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Abstract

This paper is concerned with modeling possible future paths for Lebanon's electricity future and evaluating them. The baseline scenario reflects the business-as-usual state of affairs and thus describes the most likely evolution of the power sector in the absence of any climate change-related or other policies. Two alternative scenarios are examined in contrast to the baseline scenario; the renewable energy scenario and the natural gas scenario. Using the Long range Energy Alternatives Planning System (LEAP) software we conduct a full-fledged scenario analysis and examine the technical, economic, and environmental implications of all scenarios.

From an economic standpoint as well as from an environmental perspective both alternative scenarios are superior to the baseline. Hence, the results of the simulation show that the alternative scenarios are more environmentally and economically attractive than the baseline scenario. They would help Lebanon meet its social, environmental, and economic development goals, while at the same time providing other unquantifiable benefits that are discussed further in the paper. Anticipated barriers to the shift in energy mix from conventional sources to renewable energy sources are also presented and discussed.

Keywords: renewable energy; LEAP; CO_2 emissions; electricity generation; scenario analysis.

1. Introduction

After 15 years of civil war, the Lebanese electricity sector at the beginning of 1990 was in a deplorable shape; major elements of the generation, transmission, and distribution sectors were destroyed during the war years, and the parts that were not destroyed suffered from lack of maintenance and neglect. A major rehabilitation plan (Power Sector Master Plan) in the 1990s, during which the generating capacity was expanded and the transmission and distribution networks were overhauled, proved to be disappointingly deficient.

First, Lebanese electricity consumers in 2010 still suffer from severe blackouts reaching 13 hours per day in some cities [1], and hence have to rely on off-grid distributed (backup) generators during those blackout periods. Typically, rationing hours are unevenly distributed between cities, differ from day to day, and the consumer cannot get any advance information on the rationing schedule. For a comprehensive analysis of the role of backup generators see Dagher and Ruble [2]. The utility has been increasingly unable to satisfy electricity demand that is crucial for the country's development.

Second, as the result of the current setup, the Lebanese consumer ends up paying a very high price for electricity; he has to pay both the utility's bill as well as the standby generator's fee. The World Bank [1] social impact analysis survey reveals that expenditures on private generation are almost double those on public electricity. Given the low prices of electricity in the region, the Lebanese consumer currently pays the highest electricity bills, while unfortunately, experiencing the most unreliable and lowest-quality service in the region.

Third, the electric utility Electricite du Liban (EDL) experiences substantial financial yearly losses requiring huge transfers from the government; its annual subsidies in 2006 were just under a billion USD, which corresponds to 4% of the GDP or more than 20% of government revenues [3,4]. This situation is unsustainable given that the Lebanese civil war led to a substantial public debt that reached 163.5% of GDP in 2008 making Lebanon's debt to GDP ratio the third highest in the World [5].

On one hand, the first point implies that the expansion of the generating capacity is an imminent matter; adequate electricity provision is necessary and vital for the continued economic growth and advancement of a country. On the other hand, points two and three indicate the presence of some potential financing problems. Clearly, Lebanon faces tough energy decisions in the years ahead. This paper evaluates the alternative expansion strategies that would help Lebanon meet its social, environmental, and economic development goals, while at the same time reducing its dependence on foreign oil or at least diversifying its energy mix.

Given that demand-side management options have been extensively studied, this paper will strictly focus on the supply side of the Lebanese power system by investigating the following two options: employing a cleaner fuel mix and introducing renewable energy plants. As far as we know, very few papers have examined the future expansion paths from the supply side; Karaki et al. [6] develop a generation expansion planning tool to determine the optimal investment plan of unit additions. However, the new units considered do not include any renewable energy sources and are mainly limited to traditional generating units that burn fossil fuels. Dagher and Ruble [2] focus on the backup sector and its environmental impacts, while Chedid et al. [7] investigate different capacity expansion scenarios and find that mitigation is cheaper with natural gas than with renewable energy, but stop short of performing any further economic analysis. The present study is broader, in that it will look at the overall electricity sector and evaluate its technical, economic, social, and environmental implications.

