a state of gas through pipeline linking directly the production cost to the distribution point where it is stocked and distributed at later stage to final user and second, as a liquefied gas transmitted from the production point in specific tanks and re-gasified at the distribution point where it is stored.

In order to procure natural gas and liquefied natural gas (LNG) for the operation of the Thermal generating plants, The Lebanese government had different options based on different sources of NG and LNG.

First, the procurement through pipelines transmitting the Egyptian and Syrian natural gas was one of the leading sources. However, many challenges forbid a secured and unceasing supply from both pipeline sources.

Concerning the Egyptian natural gas it was transmitted through the Arab Gas Pipeline which is transmitting Gas from Arish production point to respectively Aquaba and Amman in Jordan than Damascus and Homs in Syria, and then to Turkey and Europe. From the distribution point Homs, Lebanon received a modest branch linked to Tripoli. It is crucial to note that Egypt has had a long contract since 2005 with the Israeli government for gas supplying through The Arab Gas Pipeline that has also an underwater branch pipeline to Ashkelon. Moreover, the Egyptian gas has a supplying contract with Spain to secure a part of the Spanish needs for gas through the export of LNG. Mainly two factors contributed to the insecurity of supply of Egyptian natural gas to Lebanon. First, During Mubarak Era Egypt over committed themselves for exporting natural gas, then it was realized that they need gas domestically. Contract with Spain and the Israeli government is breached (Personal communication with Dr. Walid Khaddouri on January 2012).. And the transmission to Jordan is significantly minimized during Spring 2012 until Winter 2013, which drove the Jordanian electricity tariff upwards tremendously (Zedan, May 28, 2012). Second interruption factor is mainly a strategic factor not technical factor. Syria had suggested to retrieve the Lebanese share of the Lebanese market from the Egyptian gas and to supply instead an equal quantity from the Syrian gas (Abi Said, 2008). Some Lebanese experts suggested the construction of an independent pipeline branched directly from the Arab Gas pipeline to Zahrani plant passing through Syrian territories. In February 2008, The interim Lebanese Ministry of Energy and Water met with its Arab counterparts to negotiate the gas supply ‘‘ independency’’ suggestion, but it seems mainly due to political pressure; it was rejected in favor of the Syrian suggestion.

Concerning the Syrian gas, The Lebanese Ministry of Energy and Water signed in December 2000 a twenty year contract with the Syrian Petroleum company, a state-owned company, to sell Lebanon at first stage 1.5 million cubic meters/day, then to increase this quantity to 3 million cubic meters/day as second phase and then to 6 million cubic meters/day at final third stage. Upon this contract, the Lebanese side completed an off shore pipeline from Homs in Syria to Deir Ammar (Baddawi) power plant (Abi Said, 2008). Unfortunately, the contract was never completely applied by the Syrian side and the supply was frequently interrupted with the absence of any technical appropriate justification.

Second, to seek security of supply and strategic independency, another procurement solution was discussed in order to secure natural gas to the Lebanese thermal power plants; this solution was to import liquefied natural gas by sea through a terminal to be constructed at the Zahrani shore. It is true that this choice has a ‘strategic value, allowing diversification and more reliability of supply’ (Abi Said, 2008) but the financial feasibility study proves the process to be relatively an expensive option with a yearly cost around \$4 to \$5 billion.(Personal communication with Dr. Walid Khaddouri on January 2012).

Third, a natural gas procurement strategy from a purely Lebanese source sounds to be real due to advance researches in the Mediterranean area in search for gas potential. The in-house source of natural gas procurement has the ability to maintain reliability of supply, cost efficiency and environmental sustainability.

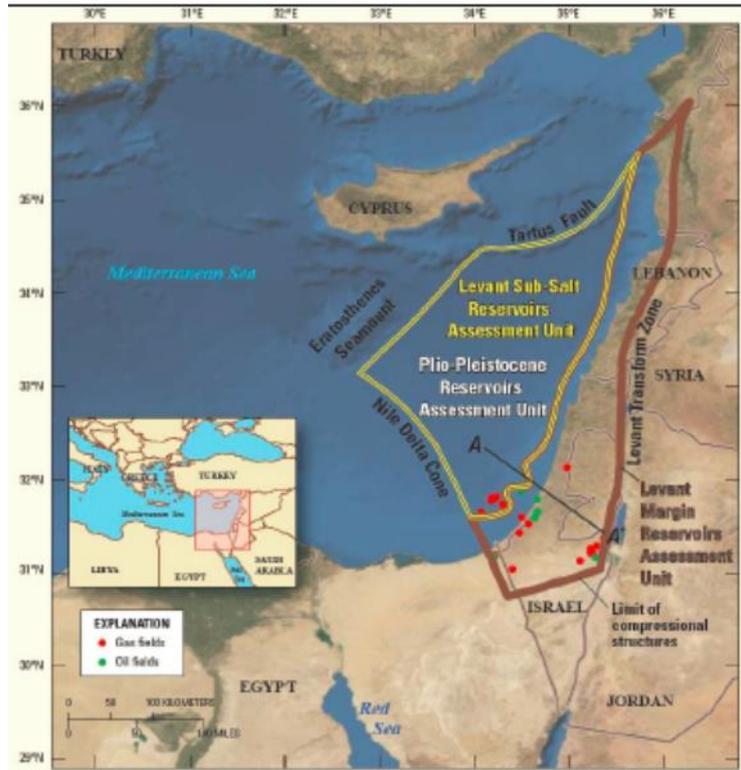
In General, The Levant Basin stretching from the north of Egypt and the south of Cyprus and north of Lebanon is estimated to contain around 122 trillion cubic feet of natural gas and 1.7 billion barrels of oil. (Oil price, 2013)

The seismic scanning in the Levant Basin shows a multiple underwater reserves in the legal Lebanese maritime territory. These reserves are dispersed along the Lebanese Shore, and due to the geological and ecological homogeneous structure in the east Mediterranean

Sea it is assumed that these reserves are mainly of natural gas.(See Figure 28 for Levant basin scan).

