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OPTIMAL RENEWABLE ENERGY MIX OF THE POWER SECTOR BY 2020

Investment Cost Implications for Lebanon

2015 MINISTRY OF ENVIRONMENT

OPTIMAL RENEWABLE ENERGY MIX OF THE POWER SECTOR BY 2020:
Investment Cost Implications for Lebanon

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Optimal Renewable Energy Mix of the Power Sector by 2020: Investment Cost Implications for Lebanon

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Foreword

Ministry of Environment

Through the publications of Lebanon's Initial and Second National Communications to the United Nations Framework Convention on Climate Change, and the Technology Needs Assessment for Climate Change, the Ministry of Environment drew the large climate change picture in the country. The picture shed the light on a number of climate change matters: Lebanon's contribution to global greenhouse gas emissions, the sectoral share of national emissions, the socio-economic and environmental risks that the country faces as a result of climate change, and the potential actions that could and should be undertaken to fight climate change both in terms of mitigation and adaptation.

Through these series of focused studies on various sectors (energy, forestry, waste, agriculture, industry, finance and transport), the Ministry of Environment is digging deeper into the analysis to identify strengths, weaknesses, threats and opportunities to climate friendly socio-economic development within each sector.

The technical findings presented in this report (Optimal Renewable Energy Mix of the Power Sector by 2020: Investment Cost Implications for Lebanon) will support policy makers in making informed decisions. The findings will also help academics in orienting their research towards bridging research gaps. Finally, they will increase public awareness on climate change and its relation to each sector. In addition, the present technical work complements the strategic work of the National Climate Change Coordination Unit. This unit has been bringing together representatives from public, private and non-governmental institutions to merge efforts and promote comprehensive planning approach to optimize climate action.

We are committed to be a part of the global fight against climate change. And one of the important tools to do so is improving our national knowledge on the matter and building our development and environmental policies on solid ground.

Mohammad Al Mashnouk

Minister of Environment

Foreword

United Nations Development Programme

Climate change is one of the greatest challenges of our time; it requires immediate attention as it is already having discernible and worsening effects on communities everywhere, including Lebanon. The poorest and most vulnerable populations of the world are most likely to face the harshest impact and suffer disproportionately from the negative effects of climate change.

The right mix of policies, skills, and incentives can influence behaviour and encourage investments in climate development-friendly activities. There are many things we can do now, with existing technologies and approaches, to address it.

To facilitate this, UNDP enhances the capacity of countries to formulate, finance and implement national and sub-national plans that align climate management efforts with development goals and that promote synergies between the two.

In Lebanon, projects on Climate Change were initiated in partnership with the Ministry of Environment from the early 2000s. UNDP has been a key partner in assisting Lebanon to assess its greenhouse gas emissions and duly reporting to the UN Framework Convention on Climate Change. With the generous support of numerous donors, projects have also analysed the impact of climate change on Lebanon's environment and economy in order to prioritise interventions and integrate climate action into the national agenda. UNDP has also implemented interventions on the ground not only to mitigate the effects of climate change but also to protect local communities from its impact.

This series of publications records the progress of several climate-related activities led by the Ministry of Environment which UNDP Lebanon has managed and supported during the past few years. These reports provide Lebanon with a technically sound solid basis for designing climate-related actions, and support the integration of climate change considerations into relevant social, economic and environmental policies.

Ross Mountain

UNDP Resident Representative

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Acronyms

BAU	Business as Usual
CAPEX	Capital Expenditures
CCGT	Combined Cycle Gas Turbine
CEDRO	Country Energy Efficiency and Renewable Energy Demonstration Project for the Recovery of Lebanon
CSP	Concentrated Solar Power
DNI	Direct Normal Irradiance
EDL	Eléctricité du Liban
FIT	Feed-in-Tariff
GA	Genetic Algorithms
GDP	Gross Domestic Product
GoL	Government of Lebanon
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IMF	International Monetary Fund
IPPs	Independent Power Producers
IRENA	International Renewable Energy Agency
kWh	Kilowatt hour
LCOE	Levelized Cost of Electricity
MoEW	Ministry of Energy and Water
NG	Natural Gas
O&M	Operation and Maintenance
PV	Photovoltaic
RE	Renewable Energy
SEA	Strategic Environmental Assessment
SOGREAH	Société Grenobloise d'Etudes et d'Applications Hydrauliques
VOLL	Value of Lost Load

Executive summary

In 2009, the Government of Lebanon (GoL) committed to reach 12% renewable energy in its energy mix by 2020. In addition, the Ministry of Energy and Water (MoEW), in its Policy Paper for the Electricity Sector, plans to increase the electricity generation capacity based on diversity and security, where two-thirds of the fuel mix is composed of natural gas with multiple sources of supply[1]. According to a number of studies, Lebanon demonstrates a high capacity potential of generating 215 million Gigawatt hours (GWh) of electricity, from a pure technical point, through the deployment of three renewable energy technologies: hydropower, windpower and solar (Photovoltaic (PV) and concentrated solar power technologies)[2].

It is acknowledged that renewable energy investments incur high costs on governments, typically with large up-front capital costs. In Lebanon, however, it is expected that producing electricity from renewable energy sources will be less costly than from conventional thermal power plants, especially since the government is spending around USD 2 billion annually in the form of treasury transfers to Eléctricité du Liban (EDL).

In order to determine the optimal energy mix considering the cost burden to the government, this study incorporates the capacity potential of the three mentioned renewable technologies with the assumption of meeting the estimated/expected 29,784 GWh demand[3] by 2020 in a number of scenarios, and showcases the importance of renewable energy in the portfolio of electricity supply under the cost criterion. Two additional cases are analyzed with estimated demand at 21,571 GWh and 33,215 GWh by 2020.

The report first converses simulation optimization models with the cost criterion to determine the optimal supply mix from renewable energy, according to two scenarios: the 12% target (scenario C1), and a more ambitious 20% share (scenario C2). Results of the three demand cases under C1 and C2 scenarios are conveyed in the below table:

	Low demand		Medium demand		High demand	
	21,571 GWh		29,784 GWh		33,215 GWh	
Shares (%)	C1	C2	C1	C2	C1	C2
Hydropower	7.94	8.02	5.80	5.84	5.21	5.25
Windpower	2.95	3.23	2.57	3.01	2.30	2.84
Solar PV	1.11	8.75	3.63	11.16	4.49	11.91

[1] Policy Paper for Electricity Sector, Ministry of Energy and Water, June 2010.

[2] Potential capacities are based on the SEA Scoping Consultation Working Booklet, the Société Grenobloise d'Etudes et d'Applications Hydrauliques (SOGREAH) report, the National Wind Atlas of Lebanon, and the Solar Atlas for the Mediterranean.

[3] This is the 4,000 MW demand estimate, where 4,000 × 0.85 × 8,760 = 29,784,000 MWh

List of scenarios

Cost model scenarios	
C1	Cost model with 12% Renewable Energy (RE) target, and 29,784 GWh supply by 2020. The remaining 88% of total energy supply comes from current and new Combined Cycle Gas Turbine (CCGT) power plants with Heavy Fuel Oil (HFO).
C2	Cost model with 20% RE target, and 29,784 GWh supply by 2020. The remaining 80% of total energy supply comes from current and new CCGT power plants with HFO.
Financial analysis scenarios	
BAU	Energy supply will be at current and near term levels at 17,176 GWh (of which 463 GWh are from current hydropower production).
BAU_{12}	Energy supply will be at current and near term levels at 17,176 GWh, with additional 1,770 GWh from RE. The total of RE generation will be at 2,233 GWh (12% of the total).
BAU_{20}	Energy supply will be at current and near term levels at 17,176 GWh, with additional 3,665 GWh from RE. The total of RE generation will be at 4,128 GWh (20% of the total).
F1	Energy supply will meet the demand of 29,784 GWh, with around 98% from CCGT plants with HFO and no new RE sources.
$F1_{12}$	Energy supply will meet the demand of 29,784 GWh, with around 88% from CCGT plants with HFO. RE comprises 12% of the total share.
$F1_{20}$	Energy supply will meet the demand of 29,784 GWh, with 80% from CCGT plants with HFO. RE comprises 20% of the total share.
F2	Energy supply will meet the demand of 29,784 GWh, with around two-thirds from CCGT plants with natural gas and no new RE sources. The remaining mix comprises existing CCGT plants run on HFO.
$F2_{12}$	Energy supply will meet the demand of 29,784 GWh, with around two-thirds from CCGT plants with natural gas. RE comprises 12% of the total share. The remaining mix comprises existing CCGT plants run on HFO.
$F2_{20}$	Energy supply will meet the demand of 29,784 GWh, with around two-thirds from CCGT plants with natural gas. RE comprises 20% of the total share. The remaining mix comprises existing CCGT plants run on HFO.