As noted above, numerous researchers have explored the demand-side management options for Lebanon. Some papers have addressed the implementation of energy efficiency options and policies in the building sector such as Chedid and Ghajar [8], Cantin et al. [9], and Ghaddar and Bsat [10]. Others have focused on energy-efficiency solutions in the industrial sector and those include El-Fadel et al. [11] and Ghaddar and Mezher [12]. Chaaban and Rahman [13] survey 700 households to collect data on their energy use trends. Based on this information, they propose energy conservation options at the household level. Chedid et al. [14] investigate several energy-efficiency measures in the residential and industrial sectors, while Chedid [15] conducts an extensive assessment of the potential of domestic solar water heaters.

Ghaddar et al. [16] emphasize the importance of renewable energy sources for sustainable development and poverty alleviation, while Mezher et al. [17] use a multi-objective allocation model to allocate limited energy resources to household end-uses. Both El-Fadel and Bou-Zeid [18] and El-Fadel et al. [19] assess mitigation options in the power sector. The former study examines two options, combined cycle utilization and end user efficiency improvements, and finds that both are economically attractive (negative mitigation cost). The latter study emphasizes the usage of renewable energy but does not investigate the use of wind energy as the information available at that time did not support wind harvesting. More recently, El-Fadel et al. [20] examine the Lebanese power sector with a special emphasis on sustainability. The authors conduct an extensive lifecycle analysis of the Lebanese power sector, taking into consideration environmental, economic, and reliability aspects and conclude that renewable energy sources are competitive in a levelized cost comparison.

A few researchers have attempted to model and in some cases forecast electricity consumption in Lebanon [21-25], but most have used univariate or limited multivariate models due to the lack of data. Badelt and Yehia [26] investigate ways to restructure the Lebanese power sector and conclude by proposing an action plan for restructuring. The paper also presents a set of technical and financial efficiency indicators for performance evaluation and ease of comparison with the international benchmarks.

The remainder of this paper is structured as follows. In section 2, we survey the current state of affairs in the power sector. Section 3 details the modeling framework and defines the baseline as well as the alternative scenarios. In section 4, we present and analyze the results of the simulation output, emphasizing their technical, environmental, and economic implications. Policy implications and expected barriers to the strategies presented are discussed in Section 5.

2. Overview of the electric sector

As is common in most developing countries, electricity generation, transmission, and distribution in Lebanon is monopolized by a vertically-integrated public utility, Electricite du Liban (EDL). However, unlike other similar developing countries, Lebanon enjoys a high degree of electrification; almost all households are connected to the electricity network [1]. Hence, modeling will focus on capacity expansion with centralized grid-connected systems, but will however take into account the existing off-grid backup generators.

Currently, electricity generation is limited to two types of power plants: thermal plants (2034 MW) and hydropower plants (273 MW), with a total capacity of 2307 MW [27]. Thermal power plants run on diesel oil, fuel oil, or natural gas depending on their turbine technology; steam turbines (1024 MW) use fuel oil, gas turbines (140 MW) use diesel oil, and combined cycle gas turbines (870 MW)[1] can

[1] There are currently two combined-cycle power plants one at Beddawi and one at Zahrani. However, only the one at Beddawi is currently physically connected to a gas pipeline. As of the end of 2009, Beddawi was still largely running on diesel oil; only one of the units was in the testing phase of burning natural gas instead.

either burn diesel oil or natural gas. The shares of electric capacity by fuel type usually differ from the shares of electricity generated because not all generating units constantly operate at full capacity. Figures 1a and 1b show the percentages for the year 2006.

[Figure 1a: EDL's Nameplate Generating Capacity (2006) Figure 1b: EDL's Electricity Generation (2006)]
Source: authors' calculations based on data from ALMEE [27], Wold Bank [1,4, 28], and LCECP [29] reports.

Lebanon is not an oil-producing country and hence electricity production relies heavily on imported fuel. For example, in 2006 only 7% of the total GWh were produced from indigenous resources (hydro sources) and the remaining 93% were from imported fuel oil and diesel oil (Figure 1b). In 2006, Lebanon imported 1,596 ktons of diesel oil, of which 1,057 ktons were used by EDL for electricity production [30]. The remaining portion was consumed for industrial use, residential heating, self-generation, transportation and other uses. In the same year, Lebanon imported 1,040 ktons of fuel oil, of which 957 ktons were consumed by EDL for electricity production and the rest for industrial use [30].