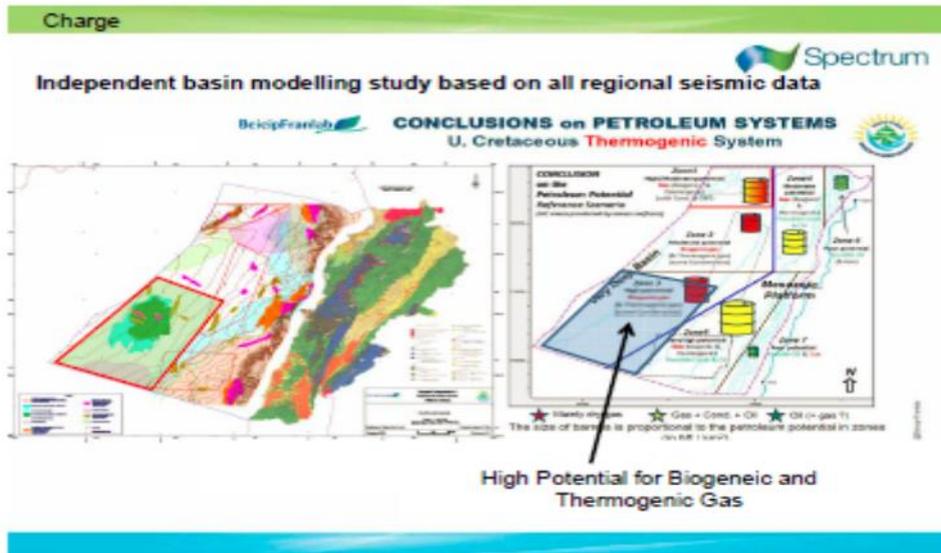
According to researches and seismic scanning, The Levant Basin proves to be a rich reserve of natural gas and Oil. The US Geological Survey estimated that the Levant Basin holds around 122 trillion cubic feet of natural gas reserve (Natali, 2012). The Israeli government started discovery process year 1999, and it was until 2009 when Tamar1, a natural gas field of approximately 80 KM west of Haifa, is drilled at a depth of 16000 feet. The field estimated to have about 9.7 trillion cubic feet of natural gas. In June 2012, the Israel Electric company declared that the cost of using diesel and Fuel Oil instead of gas for power generation is around \$US 14 million per day (Israel Electric Corporation, 2012).

Lebanon has covered almost a big part of its maritime area. A two dimensional scanning is done over 14000 square Km, while a three dimensional scanning run over a 12000 square Km of water territory. The data interpretation showed a prominent success for Lebanon in the fuel discovery process. It is assumed that the level of certainty and accuracy, even before drilling activity, is predicting a probability of 25% in drilling success (Bassil, 2012).



**Figure 28: Levant Basin scan (Source: US Geological Survey via Khaddouri December 2012)**

Further regional researches generated by Spectrum unveil the prominent prospective of the natural gas discovery in the Lebanese maritime water. (See Figure 29 for the basin modeling study based on All regional seismic data.) Up to Spectrum study, there is a high certainty concerning the nature of reserves fronting South Lebanon, that is assumed to contain Biogenic and Thermogenic gas, Whereas there is a lesser certainty concerning the nature of reserves found fronting the North Lebanese shore.



**Figure 29: the Levant Basin modeling study (Source: Hodgson, N. Spectrum 2012)**

The ecological homogeneity of land with the regional surrounding and the primary optimistic surveys generated draw an expectant future potential for Lebanon for the natural gas discoveries and enlighten a sense of interest among many international oil companies (IOCs). Along with this, The Lebanese government launched, in January 2012, the petroleum Activity Regulation with all necessary financial and administrative bylaws for Petroleum Administration and accomplished the Strategic Environmental Assessment. Directed studies and Geophysical data were bought to interested IOCs who witnessed a full readiness from the Lebanese part who also prepared the platform for further survey for shallow water and Lebanese Land.

The natural gas discovery in Lebanon seems to be prominent due to a significant advantage of well-prepared surveys and studies attracting international investors into action.

However there are many challenges facing the fast resolution of a tangible outcome in this domain:

- Regional conflict with neighboring countries due to unclear demarcation of maritime water.
- The interior political conflict between the various leading teams in Lebanon.
- The nature of the Levant Basin characterized by deep waters of 15000 to 20000 feet (Khaddouri, December 2012)

First, The regional conflict between Lebanon and the Israeli government is held in the United nation. The Lebanese proposal includes reserves with a prospective value of billions of dollars. An American support is expressed for the Lebanese proposal. Keeping the general atmosphere calm for both parties is a major concern for the US as American companies are involved in the discovery and production process of natural gas in the Levant basin ( (Ravid, 2011). According to Doctor Walid Khaddouri, a consultant at Middle East Economic Survey (MEEZ) , Lebanon should not lose time waiting for regional conflict to be resolved, but meanwhile serious work should be held in the other reserves in the well-defined Lebanese maritime water. Moreover he estimated that the period for effective production is around 5 to 6 years, so real steps towards achievements should get started despite regional conflict. (Walid Khaddouri, personal communication, January 2013.)