وأخيراً، تم تطبيق تحليل مالي بهدف تقدير الكلفة الاجمالية على عاتق الدولة والاقتصاد في عدد من السيناريوهات، مع تأمين ثلثي الامداد بالطاقة عن طريق محطات التوربين الغازي (Combine-Cycle Gas Turbine) التي تعمل إما بالوقود الثقيلة (heavy fuel oil) أو بالغاز الطبيعي، أيضاً مع دمج المزيج الأمثل الـ١٢٪ والمزيج الأمثل الـ٢٠٪ من الطاقة المتجددة. وبالإضافة إلى ذلك، فإن التحليل المالي لسيناريو «الأعمال مستمرة كالمعتاد» (Business as Usual (BAU) يفترض بأن الامداد بحلول العام ٢٠٢٠ لن يعرف زيادة من الانتاجات الحالية والقصيرة الأمد، أو بإمداد بنسبة ١٢٪ من الطاقة المتجددة (BAU_{12})، أو بإمداد بنسبة ٢٠٪ من الطاقة المتجددة (BAU_{20}).

وتم تحديد برنامج التعرفة التفضيلية ((feed–in tariff) المرتبطة بكلفة توليد الكهرباء) من كل من التكنولوجيات طاقة الرياح والطاقة الشمسية وإدراجه في التحليل المالي لهذا التقرير. وتظهر النتائج بأنّ خيار دعم برنامج التعرفة التفضيلية بهدف تشجيع الاستثمارات في الطاقة المتجددة من جانب القطاع الخاص إنما سيكون ذات كلفة أقل بالنسبة إلى الدولة بالمقارنة مع الاستثمارات الاضافية في مصادر الطاقة التقليدية. وتكون الكلفة أعلى في حال لم تقم الحكومة بزيادة الامداد بالطاقة بحلول العام ٢٠٢٠.

التوصيات الرئيسية على صعيد السياسات والتي يمكن تسليط الضوء عليها في هذا التقرير هي أولاً المصادقة على وتحديث القانون ٤٦٢ من أجل تسهيل مشاركة القطاع الخاص في إنتاج الكهرباء على مستوى الشبكة الوطنية. ثانياً، يستحسن بالدولة رفع تعرفة الكهرباء التي يسددها المستخدمون النهائيون من أجل تغطية جزء من تكاليف تلبية الطلب على الكهرباء على المستوى الوطني بحلول العام ٢٠٢٠. وأخيراً، فإن برنامج التعرفة التفضيلية لإمدادات الطاقة المتجددة ذات الحجم المحدد والتكنولوجيا المحددة إنما ينبغي تطبيقه من أجل زيادة الثقة في سوق الطاقة المتجددة لدى المستثمرين من القطاع الخاص. كما يجب إجراء المزيد من الدراسات تأخذ بعين الاعتبار معايير أخرى غير الكلفة: أمن الطاقة والمخاطر البيئية والاستثمارية.

الملخص التنفيذي

لقد تعهدت الدولة اللبنانية في عام ٢٠٠٩ برفع إنتاج الطاقة المتجددة إلى ١٢٪ في مزيج الطاقة اللبناني بحلول العام ٢٠٢٠. وبالإضافة إلى ذلك، تخطط وزارة الطاقة والمياه ضمن دراستها حول قطاع الكهرباء، زيادة القدرة على توليد الكهرباء المعتمدة على التنوع و الحماية، بحيث يشكل استعمال الغاز الثلثين مع تنويع و تعدد مصادره [١]. ووفقاً لعدد من الدراسات، يملك لبنان قدرة تقنية محتملة عالية في الطاقة المتجددة لتوليد ٢١٥ مليون جيجاوات ساعة من الكهرباء عبر اعتماد ثلاث تكنولوجيات طاقة متجددة: الطاقة الكهرمائية، طاقة الرياح والطاقة الشمسية (تكنولوجيات الطاقة الشمسية المركزة والضوئية)[٢].

ومن المعروف أن الاستثمارات في مجال الطاقة المتجددة تكبد تكاليف باهظة على الدول، وخاصةً مع السداد المبكر لتكلفة رأس المال. ومع ذلك، في لبنان، من المتوقع أن إنتاج الكهرباء من مصادر الطاقة المتجددة سيكون أقل تكلفة من الإنتاج في محطات الطاقة الحرارية التقليدية، خصوصا وأن الحكومة تنفق حوالي ملياري دولار سنويا في تحويلات الخزينة إلى مؤسسة كهرباء لبنان.

من أجل تحديد مزيج الطاقة الأمثل نظرا إلى عبء التكلفة للدولة، تتضمن هذه الدراسة إمكانية قدرة تكنولوجيات الطاقة المتجددة المذكورة الثلاثة مع تلبية الطلب[٣] على ٢٩،٧٨٤ جيجاوات ساعة بحلول العام ٢٠٢٠ في عدد من السيناريوهات، بهدف إظهار أهمية الطاقة المتجددة في محفظة الامداد بالكهرباء وفقاً لمعيار الكلفة. وتم تحليل حالتين إضافيتين مع الطلب على ٢١،٥٧١ جيجاوات ساعة و ٣٣،٢١٥ جيجاوات ساعة بحلول العام ٢٠٢٠.

ثمّ يقدم التقرير نماذج حاسوبية تستخدم الدرجة المثلى من المحاكاة (simulation optimization) بمعيار الكلفة من أجل تحديد مزيج الامداد الأمثل من الطاقة المتجددة وفقاً لسيناريوهين اثنين: هدف الـ١٢٪ (السيناريو C1)، وهدف أكثر طموحاً بنسبة ٢٠٪ (السيناريو C2).
وتظهر النتائج في الجدول أدناه مزيج الطاقة المتجددة الأمثل ضمن الحالات الطلب الثلاثة و سيناريوهات C1 و C2:

	طلب منخفض		طلب متوسط		طلب مرتفع	
	٢١،٥٧١ جيجاوات ساعة		٢٩،٧٨٤ جيجاوات ساعة		٣٣،٢١٥ جيجاوات ساعة	
الحصة (٪)	**C1**	**C2**	**C1**	**C2**	**C1**	**C2**
الطاقة الكهرومائية	٧,٩٤	٨,٠٢	٥,٨	٥,٨٤	٥,٢١	٥,٢٥
طاقة الرياح	٢,٩٥	٣,٢٣	٢,٥٧	٣,٠١	٢,٣	٢,٨٤
الطاقة الشمسية (التكنولوجيات الضوئية)	١,١١	٨,٧٥	٣,٦٣	١١,١٦	٤,٤٩	١١,٩١

[١]ورقة سياسة قطاع الكهرباء، وزارة الطاقة والمياه، حزيران (يونيو) ٢٠١٠.
[٢] ترتكز معلومات القدرات المحتملة في الطاقة المتجددة على كتيب عمل التشاور بشأن دراسة نطاق التقييم البيئي الاستراتيجي، وتقرير «سوغريا» (SOGREAH)، وأطلس الرياح الوطني في لبنان والأطلس الشمسي لمنطقة البحر الأبيض المتوسط.
[٣]تعتمد هذه على تقديرات الطلب على ٤،٠٠٠ ميغاواط، أي ٤،٠٠٠ X ٠,٨٥ X ٨,٧٦٠ = ٢٩،٧٨٤،٠٠٠ ميغاواط/ساعة

1. Introduction

The electricity generation portfolio in Lebanon is highly exposed to fuel price risks, since only 8.1% of electricity generation comes from hydropower, while 91.9% is based on imported oil[4]. In the reference scenario (Figure 1 below), Brent spot crude oil prices are expected to decline from 722 USD/tonne in 2014 to 670 USD/tonne in 2017, but increase thereafter to 705 USD/tonne in 2020. However, investments in Renewable Energy (RE) will involve higher capital costs, but will not include actual supply and cost risks of fuel. Therefore, it is important to obtain the optimal RE mix based on primarily cost criterion, while analyzing and acknowledging the overall risks of energy investments.