Transmission and distribution losses are estimated to be 15%, while technical losses for some of the best performing electric utilities can be as low as 8% [4]. In addition, non-technical losses mainly due to theft amount to another 23% of the total electricity generated [1]. EDL employs a fixed and a variable rate consisting of an inclining 5 block tariff that has remained unchanged since 1996. The following rates apply to the residential and commercial sectors; 0-100 kWh at 2.3 cents/kWh, 100-300 kWh at 3.8 cents/kWh, 300-400 kWh at 5.3 cents/kWh, 400-500 kWh at 8 cents/kWh, and more than 500 kWh at 13.3 cents/kWh. The average electricity tariff in Lebanon in 2006 was in the order of 9.4 US cents/kWh [4]. Although the standby generator's fee cannot be accurately calculated because it essentially is a function of the total number of hours the alternative supply operates, in any case it is much higher than that charged by EDL. For example, in 2008 the expenditures on private generation were almost double those on public electricity; an average EDL bill was $26 compared to $47 for backup supply [1,4]. This could mean that once the cost of standby power is factored in, the Lebanese become the highest paying electricity consumers in the region.

The electric power sector is the largest single source of CO_2 emissions in Lebanon. In 2006, our base year[2], total electricity produced by EDL was 9,286 GWh resulting in 6.39 $MtCO_2$ being emitted, which represents approximately 48% of total CO_2 emissions [30]. The power sector's contribution to CO_2 emissions has grown from 40% in 2000 to 48% in 2006 [30]. It should be noted here that according to the

[2] Note that we chose to use 2006 as our base year because it is the most recent year for which a complete data set was available.

Intergovernmental Panel on Climate Change (IPCC) Guidelines, the national inventories of GHG define the power sector as being strictly limited to main activity producers, i.e. EDL, and thus under the sectoral approach the emissions from backup generators are not included under the "energy industries" category. If we add the power produced by backup generators, total electricity produced would be 11,841 GWh and the resulting emissions will amount to 8.72 $MtCO_2$, which represents approximately 65% of total CO_2 emissions [30].

Although aggregate CO_2 emissions amount to only 0.06% [31] of the world's emissions, Lebanon's per-capita emissions reach the world's average of 4.4 tCO_2. This value is relatively high for a developing country and comparable to China and India, the first and sixth largest polluters worldwide. Lebanon has undertaken several steps in its efforts to combat climate change. It has ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994 and acceded to the Kyoto Protocol in 2006. Lebanon has also been actively engaged in most of the climate change related meetings through the Ministry of Environment. It issued its first national communication in 1999, a report which details the greenhouse gas inventory and discusses adaptation and mitigation measures [32]. In 2007, it commenced work on its second national communication [30].

Currently, there are two government-led programs aimed at reducing GHG emissions. One is the 'Lebanon cross-sectoral energy efficiency and removal of barriers to ESCO operation' that targets GHG emission reduction resulting from inefficient end-use energy consumption in all sectors of the economy. The other is 'The climate change project' designed to address GHG issues in Lebanon. The former effort is implemented by the Ministry of Energy and Water and the latter is implemented by the Ministry of Environment.

Several phases of the plan to connect the grids of Egypt, Iraq, Jordan, Lebanon, Syria, and Turkey (EIJLST Interconnection project) have been implemented. A 400 kV interconnection between Ksara in Lebanon and Dimas in Syria with a nominal capacity of 200MW was completed in 2000. However, the exchange of electricity between the two countries has been minimal so far. Alkhal et al. [33] examine the potential benefits from an integrated electricity planning approach in the Northern Middle East region (including Egypt, Iraq, Jordan, Lebanon, and Syria) at several levels, namely, lower reserve requirements, load diversity, economies of scale, variation in fuel resources, and economic cooperation.

The pressing expansion of the electric generating capacity presents a unique opportunity for Lebanon to show that it's not only talking the talk, but is also willing to walk the walk. The IPCC in its Fourth Assessment Report has emphasized that mitigation efforts in the next 15 to 20 years will have a large impact on opportunities to achieve lower stabilization levels and thus have the potential to minimize major climate change impacts [34].