Second, the interior political conflict between various Lebanese parties should be resolved in order to insure a constructive and appealing environment for IOCs and IPPs. An objective road map and execution process explaining administrative and financial laws, a production plan, and Lebanese economic priorities should be issued and adopted by successive governments despite their different political views.

Third, due to the extensively deep water in the Levant Basin which is estimated to be around 15,000- 20,000 feet, the most advanced technology should be used in order to accomplish effective and safe exploration process, and efficient development and production mechanism. Advanced technology use is explained as higher cost, and just with a wide

spectrum of exploration for the discovery of commercial size gas field, the huge investment would be justified.(Khaddouri, December 2012)

Moreover, it is important to launch a main national gas transmission network along the Lebanese shore branched into several local networks as a necessary infrastructure for IPPs and industry sector investors. The exploration of natural gas should be a serious step to be taken immediately by the Lebanese, not as a gate to insure a fruitful share in the pie, but as a genuine medium to relieve the pressure in the economy generally and in the electricity sector particularly.

There are many forthcoming advantages directly linked to the exploration of natural gas:

- The in-house procurement of gas will attract IPPs to launch new thermal power plants due to the security, reliability and affordability of gas supply.
- Higher production efficiency would be reached by existing thermal power plants and less operating and maintenance hours are needed due to a natural gas shift.
- Operating plants of different sizes in different Lebanese areas would reflect a liberal market involving different investment capacities in the electricity sector. Small scale plants would operate efficiently at full capacity to serve local demand.

Lebanon should not hesitate to take active steps toward natural gas discovery despite the increasing Lebanese debt. Due to the readiness of research and to the high positive probability, Lebanon will attract foreign drilling companies investing in the discovery process. The discovery process accompanied with a complete necessary national gas transmission network and with a suitable attractive legal platform for private investment will lead to the reduction of annual fuel exports by more than \$3000 million. Also, it is estimated that taking forward serious steps in this field will result in an investment inflow not less than \$3000 million with a significant share in the electricity sector. With the legal possibility for

local investors to enter the market, Lebanese people would be able to own shares in current and prospective companies in the field, hence Lebanon would not need to borrow more than \$5000 million for just two years as payback period (Iskandar, April 2012).

## **Chapter IV**

### **Legislation and Free Electricity Market**

This chapter describes the importance of privatizing EDL and Liberalizing the Lebanese electricity market, to explore the related challenges in the Lebanese context and to discuss the pre-conditions toward competitive liberal electricity market. The main objectives of a new electricity policy would be:

- the security of supply
- the competitive efficiency
- the satisfaction of increasing demand

#### **An Overview of the Electricity Structure in Lebanon**

In Lebanon, The generation, the transmission and the distribution are primarily integrated under one and only electric utility, the EDL, with the only exception of two small hydro-generation concessions and three small distribution concessions for that are taking place in Zahleh, Aley, and Byblos. Unfortunately, they are going to be merged into EDL, once their concession contracts are expired at the end of this decade.

The previous chapter presented the unrealistic cost of electricity generated in Lebanon and its tendency to soar due to its direct technological dependency on fuel oil.

Also it covered how the aging plants are losing their capacities to generate electricity each year 3% while the demand is increasing each year by 7%.

In order to cater for this increasing demand of 4500 MW in year 2020, it is necessary to establish new power plants and to rehabilitate the existing power plants (See Appendix for the plant generation pie above). Moreover it is necessary to benefit from the Renewable

energies (RE) potential in Lebanon that proves to be of 1500 MW from wind Sources and from the Concentrating solar energy that proves to be feasible in Lebanon (see Hirmel case) besides natural gas.

Due to the detrimental financial and managerial situation of EDL, It is crucial to note that any attempt to increase generation by establishing new conventional or even unconventional power plants by EDL would aggravate the financial situation of the power sector due to possible increased subsidies. These annual subsidies paid by the MOF reached \$ 2 billion as cost of fuel and operation. Any fuel oil operated plant will increase the size of subsidies due to the increasing prices of fuel and its volatile nature.

Based on the cost function comparison conducted in the previous chapter and based on the resources availability, such as wind, solar and LNG, and Hydro, any new establishment based on these resources would be a point of attraction for investors in the Lebanese power system.

Despite the relative cost efficiency of the RE and of LNG power plants once compared to the fuel oil and diesel plants adopted by EDL, the legal framework and market electricity structure in Lebanon constitute a drawback for new investors in the market.

**The electricity in the monopolistic context.** The monopolistic nature of EDL makes it the solo player in the electricity market which discourages new investors to step in the market due to price and entry regulations. EDL and ministry of power are selling electricity at a pegged tariff far below the cost of generation in order to promote their political image. This electricity tariff did not change since 1996 when the price of fuel barrel was just \$21.(World Bank,2008). Year 2011, the cost of a barrel of fuel reached \$105 and the

generation cost in some Lebanese thermal plants reached \$40 per KWh, but the unit of KWh is still sold at ₪ 9.(See Appendix for energy plant cost )

EDL is maintaining the status of a natural monopoly without benefiting from being the solo player in the market. Due to the aging plants and networks, not being rehabilitated, there are huge technical losses in transmission reaching about 22% in some areas<sup>36</sup>. Moreover, due to managerial deficiencies, the electricity sector is enduring a tremendous nontechnical losses related to electricity theft, and bill collection. Actually, technical losses are estimated to be around 18% which translates into US \$M 150<sup>37</sup>(World Bank, 2008). EDL proves to be not able to meet its costs. Lebanon has neither a cost advantage which is one of the highest in the region nor customer satisfaction (Arab Union of Electricity, 2010). Also, in some plants the cost of producing one KWh is surpassing 40 cents.