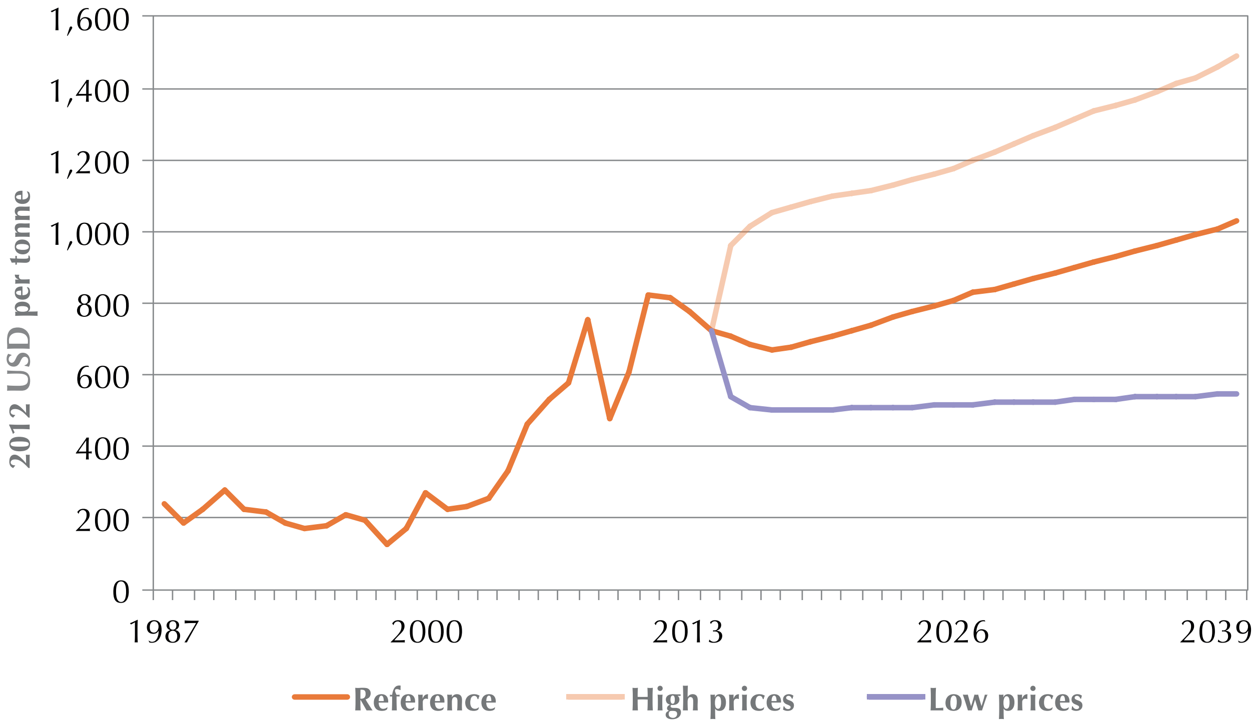


Figure 1: Projected average annual Brent spot crude oil prices in three cases, 1987-2040
Source | International Energy Agency (Annual Energy Outlook, 2014)

In Lebanon, the significant RE sources to generate electricity include hydropower, windpower and solar electricity from Photovoltaic (PV) and Concentrated Solar Power (CSP) installations, having an estimated technical capacity potential at 215 million Gigawatt hour (GWh). It is important to mention that this potential is considering all areas in Lebanon where RE installations can be built, but is not a realistic potential considering all other financial and economic barriers. Data on potential capacity in Megawatt (MW) and capacity factors are extracted from the Strategic Environmental Assessment (SEA) of the RE sector scoping consultation working booklet[5]. Lebanon may have capacity potential in other sources such as waste-to-energy, geothermal energy, biomass, but these technologies were not incorporated here due to the lack of proper capacity assessments and/or the complexity of conducting a similar estimation of investment costs.

[4] According to the Ministry of Energy and Water (MoEW) and based on 2012 productions.

[5] The SEA Workshop Consultation Booklet is based on the SOGREAH report, the National Wind Atlas of Lebanon,and the Solar Atlas for the Mediterranean.

Furthermore, the Levelized Cost of Electricity (LCOE) is based on expert[6] estimates of the Capital Expenditures (CAPEX) required to build power plants, cost of grid connection, and the Operations and Maintenance (O&M) costs, as well as a range taken from the International Renewable Energy Agency (IRENA, 2013) (see Annex I and Annex IV). The costs are levelized over a 30-year horizon with a range of discount rates between 7% and 12%. For thermal power plants, the range in Heavy Fuel Oil (HFO) prices is taken between 503 USD/tonne and 1,097 USD/tonne. Diesel oil prices are taken to range between 1,100 USD/tonne and 1,727 USD/tonne. Figure 2 shows the ranges of the simulated levelized costs of the various sources of energy.

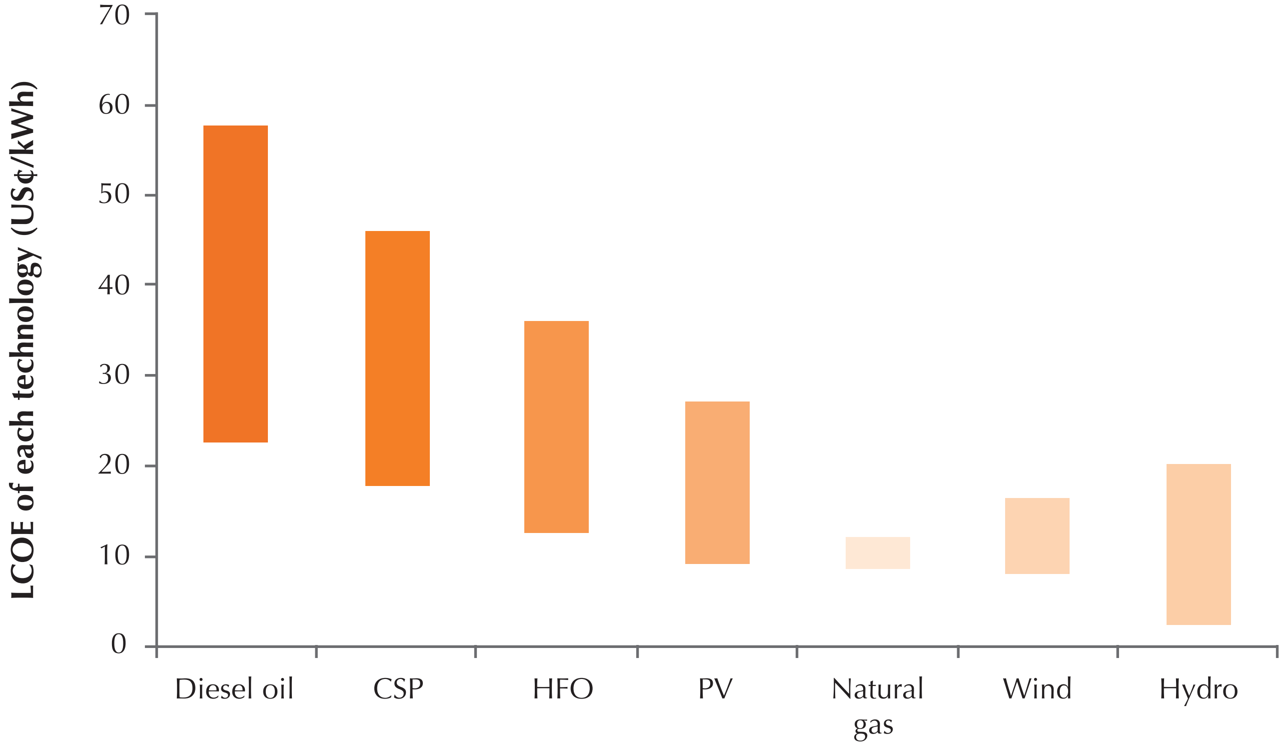


Figure 2: Ranges in levelized costs of the various energy sources

Source | CAPEX ranges are based on reports by the International Renewable Energy Agency (IRENA, 2012) and experts' estimates; oil price ranges are based on forecasts of the International Energy Agency (IEA, 2014)

The report introduces the methodology employed in this study including the assumptions and development of the cost models, as well as the detailed results of all three demand cases. It also integrates a financial analysis of the optimal mix of the medium demand case. The study then concludes with a set of recommendations.

2. Methodology

Optimization modeling uses applied mathematics to find the best solution from a set of feasible options. The cost model utilized is simulation optimization aimed at minimizing the overall cost of electricity generation. Simulation optimization models, as opposed to traditional optimization models, can handle a much larger number of scenarios and incorporate the uncertainties embedded in the input factors. Therefore, simulation optimization can

[6] Hassan Harajli, Project Manager, CEDRO, United Nations Development Programme; Karim Osseiran, Energy Consultant Expert, Ministry of Energy and Water of Lebanon.

approximate the reality value of the objective function while incorporating various sources of uncertainties and variability in the forecast, which can affect the performance of the optimization process (Better et al., 2008).

Section 2.1 conveys the details of the cost models, C1 and C2. The assumptions and the development of the models are explained, in addition to the results. These include three demand cases: low, medium, and high. Section 2.2 is a financial analysis including estimates of the cost to the government and the overall economy of the medium demand case. Figure 3 sketches the overall methodology of this study.