3. The model and scenario development

To model the electric sector we use the Long range Energy Alternatives Planning System (LEAP), which is an accounting and scenario-based modelling platform developed by the Stockholm Environment Institute [35]. It is a user friendly, interactive, and widely-used[3] software tool for energy policy analysis and climate change mitigation assessment. A growing number of researchers are making use of the LEAP software in their attempt to model, forecast, and simulate electric power systems and their emissions. These include but are not limited to: El-Fadel et al. [19] and Chedid et al. [7,14] for Lebanon, Mulugetta et al. [37] for Thailand, Islas et al. [38] for Mexico, Jun et al. [39] for South Korea, Cai et al. [40] for China, Giatrakos et al. [41] for Crete, and Kumar et al. [42] for Vietnam.

3.1 Description of scenarios

Based on a bottom-up approach, the main concept of LEAP is an end-use driven scenario analysis with a business-as-usual scenario and one or more alternative scenarios. It simulates alternative what-if energy futures along with environmental emissions under a range of user-defined assumptions. In this paper we examine three scenarios, a baseline (BS) or business-as-usual scenario, a renewable energy scenario (RES), and a natural gas scenario (NGS) for both the medium-term (2020) and long-term (2050) planning horizons.

The BS reflects the business-as-usual state of affairs and thus describes the most likely evolution of the power sector in the absence of any climate change-related or other policies. Under this scenario, it is expected that EDL will expand its capacity between 2007 and 2050, in such a way as to satisfy the total electricity demand. Given that consumers pay much higher prices for the backup-provided power, market forces are expected to naturally drive out the backup capacity. Hence, the backup sector's share of production is assumed to fall from 21.6% in 2006 to 0% in 2020. At the same time the respective shares of each of the fuels used, namely fuel oil, diesel oil (excluding the backup sector), and hydro will adjust to make up for the diminishing share of the backup sector, such that from 2020 onwards, generation from fuel oil will constitute 40.3% of all electricity generation, diesel oil 52.2%, and hydro 7.5%.

Electricity provision through the use of renewable energy carries many advantages; (1) it is almost CO_2 emissions free, (2) it reduces fuel imports resulting in a reduction in the national energy bill, and (3) helps in diversifying energy supply which improves energy security. Although its geothermal and biomass resources are quite limited [43, 44], Lebanon has an important potential of other renewable energy sources, mainly wind and solar, that is largely untapped. These sources typically entail significantly higher capital costs but significantly lower fuel costs from reduced fuel imports when compared to conventional sources [45]. A viable option would be to install several wind power farms. Of course, other solar technologies such as photovoltaics (PV) or concentrated solar power (CSP) can be considered, but we chose wind because it is the most mature and cheapest renewable energy technology.

[3] The United Nations recently announced that more than 85 countries have chosen to use LEAP as part of their commitment to report to the U.N. Framework Convention on Climate Change [36].

For example, the cost of electricity from wind ranges between 4 and 7 cents/kWh, while the costs from PV and CSP are still much higher ranging between 21 to 81 cents/kWh and 12 to 18 cents/kWh, respectively [46]. It is important to note here that the costs mentioned above might not include all relevant costs, and hence a lifecycle cost analysis might provide different results, especially when investigating the economics of traditional versus renewable energy technologies.

Wind energy has been under serious consideration during the last couple of years and some preliminary steps have been taken such as the development of a wind atlas for Lebanon. Based on a model capable of predicting wind regimes at heights of 50 m and 80 m above ground level at a resolution of 100 meters, the potential onshore wind capacity of Lebanon is estimated to be 6.1 GW [47]. To further facilitate the development of wind energy power plants in Lebanon, the Ministry of Energy and Water has also set up the needed legal and administrative framework [47].

The renewable energy scenario incorporates new specific policies aimed at expanding renewable energy's share and reducing GHG emissions. In the RE alternative scenario it is assumed that EDL completely satisfies the growth in electricity demand up to 2050 by the introduction and expansion of wind energy systems along with an expansion of the existing technologies. Under the RES, again the basic assumption is that the backup sector's share of production would fall from 21.6% in 2006 to 0% in 2020. During that period, wind-based electricity will expand from 0% in 2006 to 12% in 2020 and 15% in 2050. We have chosen the growth in the share of wind energy such that it is consistent with the national plan aiming for 12% renewable energy in 2020. The respective shares of each of the existing fuels will be 35% and 26% fuel oil, 48% and 56% diesel oil, and 5% and 3% hydro in 2020 and 2050 respectively.