The average cost of production in Arab countries is 7.75cents per KWh whereas the cost in some Lebanese plants as Tyre and Baalbeck is over 40 cents per KWh (Ghajar,2011).

The average tariff for household's consumption above 1000 KWh in Arab countries is 6.2 cents per KWh whereas the average tariff for households consumption above 1000 KWh in Lebanon is 9cents per KWh (Arab Union of Electricity,2008). The difference between cost of production and tariff in Lebanon is reflecting the size of subsidies paid yearly by the Ministry of Finance in order to cover the sector losses.

Moreover, it is important to note that the loss at EDL is not mainly due to the drop in operational level and to the increase of fuel oil cost but also due to managerial inefficiency and corruption. At EDL, there are about 2000 regular employees and about 1850 contractual employees. Year 2012, The average productivity among the Arab countries in the electricity sector is around 2005 MWh per employee which is the electricity produced in MWh over the

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<sup>36</sup> As long the physical network is as greater is the technical loss in transmission

<sup>37</sup> At the average 2007 tariff of US ₪9.4/KWh

number of employees working in the sector whereas in Lebanon productivity is the lowest among Arab countries, and it reaches 3 MWh per employee. (Arab Union of Electricity, 2010)

**Concessions efficiency.** Concessions are mutual arrangements between the government and a firm in which the firm obtains the exclusive right to operate and to provide a particular service under pre-specified conditions of significant market power, and this decentralization and small scale management show an increase in efficiency of distribution and bill collection to be efficient. A brief comparison between the performance of EDL and of the three operating concessions shows that the latter's experience in reducing technical and nontechnical losses is quite successful. For example, at EDZ (Electricity of Zahle), the technical losses dropped reaching around 5% year 2010 and in both Aley Electricity and EDZ the bill collection reached around 99% at monthly closing (Mr. Nicolas Saba, personal communication, April 2012) (Mr. Albert Khouri, personal communication, July 2012).

### **The Market Mechanism under Liberal Market**

The Managerial corruption, the low productivity, the huge gap between deteriorating supply and increasing demand, the relative high cost of electricity production and the relative high cost of tariff are evidence for the complete failure of the EDL as a monopoly. This failure constitutes a financial burden and causes pressure for all Lebanese governments.

The shift toward a competitive liberal market through legal reform can trigger rivalry in market behavior. In a competitive environment only the efficient units of production or distribution will prevail while inefficient utilities are bankrupted and exit the market. Moreover, the shift toward a liberal market attracts new competitive entrepreneurs in the electricity sector. To survive the new environment, serious and

urgent alterations should be considered at EDL. Seeking efficiency, through structure alteration (privatization or partial privatization) or through efficient market penetration are some of the decisions to be taken by EDL in order to prevail in the competitive market. If the electricity is seen, in a closed market, as a government service sold at a price below cost to end users, in a liberal competitive open market, electricity would be a profitable good where both suppliers and consumers seek subjective benefit.

Profit drive and market competition result in higher productivity and higher market efficiency, which will be reflected through lower production cost and lower prices paid by the end user. Thus, competition is a key element for a healthy productive and efficient economy.

Market competition proves to be successful even in the electricity sector where many countries open up to absorb new investors in the sector. In many scenarios and due to its inability to compete in the new environment, the state-owned utility shifts to private or partial private utility. A structure alteration of EDL, a privatization or partial privatization, enhanced through liberal market structure may provide important profits for the government and lessens future accumulated liabilities ( Newbery and Pollit, 1997 ). Entrepreneurs profit drive in a privatized previously state-owned utility may result in relatively significant efficiency improvement and cost saving ( Vickers and Yarrow, 1988).

In a perpetual changing environment where new technologies are discovered, consumer taste is altered, and resources availability is fluctuating, it is necessary to unbind the market activity. People should be able to act to what they consider as beneficial, efficient, and profitable.

Market players, suppliers and consumers, are the only individuals to decide upon which electricity system to launch, where to operate, where to invest, and any restriction to the freedom of choice should be abolished by law.

## **Law 462 and Privatization Resistance**

Law 462, enacted during 2002, highlights important reform elements in the sector. It explains EDL restructuring, its corporatization, the clear dissection of its vertical units of generation, transmission and distribution, the introduction of the partial privatization and the formation of a regulatory authority to control the transitional process. The development of the Lebanese electricity market and its transition toward a competitive market could not be reached just through the full implementation of Law 462.

Despite a technical and financial international support from the World Bank and the European Union (EU) in the formation of this decree, its implementation remained unreal due to political disagreement between the different Lebanese parties in the government.

In January 2007, the Paris III international donor's conference, held to support Lebanon after July 2006 war, provided a positive environment and some encouragement to start serious electricity reforms. From the heart of this event, the Lebanese government officially affirmed its true intention to apply the reform principles enacted by the law 462. On these reform bases, the Lebanese government received \$100 million from the World Bank which were released for the Lebanese power sector (BIC, 2012).