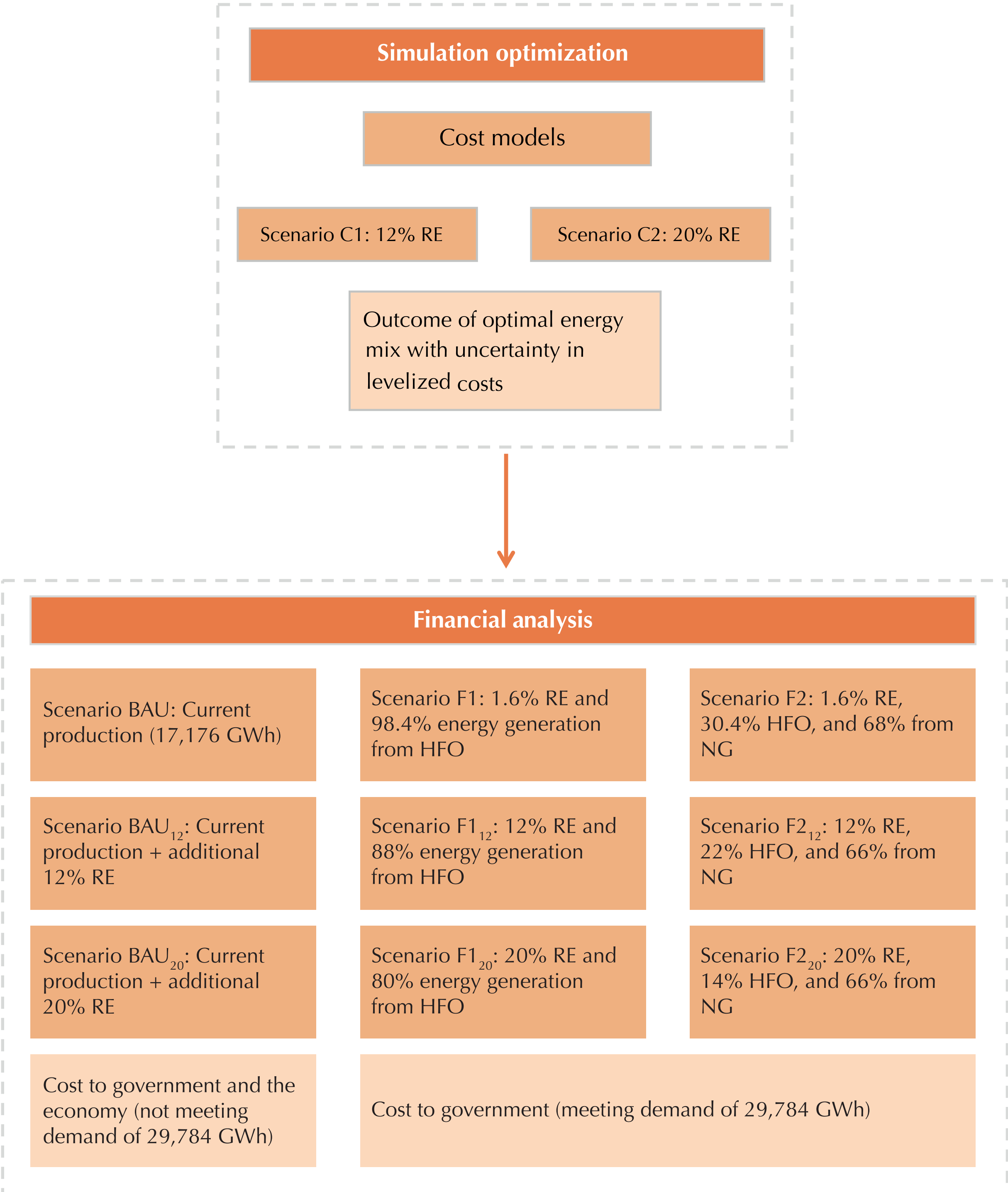


Figure 3: Flow chart of the employed methodology

2.1. The cost model

The objective of the cost model is to determine the best RE mix according to one criterion: minimizing the overall cost of electricity generation. The uncertainty of the levelized cost of each technology was incorporated according to a range of distributions to ensure robust solutions. Figure 4 depicts the steps taken in order to complete the cost optimization model.

Step 1: Simulation	Step 2: Optimization	Step 3: Results
Incorporate uncertainty in LCOE levels	Optimization of cost criterion with two scenarios	Optimal renewable energy mix

Figure 4: Steps of the cost optimization model

2.1.1. Three demand cases

Estimation of real electricity demand by 2020 is not straightforward in Lebanon's case for a number of factors:

i. Current supply falls short of today's demand;
ii. The existence of self-powered generation and black-outs in many Lebanese areas;
iii. There are no accurate estimates for the current Lebanese population[7].

Therefore, a number of demand cases were developed to eliminate a number of estimation errors resulting from the assumptions made in these calculations.

Low demand case

The first demand case is based on the electricity demand level at 18,000 GWh in 2012[8]. In order to forecast demand increase in the future, a simple correlation trend between historical Gross Domestic Product (GDP) growth and electricity consumption was calculated for the years between 2001 and 2011. It was then assumed that the same trend will follow in the coming years, and the increase in electricity demand was based on GDP growth forecasts by the International Monetary Fund (IMF). Results show that electricity demand will reach 21,571 GWh by 2020. The drawback of this case is that it is based on historical consumption levels and not real demand. However, it minimizes the use of assumptions and proxies and is therefore based on real data.

[7] Additional electricity demand by Syrian refugees was not accounted for.

[8] Latest available estimates from MoEW/EDL.

Table 1: Estimated electricity consumption by 2020

		2012	2013	2014	2015	2016	2017	2018	2019	2020
Electricity consumption, based on forecast demand	**GWh**	18,000	18,331	18,607	18,888	19,359	20,033	20,533	21,046	**21,571**
Annual increase in demand	%	1.8	1.5	1.5	2.5	3.5	2.5	2.5	2.5	**2.5**
GDP growth	%	2	1	1	3	4	2.5	2.5	2.5	**2.5**

Source | GDP growth is based on projections by the IMF WEO database (April, 2014)

Medium demand case

The medium demand scenario of 29,784 GWh is based on the assumption of a 4,000 MW demand, and a capacity factor of 0.85, where 29,784,000 Megawatt hour (MWh) = 4,000 × 0.85 × 8,760.

High demand case

In the third case, the upper-end of demand increase forecasts in Lebanon at 8% annually is used (Dagher and Ruble, 2011) to generate a high demand case. According to this, electricity demand will reach 33,215 GWh by 2020.

2.1.2. Assumptions and development of the model

Two scenarios are generated for all demand cases: scenario C1 assumes a 12% supply from renewables in line with Lebanon's voluntary commitment by 2020, while the remaining 88% of the total energy supplied is from Heavy Fuel Oil (HFO). Scenario C2 assumes a more ambitious 20% RE target, while the remaining 80% is provided from HFO.

The supply from existing thermal and hydropower plants is expected to be maintained at current production and less than the maximum potential value. Also, the supply from potential sources of renewable technologies (including solar, windpower, and additional hydropower sources) is constrained by the maximum potential value.

It is important to mention that the open cycle power plants of Tyre, Baalback, and Hreisheh run on diesel oil and are not considered in this analysis, since they are currently used only at peak demand, due to their high cost of generation. Considered thermal plants are the combined cycle power plants of Deir Ammar and Zahrani, and the conventional oil fired power plants of Zouk and Jiyeh.

Table 2: The simulation optimization cost model

Objective	Minimize total cost	**USD**
Search variable	Optimal production of each technology	**kWh**
Output	Range of total cost	**USD**
Constraints	Total supply >= demand by 2020	**kWh**
	Share of supply from thermal >= 80% / 88%	
	Supply from existing thermal and hydro plants >= current supply	**kWh**
	Supply from each technology <= potential capacity	**kWh**

2.1.3. Cost model results

Low demand case

The results here convey the overall optimal mix of energy supply of thermal, hydro, solar and wind technologies for scenarios C1 and C2. Disaggregated results are in Annex V.