Combined-cycle (CC) generators that burn natural gas can also be considered as a viable alternative to the baseline scenario. It is important to note that a pipeline connection between the Beddawi power plant in Lebanon and Syria was completed in 2008, as part of the Arab Gas Pipeline network connecting Egypt, Jordan, Syria, and Lebanon. Natural gas use carries some but not all of the renewable energy advantages noted above; (1) its CO_2 emissions are considerably lower than fuel oil or diesel oil, (2) it is more efficient and hence could potentially reduce the national energy bill, and (3) helps in diversifying energy supply to a certain extent which improves energy security. The capital costs of a CC generator are comparable to conventional generators and hence more economical than any renewable energy technology. Again, a lifecycle cost approach might yield different conclusions regarding the economics of conventional versus renewable energy technologies, where capital costs might be outweighed by other costs included in the analysis.

In the NG alternative scenario it is assumed that EDL completely satisfies the growth in electricity demand up to 2050 by the introduction and expansion of natural gas-using CC generators along with an expansion of the existing technologies. Under the NGS, again the basic assumption is that the backup sector's share of production would fall from 21.6% in 2006 to 0% in 2020. During that period, natural gas-based electricity will expand from 0% in 2006 to 22% in 2020 and 24% in 2050. The respective shares of each of the existing fuels will be 32% and 32% fuel oil, 41% and 41% diesel oil, and 5% and 3% hydro in 2020 and 2050 respectively.

In all scenarios we assume that a national priority is to satisfy 100% of electricity demand given the substantial economic losses due to outages, estimated by the Ministry of Energy and Water at $2.5 billion for the year 2009 [48]. The World Bank [4] suggests the losses are most severe for textile and clothing firms and hotels which represent some of Lebanon's key industries. With the reduction of power outages there will automatically be a phase-out of the backup sector expected to be completed by the year 2020. Dagher and Ruble [2] investigate the role of the backup sector in the Lebanese power sector and conclude that a clear strategy on dealing with this sector needs to be devised simultaneously if not prior to any climate change policy at the national level. Hence, the implied strategy in the current model would be a natural phase-out due to an expansion of EDL's capacity.

3.2 Electricity demand growth

There exists no electricity demand outlook for Lebanon, however the predominant rates of annual electricity demand growth in the literature vary between 3% and 5% [8, 14, 49]. The existing literature focusing on demand-side management does suggest that demand growth can be partially mitigated by applying energy efficiency measures in the residential, commercial, and industrial sectors, but none of the studies, however, predict a growth rate slower than 3% even when taking into account the efficiency measures proposed. For the building sector, Chedid and Ghajar [8] estimate a maximum of 18% reduction in energy use over 40 years due to applying more energy efficient building standards. Given that only 44% of energy consumed for heating and cooling in the building sector is electricity based [8], the adjusted percentage of electricity savings would be 8%. Another 21% savings (Chedid et al. [14] estimate it to be between 20% and 24%) can come from an increase in the use of energy-efficient appliances, namely lighting, refrigerators, and solar domestic water heaters [8]. Again, adjusting this number to reflect electricity savings only would yield savings of around 14%. Both measures together would then give a reduction of 0.55% in residential and commercial electricity use per year, which is still negligible given that electricity demand is expected to grow between 3% and 5% per year. Cantin et al. [9] evaluate the prospects of energy certification for buildings by identifying the key variables and actors, while Chaaban and Rahman [13] propose energy conservation options at the household level. However, both do not quantify the expected savings in energy consumption. Similarly, Ghaddar and Bsat [10] investigate different energy efficiency measures in buildings but do not provide a figure for savings at the country level. Savings in the industrial sector are given for fuel oil, diesel oil, and electricity together [11, 12] and although it is difficult to come up with a figure for electricity reductions only, the analyses imply a more modest reduction than the 0.55% per year for the residential and commercial building sector. Thus, for this analysis, a growth rate of 3% will be used which falls at the lower end of the commonly used range, and can hence be designated as a conservative growth estimate for Lebanon. Figure 2 illustrates the predicted electricity demand path up to the year 2050.