As a result a modest reform was made on the distribution level and EDF assigned special consultants to assist local companies in improving the electricity billing and collection process. A 50% increase in the rate of billing collection in Great Beirut was the main outcome. However, in rural areas this was subject to minor deterioration.

The reform process was slow and reserved, and the planned Agenda signed in Paris III remained unaccomplished. A chain of political assassination took place between 2007 and 2008, and a major street conflict between major parties took place in May 2008. As a result, the government experienced a series of deadlocks and a period of miscommunication among various members which resulted in the suspension of any kind of reform and any kind of mutual agreement. Thus, the privatization reform law 462 is aborted atrociously due to political conflict and disagreement among various parties. Due to the lack of any sustainable achievement in this sector, this loan came as an increase to the Lebanese national debt that reached more than 180 percent of the GDP.

However, shortly after, in 2009, and after elections, the formation of a national unity government pushes the reform electricity plan again into a priority level. In his reform policy paper for the electricity sector 2010, the ministry of Energy and Water suggested under the reforms strategies the necessity to invest in the electricity sector about \$ 4.87 billion of which \$2.37 billion are supposed to be from private sources and \$1 billion from foreign international donors (Ministry of Energy and Water, 2010).

The policy initiates a gradual execution of the initiatives in the short, medium and long term with a total of \$6520 million. The policy suggests that this spending will result in 4000MW of electricity provided 24/24 hours per day. This budget is used for renting 250MW as a stop gap and as a standby capacity provider while old plants are rehabilitated and maintained. The rehabilitation and maintenance of old plants increase the overall plants capacities by about 845MW due to replacement, rehabilitation or introduction of new modalities. Also, launching new power plants of 1500MW capacity on the expense of private sector and international funds would increase capacity for 1500MW.

Despite general approval, some financial challenges arise to be part of the issues toward fast implementation. However, new political conflicts became serious obstacles: the fall of the government in January 2011.

In 2011, the government headed by Nagib Mikati carried the electricity issue again to the attention of the public. It was obvious that the urgency in the power sector went beyond political disagreement. A reform consensus took place and the government endorsed the Policy Paper. But until 2012, there is no reform concerning a clear roadmap for the implementation of the law 462 at its provisions. Instead, the only reform inspired from the Policy Paper 2010 until recently was the leasing of two power barges of a capacity of 250 MW. This should be just a short term solution to deal with the gap urgency between detrimental supply and growing demand for electricity. If these barges are to be considered a long term solution, it would be a way to deviate from the priorities and to aggravate the national debt. Any attempt to overspend for electricity supply while ignoring the crucial need for plants rehabilitation or the importance of legal and legislative reforms will place the nation on the road of debt aggravation. It is just a ‘one day solution’ and an ‘anesthesia medicine’ that keeps other major issues reaching shocking proportions.

The legal framework for privatization, liberalization, unbundling of the sector, and corporatization of the EDL is not applied (law 462). However, what is still applied is the law that gives EDL the ultimate power of a monopoly with the exclusive authority to manage the three different areas in the electricity sector: the generation, the transmission and the distribution.

**Other Barriers against a competitive market.** Besides legal barriers, the political factor did and still extensively contributing to the delay of the major reform in the electricity market toward an efficient competitive market. First, there has been always political

disagreement between the different negotiators upon major priorities. as previously mentioned, major regulatory and legislative reforms are delayed due to discontentment between the politicians who are not just adopting different political and economic views but also are eager to ‘‘abort’’ what they view as predecessors plan. Dr. Shafik Abi Said, an electricity expert and a former EDL, remarked ‘‘these ministers kill all the plans of the predecessors just to show that their schemes are better. But in the end, the state of the power plants deteriorates and the suffering of the citizens continues,’’ (The Daily Star, Ossama Habib, May 5, 2010)

Second, the *political instability* is repelling foreign investors from seeing the Lebanese market as a ‘‘safe’’ investment opportunity. The history of Lebanon witnessed a series of socio-political conflicts that created uncertainty in the economic and political environment. One of the key factors in investment decision making is the payback period. Electricity projects are long term investments especially in a competitive market, thus they have an extended payback period. A foreseen political uncertainty may repel investors from financing in electricity projects in Lebanon.

Thus, many political, economic, and technical challenges are a turn off for new investors in the Lebanese electricity sector. It is true that the legal platform, applying the law 462, is the official positive beckon for investors, but the latter aspects should be taken into consideration. Network and plants rehabilitation, the political stability, a positive constructive atmosphere between negotiators, the development of network, and the legal appropriate policy of privatization will open the doors toward an efficient competitive electricity market satisfying the end user, increasing the security of supply and lessening the national burden caused from annual subsidies and inefficient operating process.

## **The Electricity Sector toward Efficient Restructure**

A liberalized market is characterized by 'decentralized ownership, a large pool of private actors competing in the market place, unbundling of generation, transmission, distribution and supply, and full market access' (Voss, 2001).

The exclusive right for operation given to EDL through the decree 16878/1964 and 4517/1972, withholds potential IPPs from considering the Lebanese electricity sector an investment option and as a result restrain any prominent development in the sector. The centralized structure of EDL, the large scale processes, and the monopolistic nature lead to management failure, supply insecurity, high technical and nontechnical losses, and to the increase of the national financial burden. Nowadays, it is important to reconsider a more efficient structure for the electricity sector reinforced through applying law 462.