Thermal

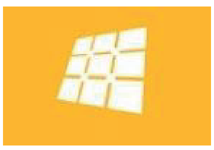
Total share: 88%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Zouk	241	1,897
Jiyeh	155	1,218
Deir Ammar	378	2,978
Zahrani	378	2,984
New plants (HFO)	1,256	9,905

Hydro

Total share: 7.94%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Kadisha Valley	21	76
Litani-Awali	51	197
Nahr Ibrahim	32	105
Nahr Al Bared	17	62
Safa Spring	13	23
New plants		
28 new plants*	343	1,249



Solar

Total share: 1.11%

Capacity factor	Effective capacity (MW)	Supply (GWh)
20.8	131	239

Wind

Total share: 2.95%

Capacity factor	Effective capacity (MW)	Supply (GWh)
42.1	125	461
38.4	52	176

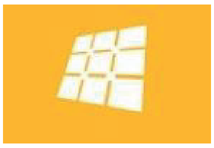
Figure 5: Results of the cost model scenario C1 – demand case 1

Thermal
Total share: 80%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Zouk	241	1,897
Jiyeh	155	1,218
Deir Ammar	378	2,978
Zahrani	378	2,984
New plants (HFO)	1,038	8,180

Hydro
Total share: 8.02%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Kadisha Valley	21	76
Litani-Awali	51	197
Nahr Ibrahim	32	105
Nahr Al Bared	17	62
Safa Spring	13	23
New plants		
28 new plants*	347	1,267



Solar
Total share: 8.75%

Capacity factor	Effective capacity (MW)	Supply (GWh)
20.8	321	585
20.10	739	1,302

Wind
Total share: 3.23%

Capacity factor	Effective capacity (MW)	Supply (GWh)
42.1	125	461
38.4	70	236

Figure 6: Results of the cost model scenario C2 – demand case 1

Medium demand case

Thermal
Total share: 88%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Zouk	241	1,897
Jiyeh	155	1,218
Deir Ammar	378	2,978
Zahrani	378	2,984
New plants (HFO)	2,173	17,133

Hydro
Total share: 5.80%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Kadisha Valley	21	76
Litani-Awali	51	197
Nahr Ibrahim	32	105
Nahr Al Bared	17	62
Safa Spring	13	23
New plants		
28 new plants*	347	1,265

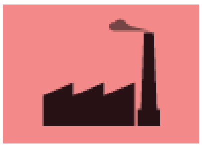
Solar
Total share: 3.63%

Capacity factor	Effective capacity (MW)	Supply (GWh)
20.8	290	528
20.10	314	553

Wind
Total share: 2.57%

Capacity factor	Effective capacity (MW)	Supply (GWh)
42.1	125	461
38.4	60	201
34.8	34	102

Figure 7: Results of the cost model scenario C1 – demand case 2

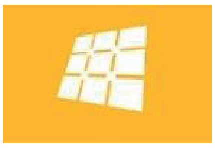


Thermal
Total share: 80%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Zouk	241	1,897
Jiyeh	155	1,218
Deir Ammar	378	2,978
Zahrani	378	2,984
New plants (HFO)	1,871	14,750

Hydro
Total share: 5.84%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Kadisha Valley	21	76
Litani-Awali	51	197
Nahr Ibrahim	32	105
Nahr Al Bared	17	62
Safa Spring	13	23
New plants		
28 new plants*	349	1,275



Solar
Total share: 11.16%

Capacity factor	Effective capacity (MW)	Supply (GWh)
20.8	398	726
20.10	1,086	1,911
19.5	402	686

Wind
Total share: 3.01%

Capacity factor	Effective capacity (MW)	Supply (GWh)
42.1	125	461
38.4	82	275
34.8	52	159

Figure 8: Results of the cost model scenario C2 – demand case 2

High demand case

Thermal

Total share: 88%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Zouk	241	1,897
Jiyeh	155	1,218
Deir Ammar	378	2,978
Zahrani	378	2,984
New plants (HFO)	2,556	20,152

Hydro

Total share: 5.21%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Kadisha Valley	21	76
Litani-Awali	51	197
Nahr Ibrahim	32	105
Nahr Al Bared	17	62
Safa Spring	13	23
New plants		
28 new plants*	347	1,266

Solar

Total share: 4.49%

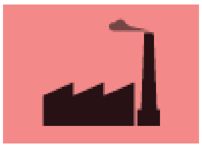
Capacity factor	Effective capacity (MW)	Supply (GWh)
20.8	240	438
20.10	418	737
19.5	186	317

Wind

Total share: 2.30%

Capacity factor	Effective capacity (MW)	Supply (GWh)
42.1	125	461
38.4	71	239
34.8	21	65

Figure 9: Results of the cost model scenario C1 – demand case 3



Thermal

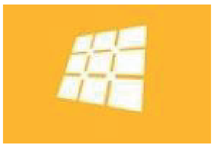
Total share: 80%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Zouk	241	1,897
Jiyeh	155	1,218
Deir Ammar	378	2,978
Zahrani	378	2,984
New plants (HFO)	2,219	17,495

Hydro

Total share: 5.25%

Existing plants (HFO)	Effective capacity (MW)	Supply (GWh)
Kadisha Valley	21	76
Litani-Awali	51	197
Nahr Ibrahim	32	104
Nahr Al Bared	17	62
Safa Spring	13	23
New plants		
28 new plants*	350	1,280



Solar

Total share: 11.91%

Capacity factor	Effective capacity (MW)	Supply (GWh)
20.8	437	862
20.10	1,255	2,210
19.5	517	883

Wind

Total share: 2.84%

Capacity factor	Effective capacity (MW)	Supply (GWh)
42.1	125	461
38.4	92	308
34.8	57	175

Figure 10: Results of the cost model scenario C2 – demand case 3

2.2. Financial analysis

Financial analysis is an important section of this report since it estimates the overall cost burden to the government under a number of scenarios:

Scenario F1 assumes that energy supply through 2020 will meet the demand of 29,784 GWh with around 98% from Combined Cycle Gas Turbine (CCGT) plants with HFO and no new RE sources. Scenario $F1_{12}$ has similar assumptions but with a 12% RE share of the total supply, of which the mix is determined from the results of the C1 model. Scenario $F1_{20}$ assumes a 20% RE share of the total supply, of which the mix is determined from the results of the C2 model.

Scenario F2 assumes that energy supply through 2020 will meet the demand, with two-thirds from CCGT plants running on natural gas. This assumption is in line with the forecasts of the Policy Paper for the Electricity Sector (2010). Scenario $F2_{12}$ has similar assumptions but with a 12% RE share of the total supply, and Scenario $F2_{20}$ assumes a 20% RE share.

The Business as Usual (BAU) scenario assumes no additional energy supply from current and near term levels[9], taken at 17,176 GWh from thermal power plants and hydro energy sources[10]. Scenario BAU_{12} assumes that additional 1,770 GWh will be supplied from RE sources and scenario BAU_{20} assumes that additional RE sources of 3,665 GWh will be supplied.

The following sub-sections explain the main Feed-in Tariff (FIT) design options and elements to be considered when establishing a FIT scheme in Lebanon, the assumptions made in the financial scenarios, and their results.

2.2.1. Establishing a feed-in-tariff mechanism for renewable energy sources

The FIT remains the most widely adopted renewable power generation policy employed at the national and state/provincial levels. As of early 2013, 71 countries and 28 states/provinces had adopted some form of FIT policy (REN21, 2013). A FIT policy states that utilities must purchase all renewable power for sale and in return receive a premium – the government sets prices (tariffs) through long-term contracts (Huang and Wu, 2011).

The challenge here is to identify a level of compensation for potential investors in RE that would provide sufficient incentives, without over-rewarding them at the expense of the electricity consumers or the government budget (Klein et al., 2008). The approach utilized is to correlate the level of FIT to the LCOE of each technology. In Lebanon, the private sector through the Independent Power Producers (IPPs) is expected to primarily launch investments in RE. Therefore, by calculating the LCOE and the net present value of the sum of annual cash flows for each one of the RE technologies under consideration, the minimum level of compensation that investors should get to generate profit is determined.

[9] Proxy to year 2012 of hydro and thermal production, and taking into account the under-construction 800 MW CCGT power plants in Deir Ammar, Jiyeh, and Zouk.

[10] Note that due to the Conveyor 800 and 900 projects to supply irrigation and potable water from the Litani river, production from current hydro power plants will decline from 918 GWh to 463 GWh.

An effective FIT mechanism induces technological development through rapid deployment and economies of scale, thereby decreasing costs of generating electricity from RE sources and improving competitiveness compared with that of conventional electricity systems that use gas, coal, oil or nuclear energy (Mendonca et al., 2010; Huang and Wu, 2011). The main FIT design options are presented in Table 3 below and are extracted from Huang and Wu (2011).