[Figure 2. Electricity Demand Forecasts]

4. Results and discussion

Table 1 lists the key assumptions used in the modeling and simulation runs. The results from the forecasting and simulation exercise will be presented under three categories: generation, environment, and costs.

[Table 1. LEAP Key Assumptions]

4.1 Generation

Under the BS, the generating sector expands to meet the growing electricity demand such that it preserves the present share of each fuel. Thus, the fuel mix remains approximately the same up to the year 2050; fuel oil, diesel oil, and hydro represent 40.3%, 52.2%, and 7.5% respectively of the total GWh produced. Figure 3 shows the breakdown by fuel and by year of the total electricity generated. The dominance of fossil fuels can be clearly seen in the figure. As noted before, the total phase-out of backup generators is achieved by 2020, when electricity demand is completely satisfied by EDL sources.

[Figure 3. Electricity generation by fuel (BS)]
[Figure 4. Electricity generation by fuel (RES)]
[Figure 5. Electricity generation by fuel (NGS)]

Under the RES, the fuel mix changes such that wind provides 12% of the electricity generated in 2020 and 15% in 2050, while the remaining fuels' shares are 35% and 26 % fuel oil, 48% and 56% diesel oil, and 5% and 3% hydro in 2020 and 2050, respectively. Again, we have chosen the growth in the share of wind energy such that it is consistent with the proposed national plan aiming at 12% renewable energy in 2020. Figure 4 shows the breakdown by fuel and by year of the total electricity generated.

Under the NGS, natural gas-based electricity will expand from 0% in 2006 to 22% in 2020 and 24% in 2050. The respective shares of each of the existing fuels will be 32% and 32% fuel oil, 41% and 41% diesel oil, and 5% and 3% hydro in 2020 and 2050, respectively. The breakdown of total electricity generated by fuel and by year is shown in figure 5.

LEAP endogenously calculates the additional capacity needed per year taking into account the electricity demand by the end-use sectors, the imposed constraints on fuel shares, and the maximum availability of each type of generator. Figures 6, 7, and

8 show the yearly additional capacity by fuel for each of the scenarios. All three graphs exhibit several spikes. The first spike occurs in 2007 when substantial additional capacity is needed to make up for the existing shortage. In 2020 we can see another spike in additional capacity when the phased-out backup capacity is being replaced. The next two spikes, at years 2037 and 2050, are merely replacements for retired generators. We have considered a generating plant's lifetime to be 30 years after which it is retired and automatically replaced by an identical generator. Also it's interesting to note that the total wind capacity added by 2050 is less than the potential capacity of 6.1 GW established by the wind atlas, confirming the feasibility of the model.

[Figure 6. Capacity Added by Fuel (BS)]

[Figure 7. Capacity Added by Fuel (RES)]

[Figure 8. Capacity Added by Fuel (NGS)]

Due to the current severe shortage in capacity, required reserve margins are non-existent. In that case capacity factor and availability factor are identical because due to the shortage of supply, generating plants are run as long as they are able to produce electricity. In our modelling, we have assumed a required reserve margin of 14% which is in line with other countries' requirements. This assumption implies that all three scenarios will result in equal reliability in terms of power supply to the end-user. LEAP also calculates the primary requirements for each of the indigenous fuels (wind and hydro) and the imported fuels (fuel oil, natural gas, and diesel oil), based on the efficiency and output of each type of generator. Figures 9, 10, and 11 show the projected imports of diesel oil, fuel oil, and natural gas in all scenarios. As a validation check on the results of the model, we compare the amount of imported fuels calculated by the model to the official figures, and find that they do not differ by more than 10%. Minor differences can result from alternate uses of the fuels such as for heating and may also be due to the inaccuracy in some estimated figures such as the share of backup generation from the total generated electricity.