The liberalized electricity sector through the application of law 462 has the opportunity to change its current structure and transform it into an appealing arena for competition where market players are free to launch their power and energy businesses with no prior restrictions. Due to differences in choices, capacities and availability of resources between potential investors, the market structure would turn to be decentralized, downscaled, and diversified.

**Decentralized structure.** The greater percentage of the power technical loss in Lebanon is not through generation process but through transmission grid, and it is about 15% which is subject to increase with transmission distance. Thus, to make power reliable and affordable, it should be produced at or near the end users (Hawken, P., Lovins, A., & Lovins, L. H., 1999). The open up for new power investors will lead to a decentralized structure where many units of generation plants are located in many different Lebanese areas and

interconnected by the grid to back up one another and secure an expected level of electricity supply load while minimizing the transmission losses.

**Downscaled structure.** Downscaling is an effective structure to be adopted in the management and operation of the various areas of the Lebanese electricity sector.

Downscaling is economically efficient in the distribution process, generation units and in the sector management practices.

Concessions in the distribution, Zahleh, Aley and Byblos prove to be successfully efficient due to the decrease in the distribution technical loss from 15 till 5%

Also, there are nontechnical losses which result from uncollected billed electricity and stolen electricity, which dropped from 28% (World Bank, 2008 ) as average EDL loss to 0.12% in Aley.

Concerning generation, the Jieh plant, for example, operates on fuel oil, and its efficiency is measured in term of its fuel consumption compared to the fuel requirement of the initial plant design. In terms of fuel g/KWh, the deviation of actual fuel consumption from the design is estimated to be in average about 26% (5 turbines).

Moreover, during 2006 and due to fuel run out, the Zouk plant's actual fuel consumption of its Turbine #1 deviated from the generator turbine design by about 20%; its actual efficiency was 224.8 gr of fuel/KWh whereas the design efficiency is about 267.4 gram of fuel/KWh(World Bank, 2008 ).

Concerning the combined cycle plants operating on diesel, the Zahrani plant, for example has two turbines GT1 and GT2 and one steam turbine, and it was occasionally operated at half load in order to save fuel or due to technical defection (World Bank, 2008 ); during April 2012, the steam turbine at Zahrani was totally off work due to technical defection which dropped generation to about 45% (Personal communication with Mr. Ahmed Abbas and Zahrani Site visit, May 2012).

It seems that with fuel dependency and with large scale generation these plants efficiency are deteriorating with time. The ‘‘Economies of Scale’’ suggests that with larger unit size, fuel as input is utilized more efficiently. But in the Lebanese case, these plants are not being able to operate at full capacity due to defection and unsecured fuel to meet their potential. So, smaller units offered greater economies through mass production than did big units through size of production ( Hawken, P. et al, 1999).

To note, these plant cases presented are not just lessons highlighting the size-efficiency relationship of the plants but also the fuel oil and diesel dependency-efficiency relationship. This relationship is subject to be stronger with time due to the increasing oil prices.

At the end of the electricity process there is the supply unit, which is a very sensitive unit, due to its communicative nature in the electricity process. It deals directly with the end user: industrial and individual household. Its duties are metering electricity consumption, preparing bills, and collecting those bills. As mentioned above, this process proved to be highly efficient under the concessions monitor comparing to that of EDL. Thus, at Zahle and Aley the collection reached maximum levels compared to collection levels of the regions related to EDL supply management.

**Diversification.** Due to subjective foreseen economic opportunities by electricity and power investors, such as the availability of resources, cost advantages, and technical advantages, the electricity sector would witness a higher level of technology diversification. New resources, far from oil dependency, would be used as wind, solar or even tidal energy. Market rivals tend to explore cost advantages of each specific area due to a pure orientation towards profit incentives. Each producer is going to generate electricity using the technology

which he believes has a marginal cost relatively lower so its profit margin is relatively subjectively higher.

The generation of energy in a diversified market may lead to higher security of supply and lower overall prices due to potential independency upon one source of energy, fuel.

### **A Brief Projection into a Liberalized Electricity Sector**

Liberalizing the energy market does not necessarily dictate public utility privatization. However, transparent and real competition is hardly achieved within the existence of public entity in the market. With entity privatization there is relatively healthier competition process due to higher profit consideration where electricity is seen as a good sold for pure profit and due to the absence of any market distorting committed through government intervention. Nevertheless the foremost efficiency advantages for consumers are the direct outcome of a competitive market.

In a liberalized market, Investors tend to spend their money in what is individually seen as profitable option in the electricity sector. Legal reforms are the beckons announcing the availability of investment opportunity in the various vertical utilities of EDL under privatization and partial privatization or in the creation of new independent utilities. These new independent utilities are either related to generation, transmission, or distribution and direct supply. Which power technology and which electricity system to operate are subject to relative foreseen costs, expected profit, resource availability and connection facilities.

Usually, in a liberal market there are multiple parallel generation systems and multiple parallel electricity suppliers, whereas transmission and distribution has been admitted to be one entity. Technically, fragmented transmission ownership is one of the direct factors into poor network performance (Jocksow, 2005). Therefore Investors usually

has no incentive to build parallel transmission and distribution networks once it exists in a specific area.

Due to unnecessary infrastructure duplication and to unused transmission capacity, it is economically and environmentally inefficient to have multiple transmission networks in the electricity market (Bonneville et al., 2005). These natural monopolies attract regional or national grid contractors.