Table 3: Basic elements and options of the FIT scheme in Lebanon

	FIT design basic elements based on international best practice	The case of Lebanon
Eligible technologies	Eligible technologies should be based on resource availability and determine which kind of power plants shall be eligible. A good FIT scheme starts with a clear definition of eligible technologies and plants.	Eligible technologies and their potential capacities are based on the SEA of the renewable energy sector and a number of other sources, where it is shown that there exists a high potential of electricity production from renewable energy sources.
FIT calculation methodology	A FIT calculation methodology based on generation costs for each technology must be transparent. A FIT that is too low will not generate investments in renewable energy technologies, while a FIT that is too high may generate unnecessarily excessive high profits and increase energy costs for consumers. Moreover, the automatic annual reduction of tariffs has become international best practice. Through this so-called tariff digression, the legislator aims to anticipate technical progress, economies of scale, rationalization, and the overall learning potential of a given technology.	The FIT calculation is based on the LCOE ranges as in Annex IV. The tariff level is taken as the average of the minimum and maximum levels of the ranges.
Technology differentiation	This is to set technology-specific and size-specific FITs. Technology-specific and size-specific supports are necessary because of the significant differences between costs for renewable energy technologies and plants sizes.	A technology-specific FIT is taken into consideration, but not a size-specific one, due to the lack of data for all renewable energy generation.
FIT payment duration	A FIT payment for 15-20 years is the most common and successful approach.	This depends on the political and legislative circumstances.
Financing mechanism	When creating a robust financing mechanism, allocating costs to all electricity consumers is acceptable. This financing burden-sharing mechanism permits the support of large shares of renewable electricity with only a marginal increase in final electricity costs for consumers.	The current tariff imposed on final consumers is around 9.6 US¢ per Kilowatt hour (kWh), and so with increased supply, it is assumed that the tariff can be raised to 14 US¢/kWh.

	FIT design basic elements based on international best practice	The case of Lebanon
Purchase obligation	Purchase obligation requires grid operators to purchase all electricity generated from renewable sources. In addition to long-term tariff payments, purchase obligation is a key component for all FIT schemes as it assures investment security.	Further updating of law 462 (in addition to amendments of law 775 and law 288) is the only legal framework that would allow the private sector involvement in electricity production at the national grid.
Targets	These targets are important as they signal long-term political commitment to investors and indicate that supportive mechanisms will last for a certain period.	The government's voluntary commitment to 12% energy supply from energy sources by 2020 is taken as the main target in this document.
Other non-economic barriers	Aside from good economic conditions and purchase obligation, non-economic factors, particularly red tape, have marked effects on FIT system performance.	The dominant barriers are legislative barriers, in addition to land permits and logistics in connecting to the grid.

2.2.2. Assumptions and financial results

To increase energy supply to 29,784 GWh by 2020 from the current centralized supply of 10,869 GWh, additional costs will be incurred by the government, either in the form of further losses from thermal power production or through a potential FIT policy scheme to encourage RE investments. However, these additional costs are expected to be lower than the cost of energy not supplied, or the Value of Lost Load (VOLL) cost.

The Policy Paper for the Electricity Sector (2010) explains that the VOLL cost has been estimated by Electricité de France and the World Bank to vary between 200 and 2,000 USD per Megawatt hour (MWh). The Policy Paper takes an average of USD 700 per MWh to calculate total cost at USD 2.5 billion in 2009. The VOLL cost by 2020 is also calculated based on the demand of 29,784 GWh, where:

VOLL cost = [total demand (MWh) - total supply (MWh)] × USD 700 / MWh

To estimate the overall cost of the power sector on the economy, under a number of scenarios, the parameters in Tables 4 and 5 are assumed. The electricity tariff is assumed to be set at 14 US¢/kWh in the F1 and F2 scenarios, where electricity supply meets demand. However, in the Business as Usual (BAU) scenarios, it is taken at the current level of 9.6 US¢/kWh. In the thermal case, the government is expected to cover EDL losses through treasury transfers. These losses are reflected in the difference between the tariff and the LCOEs. For RE sources, and with a FIT scheme, the government will pay the difference between the tariff and the FIT payment to the investors. Note that it is assumed that the government will own all the hydro powerplants in the future, and so only a FIT is determined for windpower and solar technologies. Whether the investors will generate losses or profits depends on the LCOE of these technologies.

Table 4: Financial parameters of thermal power plants

Thermal and hydropower	
Tariff (US¢/kWh)	14
Loss (US¢/kWh)	Tariff - LCOE
Overall loss (US¢)	Loss (US¢/kWh) x optimal electricity produced (kWh)

Table 5: Financial parameters of RE sources

Renewable energy sources	
Tariff (US¢/kWh)	14
FIT (US¢/kWh)	Set at the average of LCOE range
Loss (US¢/kWh)	Tariff - FIT
Overall loss (US¢)	Loss (US¢/kWh) x optimal electricity produced (kWh)

Table 6 below presents the financial results of the 9 scenarios. The BAU scenario imposes the highest cost to the economy at around USD 10.8 billion annually. Also, it is evident that when incorporating RE into the energy mix, the cost burden to the government is reduced. BAU scenarios assume that Lebanon will not meet the energy demand by 2020, and so the total cost will also include the cost to the economy from the VOLL. Scenarios BAU_{12}, and BAU_{20}, will cost the economy around USD 9.5 and 8.2 billion, respectively.

Scenarios, F1, $F1_{12}$ and $F1_{20}$, will cost the government on an annual basis around USD 2.1, 1.6, and 1.3 billion, respectively. When relying on natural gas instead of HFO in the CCGT power plants, the cost will be reduced; scenarios F2 and $F2_{12}$ will cost the government on an annual basis around USD 575 and 33 million, respectively. Scenario $F2_{20}$ is expected to provide an average profit of USD 290 million annually.

With respect to the cost implications of RE targets 12% and 20%, the results below indicate that for an eight point increase in the share of RE in the Lebanese energy mix, the difference in cost on the economy is significant at a saving of USD 323 million for the F1 and F2 scenarios and USD 1.3 billion for the BAU.

With the assumptions made in this section, the 12% and 20% RE sources will replace the most expensive thermal power technologies. In this case, the RE source will replace the CCGT power plants of Deir Ammar and Zahrani.

Table 6: Total cost/profit to the economy of the four financial scenarios

Scenario	BAU	BAU_{12}	BAU_{20}	F1	$F1_{12}$	$F1_{20}$	F2	$F2_{12}$	$F2_{20}$
Total energy produced (GWh)	17,176	18,946	20,841	29,784	29,784	29,784	29,784	29,784	29,784
Sources (GWh)	RE 463 HFO 16,713	RE 2,233 HFO 16,713	RE 4,128 HFO 16,713	RE 463 HFO 29,321 NG 0	RE 3,574 HFO 26,210 NG 0	RE 5,957 HFO 23,827 NG 0	RE 463 HFO 9,076 NG 20,245	RE 3,574 HFO 6,549 NG 19,661	RE 5,957 HFO 4,166 NG 19,661
Cost to government (per year)									
Mean (million USD)	-1,960 on average 2014 - 2017*	-1,960 on average 2014 - 2017*	-1,960 on average 2014 - 2017*	-2,177	-1,624	-1,301	-543	-37	285
Of which, the FIT scheme support (million USD)	0	3.1	-105.1	0	16.8	-25.8	0	16.8	-25.8
90% confidence interval (million USD)				-3,025 -1,335	-2,430 -821	-2,075 -521	-948 -144	-387 311	-21 591
Standard deviation (million USD)				516	491	480	241	211	185
Additional costs to the economy (per year)									
Cost of energy not supplied (million USD)	-8,825	-7,586	-6,260	0	0	0	0	0	0
Total cost to the economy (per year)									
Mean (million USD)	-10,785	-9,546	-8,220	-2,177	-1,624	-1,301	-543	-37	285

Note:

RE is Renewable Energy, HFO is Heavy Fuel Oil, and NG is Natural Gas.

*Based on data and forecasts of the Ministry of Finance.

**Disaggregated optimal RE technology mixes for $F1_{12}$, $F2_{12}$ are that of C1 and of $F2_{12}$, and $F20_{12}$ are that of C2. The mixes for BAU_{12} and BAU_{20} are provided in Annex V.

3. Conclusions and policy recommendations

Under the cost models, hydro technology proves to be the cheapest technology, where the results convey almost full consumption of the potential capacities of the hydro power plants. Also, the cheapest options in solar (PV) and wind are incorporated to provide a 20% share of RE.

With a simple FIT design scheme, where the FIT is set at the average of the LCOE ranges, the results show that the cost to the government will be lower with portfolios with renewable energy even when not including a carbon or pollution cost. This could be attributed to the fact that **a FIT scheme to encourage renewable energy investments is forecasted to cost the government much less than the losses it is making in the form of support to EDL.**

In brief, it can be concluded that if renewable energy sources are incorporated into Lebanon's energy mix, the overall cost to the economy will be reduced.