[Figure 9. Primary Requirements of Diesel Oil by Scenario]

[Figure 10. Primary Requirements of Fuel Oil by Scenario]

[Figure 11. Primary Requirements of Natural Gas by Scenario]

4.2 Environment

The model calculates the resulting emissions from electricity generation based on emission factors and other technical characteristics taken from the Technology and

Environmental Database (TED) that is incorporated into LEAP. Under the business-as-usual scenario, the electricity-related CO_2 emissions are projected to grow from 8.72 $MtCO_2$ in 2006 to 13.56 $MtCO_2$ by 2020, and 32.92 $MtCO_2$ by 2050. Under the RE scenario, the base year emissions of 8.72 $MtCO_2$ are expected to grow to 12.17 $MtCO_2$ by 2020, and 29.23 $MtCO_2$ by 2050. Hence, emissions are reduced by 1.39 $MtCO_2$ or 10.2% in 2020, and 3.69 $MtCO_2$ or 11.2% in 2050, relative to the baseline case. These potential reductions are feasible with the proposed shares of wind energy (12% by 2020 and 15% in 2050). Under the NGS, the base year emissions of 8.72 $MtCO_2$ are expected to grow to 12.19 $MtCO_2$ by 2020, and 29.92 $MtCO_2$ by 2050. Hence, emissions are reduced by 1.37 $MtCO_2$ or 10.1% in 2020, and 3 $MtCO_2$ or 9.1% in 2050, relative to the baseline case. These potential reductions are due to the lower carbon intensity of natural gas when compared to diesel oil or fuel oil. Figure 12 traces the projected emission profiles of all three scenarios throughout the modeling period. As can be seen from the figure, the RES and NGS have similar emission profiles, yet the RE scenario's emissions are slightly lower. Both scenarios imply major reductions in GHG emissions when compared to the baseline, thus facilitating any GHG reduction commitment made in the future.

[Figure 12. Total CO_2 Emissions from Electricity Generation]

4.3 Costs

In general, there are two types of costs to be considered; the annualized capital costs of power plants and the annual fuel costs. It is important to note here that in a scenario comparative analysis, only costs that differ from the baseline case need to be considered because common costs in both scenarios will cancel out in the final calculation. Note that a discount rate of 8% is used to compute the net present values of annualized costs and all monetary values are reported in 2007 USD. As expected, the baseline scenario has lower capital costs but higher fuel costs compared to the RES, whereas the NGS indicates lower capital costs as well as fuel costs.

A cost-benefit analysis reveals that the RE scenario has a negative net present value (for the period up to 2050) of $1,647 million (2007 USD) compared to the baseline scenario, while the NGS has a negative net present value of $3,561 million. Hence, each of the analyzed scenarios can be considered to be a no regrets policy as long as the assumptions underlying the model hold (see Table 1). This is a very interesting finding confirming the attractiveness of wind power and natural gas fired CC generators.

These results have clear policy implications and are of potential use for any future government legislation on greenhouse gas mitigation in the power sector. Both scenarios assume a substantial shift in the electricity generation mix by 2050, which is expected to pose several challenges that are examined in the next section.

The impact of changes in fuel prices on the cost-benefit analysis results were explored through additional sensitivity studies. It was found that at fuel prices 85% lower (diesel oil: $99/ton and fuel oil: $59/ton) than the average 2008 prices, the capital costs will exactly equal the fuel import costs, and hence the comparative net present value between both scenarios will be zero. Since it is highly unlikely that fuel prices will go down to these levels and stay there for long, this makes our above conclusion that the RES is more economically attractive than the BS very plausible. A similar analysis was conducted for the NGS and it was found that at natural gas prices of $0.78/cubic meter, or 2.6 times the average 2008 prices, the capital costs will exactly equal the fuel import costs, and hence the baseline and the NGS will be equivalent in terms of costs.

Another key assumption that might affect the cost-benefit analysis results is the discount rate of 8% that we used. Naturally, any discount rate lower than 8% will only make the alternative scenarios more attractive. For rates higher than 8% we ran the simulations again and found that with a discount rate of 15%, the NPV will become -$633 million and -1,342 million for the RES and NGS (in comparison to the baseline) respectively. Hence, our conclusion regarding the economic attractiveness of our alternative scenarios is valid at least up to a discount rate of 15%.