Concerning distribution utilities, the three Lebanese concessions are a successful example underlining the efficiency of decentralization. This decentralization could be achieved on two levels: regional and local. The smallest local level can be even adopted by municipalities.

In a Liberalized market, Investors are free to launch new power plants or to be part of privatized or partially privatized EDL (if corporatized). The generation liberal market would witness multiple corporate structures and diversified technologies which reflect investors' expectations and incentives. By examining the "fittest" power technology and electrical system to be adopted, entrepreneurs would take into account the existence of any policy mechanisms or market based approaches offered by the government, for example, Feed In Tariff law (FIT), Carbon Cap-and-Trade.

**FIT: Feed in Tariff Law.** Feed-in tariff law (FIT) is a policy mechanism designed to accelerate, encourage and increase the portion of investment in renewable energy systems. This policy is achieved through launching long term standard contract between the investors in Renewable Energies and the electric grid utility. The contract states an obligation imposed on the grid utility to buy electricity generated from renewable resources from all qualified suppliers. The long term contract purchase price offered is based on the related cost of generation of each eligible electricity system. Due to the nature of these long-term contracts,

it is crucial to have a stable economic and political environment to induce a certain level of certainty in the market. In a stable environment, FIT gives an advantage for sustainable electricity systems; therefore, market players may highly consider this advantage while designing an investment plan. Moreover, the legal system as general guideline and the government credibility and transparency as key application of the law and as fair arbitration among various market players are key factors in any policy mechanism.

**Liberalization and market prices.** The main rationale behind liberalizing the sector is achieving higher efficiencies along different vertical utilities, increasing the size of investment in the electricity market, and surely decreasing electricity prices.

It is important to note that the price convergence is relatively more elastic in generation and supplier parts of the four elements structured price due to their relatively higher competitive nature. Also, active consumer choice of supplier contributes enormously into effective competition that reflects in consumer gain ( Pollit & Jamasb, 2005). However, transmission and distribution, naturally monopolistic as mentioned before, constitute around 50% to 60% of the electricity price structure (Thomas, 2006). In these segments, independent incentive regulation encourages network efficiency and cost saving, and helps preventing anti-competitive cross-subsidies. Usually there is no decline in the quality of service under incentive network regulation. (Pollit & Jamasb, 2005)

By examining the EU experience, it can be witnessed that there is a drop in real electricity prices between year 1995 and 2004 for about 16.6% (Thomas, 2006). However, by looking closely into each European country, especially after 1999 where most EU countries shift into a liberalized market, a wide discrepancy is shown concerning the effect of Liberalization on prices. In UK, for example, prices dropped sharply for about 40% while increased by about 34% in Nordic areas (real term). The latter case was explained as being a result of a severe lack of generation investment after openness to competition due to harsh

dry winters in year 2001 and 2002. Moreover, a price reduction between 25 and 30 % are witnessed in France, Portugal, and Spain. Concerning Italy Greece and Belgium there is a price reduction for about 15% or more. However in Sweden, the prices soar to be the highest in the Euro Zone. It is important to note that there are many factors distorting the impact of competition on prices, fuel prices fluctuations, taxes rate fluctuations, monopoly elements price fluctuations and specific environmental obstacles for each country.

The key success of the liberalization experience is the induction of a well-rounded legal reform. “Success depends on the design and implementation of competition laws” commented Georges Sassine, an expert in the public policy and in the electricity status in Lebanon.(Sassine, 2012). It depends in the first place on the design of reform tailored to the Lebanese case market requirements and in the second place on a transparent and responsible implementation of the law. Any failure in these two elements will lead into an impasse, where capacity deteriorates and prices soar.

The key toward a healthy competition is basically a legal reform in which the decrees 16878/1964 and 4517/1972 are aborted and replaced by market liberalization laws freeing the market from any predesigned restrictions and encouraging private investors to take action in what they perceive as suitable opportunity. In a competitive market, investment in electricity sector and its optimal level of production and distribution is fine-tuned based on supply and demand under a free price system. Any attempt to pre-design the market structure, to predefine the tariff, or to intervene in electricity demanded or generated would create a market distortion in which the investor and the electricity consumers are not performing at their best potential. In a liberal electricity market where information is widely and transparently dispersed and where there is any predesigned market constraint, each market player is seeking a

subjectively perceived and desired outcome lead purely by market signals, prices. Prices are the main given in decision making process; they would tell each market player what is needed, when, and where. With these practices held, market will perform at its best, consumers will be more selective and electricity producers will be much more productive. This market interaction will shape the spontaneous optimal market order "a more efficient allocation of societal resources than any design could achieve" (Hayek, 2001, p.63).

If this occurred correctly, the prices, in the Lebanese liberalized market context, will be freed to reflect the supply cost. At the beginning the electricity tariff may shift higher than the actual pegged tariff to be more cost reflective but as new players keep entering the market and mastering economic efficiency, cost of electricity production will drop so will the prices offered for consumers.

As mentioned in the first chapter, the average tariff in Lebanon is around \$9 cents while the average cost of generation is about \$27 cent. To cover cost tariff differences, an economic cost is still paid yearly as subsidies, so even if prices increased slightly in a liberalized market above that of the current status quo, an economic total benefit would still occur due to better generation efficiency and subsidies cut off.

# Chapter V

## Conclusion

This thesis presented an empirical case study of the electricity sector in Lebanon and of the potential of introducing natural gas and Renewable Energies in Lebanon.