A set of policies are recommended to maintain stable investments in the power sector and to supply reliable, efficient, and affordable electricity to consumers:

- Continuous policy support from the government is needed to provide an enabling environment and promote renewable energy investments in the power market. First, an update to law 462 is required to cover all sufficient aspects regarding renewable energies. Note that law 775 of 2006 and law 288 of 2014 are both amendments to law 462 of 2002 only on a temporary basis.

- A technology-specific and size-specific FIT scheme needs to be implemented to increase confidence in the renewable energy market, and thus encourage investments. Since the renewable energy market is still young, a tariff digression system (an automatic, annual reduction of tariffs) is advised based on higher expected technical capacities and economies of scale for the future. The government can also reduce the investment cost risks, through providing fixed prices of electricity under the discussed FIT scheme, but also by creating an enabling environment for domestic and foreign investments in the country.

- In the case where the power sector does not undergo any changes (BAU), moving from a target of 12% RE to 20% RE is highly recommended (annual cost saving on the economy for this shift is USD 1.3 billion).

- Similarly, in the case where the power sector will be able to meet the demand with natural gas or HFO, the case of moving from a target of 12% RE to 20% is advisable (annual cost saving on the economy for this shift is USD 323 million). Specifically, it is expected that an annual cost of USD 37 million in scenario $F2_{12}$ will shift to an annual profit of USD 285 million in scenario $F2_{20}$.

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Annex I: Calculation of LCOEs

The notion of LCOE is a handy tool for comparing the unit costs of different technologies over their economic life. It would correspond to the cost of an investor assuming the certainty of production costs and the stability of electricity prices (International Energy Agency, 2010).

To calculate the levelized average lifetime costs for different technologies, the costs for investment in capital, grid connection, operations and maintenance, and fuel are utilized as follows:

$Electricity_t$	the amount of electricity produced in year t
$P_{Electricity}$	the constant price of electricity
$(1+r)^{-t}$	the discount t factor for year t
$Capital\ investment_t$	capital investment costs in year t
$O\&M_t$	operations and maintenance costs in year t
$Fuel_t$	fuel costs in year t
$Grid_t$	grid connection costs in year t

$$\sum_t(Electricity_t \times P_{Electricity} \times (1+r)^{-t}) = \sum_t((Capital\ investment_t + O\&M_t + Fuel_t + Grid_t) \times (1+r)^{-t})$$

From the above follows that:

$$LCOE = P_{Electricity} = \frac{\sum_t((Capital\ investment_t + O\&M_t + Fuel_t + Grid_t) \times (1+r)^{-t})}{\sum_t(Electricity_t \times (1+r)^{-t})}$$

Annex II: About @Risk and RiskOptimizer

In a broad sense, Risk Analysis is any method, qualitative and/or quantitative, that can assess the impacts of risk on decision situations. The goal of any of these methods is to help the decision-maker choose a course of action, and @RISK brings advanced modeling and Risk Analysis to Microsoft Excel (Guide to Using @Risk, 2010). @RISK uses probability distributions to describe uncertain values in Excel worksheets and to present results. Monte Carlo sampling was applied in this study. It refers to the traditional technique for using random or pseudo-random numbers to sample from a probability distribution (Guide to Using @Risk, 2010).

RISKOptimizer combines simulation and optimization to allow the optimization of models that contain uncertain factors. It uses a proprietary set of Genetic Algorithms (GAs) to search for optimum solutions to a problem, along with probability distributions and simulation to handle the uncertainty present in the models (Guide to Using RISKOptimizer, 2010). GAs mimic Darwinian principles of natural selection by creating an environment where hundreds of possible solutions to a problem can compete with one another, and only the "fittest" survive (Guide to Using @Risk, 2010). They are useful when a problem has multiple solutions, some of which are better than others (Grupe and Jooste, 2004).

However, Grupe and Jooste (2004) explain that as with all modeling tools, GAs are not guaranteed to solve a problem in an optimal way, although an optimal solution is possible. They mention some of the limitations of GAs:

- Most GAs rely on random number generators that produce different results each time the model runs. While there is likely to be a high degree of consistency among the runs, they may vary.

- It is known that in a few situations, the genes from a few comparatively highly fit solutions may come to dominate the population, causing it to converge on a local maximum. Once the population has converged, the ability of the GA to continue to search for better solutions is effectively eliminated.

- If the range of possible solutions is small, a GA will converge quickly on a solution. Presumably, an unbounded search space is also problematic since it may require excessive run times.

Annex III: Cost model development in @Risk and RiskOptimizer

This section will explain the mathematical formulation of the cost model:

Objective:

Minimize $Cost_{overall} = \sum_i (LCOE_i \times Supply_i)$: the total cost of electricity production meeting the 2020 target, where "i" is the range of potential technologies.

Parameters:

$Demand_{2020}$ = 21,571 / 29,784 / 33,215 GWh: the projected electricity demand cases by 2020.

$Prod_k$ is the current production from thermal power plants and $Prod_h$ is the current production from hydro plants.

Other parameters used are the available capacities, Cap_i , and the levelized cost distributions, $LCOE_i$.

Variables:

$Supply_i$: the optimal supply of each technology in kWh.

Constraints:

$\sum_i(Supply_i) >= Demand_{2020}$

$Supply_i <= Cap_i$, for every i

$\sum_k Supply_k / \sum_i Supply_i >= 0.8$, where k is the technology of thermal energy and i includes all technologies.

$Supply_k >= Prod_k$

$Supply_h >= Prod_h$

Annex IV: Input data and assumed parameters

Table 7: Input data of thermal power plants

Thermal				
Power plant	**Potential capacity (MW)**	**Available capacity (MWh)**	**Fuel (USD/tonne)**	**LCOE (US¢/kWh)**
Zouk	607	3,164,000	Uniform (503, 1,097)	Uniform (17.4, 34.6)
Jieh	327	1,704,000	Uniform (503, 1,097)	Uniform (17.3, 36.3)
Deir Ammar	450	3,275,000	Uniform (1,100, 1,727)	Uniform (24.1, 36.6)
Zahrani	450	3,283,000	Uniform (1,100, 1,727)	Uniform (22.8, 35.3)
Tyr	72	209,000	Uniform (1,100, 1,727)	Uniform (36.9, 57.6)
Baalback	64	186,000	Uniform (1,100, 1,727)	Uniform (37.1, 57.7)
Hreisheh*	70	364,000	-	Uniform (17.5, 34.6)
Power plant	**Potential capacity (MW)**	**Potential capacity (MWh)**	**Fuel (USD/tonne)**	**LCOE (US¢/kWh)**
New plants (HFO)			Uniform (503, 1,097)	Uniform (13.1, 24.0)
New plants (NG) **				Uniform (8.8, 12.1)

Note that potential and available capacities are based on data from MoEW.

*This is assumed to have the same distribution as that of Zouk.

** The range is based on IEA estimates.

Table 8: Input data of solar photovoltaic technology

Solar – PV				
Capacity factor	**Potential capacity (MW)**	**Available capacity (MWh)**	**CAPEX (USD/kW)**	**LCOE (US¢/kWh)***
16.6	4,575	6,652,782	Uniform (1,700, 2,700)	Uniform (12.5, 27.1)
17.3	15,538	23,546,770		Uniform (11, 26.7)
18.0	23,413	36,916,830		Uniform (10.5, 25.0)
19.5	23,588	40,292,167		Uniform (9.6, 23.1)
20.1	33,625	59,205,555		Uniform (9.5, 22.8)
20.8	8,808	16,047,969		Uniform (9.3, 21.7)

* The ranges in the LCOEs also reflect the range of discount rate between 7-12%.

Table 9: Input data of solar CSP technology

Solar – CSP				
DNI in KWh/m²	**Potential capacity (MW)**	**Available capacity (MWh)**	**CAPEX (USD/kW)**	**LCOE (US¢/kWh)***
2,100 - 2,200	925	1,790,000	Uniform (4,500, 7,150)	Uniform (19.4, 44.9)
2,200 - 2,300	860	1,740,000		Uniform (18.2, 43.1)
2,300 - 2,400	545	1,153,000		Uniform (17.2, 41.4)
2,400 - 2,500	445	981,000		Uniform (16.9, 39.7)
2,500 - 2,600	1,545	3,545,000		Uniform (15.9, 38.4)
2,600 - 2,700	2,540	6,058,000		Uniform (15.8, 36.6)
2,700 - 2,800	800	1,980,000		Uniform (15.3, 35.5)
2,800 - 2,833	405	1,027,000		Uniform (14.9, 34.8)

* The ranges in the LCOEs also reflect the range of discount rate between 7-12%.