5. Concluding Remarks

There is no question that new electric generating capacity will have to be added very soon. In this paper a baseline and two alternative scenarios are developed and discussed; the baseline in which the capacity added will be from conventional sources, the first alternative scenario in which wind energy is introduced, and the second alternative scenario in which the cleaner natural gas partly substitutes for fuel oil and diesel oil. The benefits of the RE scenario compared to the baseline scenario that cannot be quantified include less dependence on foreign oil (which also entails a reduction in the national energy bill) and more diversity in the supply mix improving energy security. Natural gas use carries only the second benefit.

From an economic standpoint, both alternative scenarios are superior to the baseline scenario; the RE scenario has a negative net present value of $1.6 billion and the NGS has a negative net present value of $3.5 billion Also, from an environmental perspective both alternative scenarios are superior to the baseline implying a reduction in CO_2 emissions (by 2050) of 11% and 9% in the RES and the NGS respectively. Hence, the results of the simulation show that the alternative scenarios are more environmentally and economically attractive than the BS. They would help Lebanon meet its social, environmental, and economic development goals, while at the same time providing other unquantifiable benefits.

Comparing the two alternative scenarios, NGS and RES, the former seems superior if we look only at the cost-benefit analysis. However, other considerations seem to favor the RES. First, its emissions are lower than the NG scenario's emissions, and given the current attention paid to climate change issues, that might be a particularly important consideration. Second, although both help in diversifying the supply mix, only the RES can effectively reduce the country's dependence on fuel imports. This is an extremely important factor in view of the high political instability in the region. As a matter of fact, natural gas supplies to Lebanon have been halted since an explosion in Egypt damaged part of the Arab Gas Pipeline. Third, the sensitivity analysis conducted revealed some interesting facts; under the given circumstances a price hike of natural gas to $0.78/cubic meter is not inconceivable and would eliminate its economic attractiveness.

Although substituting some of the diesel oil and fuel oil used by natural gas should be relatively easy especially given that the capital cost of a CC generator is lower than for a steam or gas turbine, that is not the case for renewable energy. One can envisage several barriers to the shift in the energy mix from fossil fuels towards renewable energy. For one, many of the current employees of EDL (average age of 52 years), half of which are political appointees, lack the required technical and managerial skills to support the introduction of renewable energy sources [48]. At a broader level, some institutional reform can facilitate the move towards cleaner fuels. For example, in 1992 India established the Ministry of Non-Conventional Energy Sources (MNES) to help in the promotion and penetration of new energy technologies [50].

Second, funding for any major project is challenging with the existing high public debt. For example, investment in the electricity sector for the period 2002-2008 was limited to $50 million [48]. However, funding for renewable energy power plants could be easier to attract than funding for conventional plants with the increasing concern in climate change. Moreover, the evidence provided by the wind atlas confirming the high potential for wind energy in Lebanon should render funding and implementation much easier. The Lebanese Center for Energy Conservation Project is working to set up a national fund for energy efficiency and renewable energy and another fund for residential solar water heaters. The former fund could eventually be used for financing in part the wind energy farms proposed in the RE scenario. Ideally, and similarly to many developed countries, a renewable energy fee could be imposed on electricity consumers by working it into the Lebanese electricity tariff. Moreover, Lebanon can take advantage of some international schemes such as the Clean Development Mechanism (CDM), or use the Independent Power Producer (IPP) setup used elsewhere, but that would require an effective regulatory body to monitor the rates.

Third, the electricity plan should encompass a comprehensive reform of the tariff structure. The current tariff subsidizes both poor and rich consumers, such that EDL loses money on each kWh produced. The fact that this plan aims to provide continuous service eliminating the need for private generators, helps in mitigating any political opposition to the restructuring of the current tariffs.

Lebanon has a golden opportunity now to expand its electricity sector in a way that is socially desirable, environmentally-friendly, and at the same time economically superior to other alternatives. The question that remains to be seen is whether Lebanon will use this opportunity and choose a sustainable development path by shifting from a carbon-intensive structure to a low-carbon one. The ministerial plan seems to suggest a tendency to move in that direction. Within the long-term plan Lebanon seeks to introduce and develop renewable energy sources such that electricity from RES constitutes 12% of overall electricity in 2020. Even if this plan does not become the official governmental plan, it still suggests a direction favoring renewable energy.

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