The first chapter explained the detrimental situation of the sector where security of supply shortage, huge inflicting costs, increasing technical and nontechnical losses, and other indirect losses are detected. The main causes of this situation that curbs the standards of life in Lebanon are the exclusive oil dependency, the managerial and administrative decay and the political disagreement upon a solution for the status quo.

The perpetual delay to fix the problem is resulting in daily losses, direct and indirect, paid by the Lebanese resident living under this situation. The delay in rehabilitating the plants is causing more technical losses, while, on the other hand, the delay in launching new power plants is triggering even more pressure on the existing plants which aggravates the volume of technical damages and losses. As a result, more severe shortages of supply are taking place every single year, while the cost, direct and indirect, of getting electricity is increasing as a social and economic burden. This vicious circle is moving in a downward vertical process which widens the gap between increasing electricity demand at an average rate of 7% and the decreasing electricity supply at an average rate of 3%. The study shows that if nothing is done to face the situation and to offer a contingent urgent solution, the gap would reach year 2025 around 78%.

Moreover, some other main problems in the sector are its structure and its administrative and managerial practices. First, The EDL as the exclusive monopolistic player in the market is forbidding any new entry to the market that would contribute in increasing

security of electricity supply and inducing the competitiveness in the market. The pegged tariff since 1996, far below the average increasing cost of generating electricity, is not just resulting in social economic losses but also in repelling the IPPs and investors seeing no fair competitiveness opportunity. The lost electricity that would have been generated under the umbrella of a competitive liberal and the related effect on cost and tariff is an additional loss. Second, the administrative and managerial practices under EDL are driving not just the average cost of electricity to be the higher among that of the Arab countries but also the employees productivity to be the lowest. Also nontechnical losses related to the non-collection of bills, electricity theft and pilferage proves to be high in the geographic areas under EDL compared to those under the distribution concessions.

Besides, the exclusive oil dependency in generating electricity is driving Lebanon to an improper levels of pollution that affects humans and natural environment. After signing and ratifying Kyoto protocol, year2006, which commits Lebanon to reduce greenhouse emissions, any environmental friendly practices in the electricity sector are initiated knowing that it was based on including a 12% from the renewable energies in the energy volume generated. Thus, It is critical to find contingent urgent solutions in order to secure the electricity supply, satisfying the increasing demand, cutting massive losses, and decreasing environmental damages.

Chapter II draws a comparative economic cost between different electricity systems: CCGT diesel, CCGT natural gas, Wind and CSP. The study shows a significant relative cost efficiency in Wind, CSP, and natural gas while driving the diesel out of the equation due to its astronomic relative running cost. Furthermore, the CO<sub>2</sub> cost inclusion in the comparative cost function shifts the operating cost of diesel and natural gas. CO<sub>2</sub> cost inclusion gives an ultimate cost advantage to RE as Wind and CSP and to natural gas relatively to that of diesel.

Chapter III examined closely the technical potential of Lebanon to adopt renewable energies as Wind and CSP and relatively cleaner fuel energy as natural gas. First, according to National Wind Atlas, the onshore wind energy has a potential of 6.1 GW. As a case study, the area of Marjaayoun, South Lebanon, has a capacity to ‘‘harvest’’ around 2.5 GWh from a single turbine of 1.5 MW. Besides, the study shows that in Qlayaat, in the North, a turbine of 3 MW rated capacity is able due to the related climatic and geographic characteristics, to generate around 10.2 GWh per year. Thus by planting 150 wind turbines in the area around 8 % of the average total demand between year 2008 and 2012 is fulfilled.

CSP Energy proves to be a real success in Lebanon especially in the internal areas due to high DNI averages. A case study examining Hirmel area shows that a 50 MW plant based on CSP parabolic trough technology similar to that of Andasol in Spain with 7.5hours thermal storage has the capacity to generate more than 170GWh of electricity of more than 170 GWh annually which is surpassing what is generated at the original Andasol 1 in Spain due to the relatively higher insolation rate in Hirmel. Thus, a 400 MW of CSP with similar characteristics launched over a land of 4 square km has the ability to generate around 1338 GWh annually covering more than 8% of the average demand for electricity in Lebanon between year 2008 and 2012.

Concerning the natural gas potential, the Levant Basin is estimated to hold around 122 trillion cubic feet of natural gas and around 1.7 billion barrels of oil. Advanced seismic scanning along the Levant Basin proves the prospective existence of natural gas in the Lebanese maritime water. The shift to NG and its in-house availability would reduce fuel exports by more than \$3000 million and open the doors for a significant volume of investment inflow especially in the electricity sector. Lebanon should consider an immediate action in this field; natural gas extraction would secure in the long run a consistent electricity supply, a cost efficiency and environmental sustainability.

Chapter IV presents an overview about the monopolistic structure of the electricity sector and its dramatic failure in the Lebanese framework. Due to this insubstantial structure, the sector is suffering unreliable electricity supply, costly exclusive oil dependency, lower productivity, demand non-satisfaction, and increasing technical and non-technical losses. These issues could be resolved naturally in a competitive liberal market where multiple utilities are free to enter and act purely based on their profit perceptions. To open the door for the IPPs and the private sector to contribute in the electricity sector with their various technologies including renewable energies, some critical legislative and legal reforms should take place and others should be activated as law 462.

In Lebanon, there is a prominent potential for a cleaner and reliable energy that proves to be technically and economically feasible. Presumably, the only required factor for electricity sector success is human action.

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