Table 10: Input data of hydropower technology

Hydro (existing plants)				
Power plant	**Potential capacity (MW)**	**Potential capacity (MWh)**	**2012 yearly production (MWh)**	**LCOE (US¢/kWh)***
Kadisha Valley	21.3	76,000	72,000	Uniform (0.8, 2.4)
Litani-Awali**	51	232,500	680,000	Uniform (0.8, 2.4)
Nahr Ibrahim	32	105,000	92,000	Uniform (0.8, 2.4)
Nahr Al Bared	17.2	62,000	54,000	Uniform (0.8, 2.4)
Safa Spring	13.1	23,000	20,000	Uniform (0.8, 2.4)

Hydro (potential plants)			
Power plant	**Potential capacity (MW)**	**Potential capacity (MWh)**	**LCOE (US¢/kWh)***
Nahr Al Bared	1.9	10,319	Uniform (2.8, 3.8)
Yammouneh	4.7	23,056	Uniform (3.2, 4.3)
Sir (Sukkar)	7.1	38,304	Uniform (3.6, 5.1)
Blat (Litani)	21.0	106,697	Uniform (4.0, 5.6)
Daraya (pointe) (El Kelb)	25.3	84,108	Uniform (4.3, 6.2)
Chamra (pointe) (El Kelb)	30.7	102,083	Uniform (4.3, 6.2)
Boustane (Kfar Helda) (El Jouz)	4.5	19,316	Uniform (4.3, 6.1)
El Ouatie (Nahr Sir)	6.5	35,303	Uniform (4.7, 6.6)
Sir (Bared sup)	1.8	9,776	Uniform (4.8, 6.8)
Qattine (Nahr Sir)	4.9	26,613	Uniform (4.9, 7.0)
Kardaleh barrage (Litani)	9.5	50,087	Uniform (4.9, 7.0)
Centrale Qarn	9.7	54,382	Uniform (5.0, 7.0)
El Mara	11.2	62,792	Uniform (5.2, 7.4)
Janneh barrage (Ibrahim)	100	219,000	Uniform (5.3, 7.5)
Hdaine (Ibrahim)	24	86,198	Uniform (5.8, 8.2)
Mayrouba (El Kelb)	5.1	23,232	Uniform (5.8, 8.2)

Power plant	Potential capacity (MW)	Potential capacity (MWh)	LCOE (US¢/kWh)*
Dammour barrage	2.2	9,417	Uniform (5.7, 8.3)
Bchamine (Abou Ali)	5.9	28,426	Uniform (6.3, 8.95)
Boqaata barrage (El Kelb)	39.0	129,823	Uniform (6.5, 9.3)
Ibrahim 4 (Ibrahim)	5.2	24,574	Uniform (6.7, 10.0)
Beit Chlala (El Jouz)	4.5	19,316	Uniform (6.9, 9.9)
Aval Joun (Awali)	4.8	28,593	Uniform (7.0, 10.0)
Kfarsir barrage (Litani)	3.5	13,726	Uniform (7.2, 10.3)
Chabrouh (El Kelb)	0.6	1,314	Uniform (7.2, 10.4)
Mtaile (Barouk) (Damour)	5.0	22,776	Uniform (7.3, 10.5)
Centrale Mechmech	3.2	17,940	Uniform (7.3, 10.5)
El Boum (Damour)	13.3	54,759	Uniform (7.7, 11.1)
Jezzine (Awali)	1.6	4,205	Uniform (8.25, 11.9)
Kannoubin (Abou Ali)	2.1	10,118	Uniform (9.7, 14.1)
Rechmaya (Damour)	8.5	38,719	Uniform (10.1, 14.7)
Mseilha barrage (Al Jouz)	0.6	2,536	Uniform (10.9, 15.7)
Dachouniye (Beirut)	4.0	13,315	Uniform (13.9, 20.3)

* The ranges in the LCOEs also reflect the range of discount rate between 7-12%.

** Due to conveyor 800 and 900 projects to supply irrigation and potable water from the Litani river, production in this site is expected to be reduced from 775 GWh to 197 GWh.

Table 11: Input data of wind technology

Wind			
Capacity factor	**Potential capacity (MW)**	**Potential capacity (MWh)**	**LCOE (US¢/kWh)***
22.0	2,355	4,538,556	Triangular (13.4, 14.9, 16.4)
25.1	1,500	3,298,140	Triangular (12.1, 13.3, 14.6)
28.2	743	1,835,448	Triangular (11.1, 12.1, 13.1)
31.4	384	1,056,246	Triangular (10.3, 11.1, 12)
34.8	199	606,648	Triangular (9.6, 10.2, 10.9)
38.4	102	343,112	Triangular (8.9, 9.5, 10.1)
42.1	125	460,995	Triangular (8.4, 8.9, 9.3)

* The ranges in the LCOEs also reflect the range of discount rate between 7-12%.

Annex V: Disaggregated results of RE mixes for C1, C2, BAU_{12}, and BAU_{20}

Table 12: Output data of RE technologies for C1 model

Optimal hydro production (existing plants)						
	Low demand case		Medium demand case		High demand case	
Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Kadisha Valley	21.3	76,000	21.3	76,000	21.3	76,000
Litani-Awali	51.1	197,000	51.1	197,000	51.1	197,000
Nahr Ibrahim	32.0	105,000	32.0	105,000	32.0	105,000
Nahr Al Bared	17.2	62,000	17.2	62,000	17.2	62,000
Safa Spring	13.1	23,000	13.1	23,000	13.1	23,000
Hydro (new plants)						
Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Nahr Al Bared	1.9	10,319	1.9	10,319	1.9	10,319
Yammouneh	4.7	23,056	4.7	23,056	4.7	23,056
Sir (Sukkar)	7.1	38,304	7.1	38,304	7.1	38,304
Blat (Litani)	21.0	106,697	21.0	106,697	21.0	106,697
Daraya (pointe) (El Kelb)	25.3	84,108	25.3	84,108	25.3	84,108
Chamra (pointe) (El Kelb)	30.7	102,083	30.7	102,083	30.7	102,083

Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Boustane (Kfar Helda) (El Jouz)	4.5	19,316	4.5	19,316	4.5	19,316
El Ouatie (Nahr Sir)	6.5	35,303	6.5	35,303	6.5	35,303
Sir (Bared sup)	1.8	9,776	1.8	9,776	1.8	9,776
Qattine (Nahr Sir)	4.9	26,613	4.9	26,613	4.9	26,613
Kardaleh barrage (Litani)	9.5	50,087	9.5	50,087	9.5	50,087
Centrale Qarn	9.7	54,382	9.7	54,382	9.7	54,382
El Mara	11.2	62,792	11.2	62,792	11.2	62,792
Janneh barrage (Ibrahim)	100.0	219,000	100.0	219,000	100.0	219,000
Hdaine (Ibrahim)	24.0	86,198	24.0	86,198	24.0	86,198
Mayrouba (El Kelb)	5.1	23,232	5.1	23,232	5.1	23,232
Dammour barrage	2.2	9,417	2.2	9,417	2.2	9,417
Bchamine (Abou Ali)	5.9	28,426	5.9	28,426	5.9	28,426
Boqaata barrage (El Kelb)	39.0	129,823	39.0	129,823	39.0	129,823
Ibrahim 4 (Ibrahim)	5.2	21,614	6.0	24,575	6.0	24,575

Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Beit Chlala (El Jouz)	3.4	14,571	4.0	17,247	4.0	17,247
Aval Joun (Awali)	4.0	23,560	4.1	24,295	4.3	25,420
Kfarsir barrage (Litani)	2.6	13,726	2.8	14,507	2.8	14,678
Chabrouh (El Kelb)	0.4	941	0.5	986	0.5	1,024
Mtaile (Barouk) (Damour)	3.2	14,362	3.7	16,802	3.8	17,090
Centrale Mechmech	2.2	12,334	2.5	14,138	2.4	13,267
El Boum (Damour)	6.7	27,586	7.7	31,583	7.8	32,143
Jezzine (Awali)	0.55	1,447	0.67	1,749	0.63	1,664
Kannoubin (Abou Ali)						
Rechmaya (Damour)						
Mseilha barrage (Al Jouz)						
Dachouniye (Beirut)						

Wind (new plants)						
	Low demand case		Medium demand case		High demand case	
Capacity factor	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
42.1	125	460,995	125	460,995	125	460,995
38.4	52	176,050	60	201,294	71	283,579
34.8			34	102,676	21	64,895
31.4						
28.2						
25.1						
22.0						

PV solar (new plants)						
	Low demand case		Medium demand case		High demand case	
Capacity factor	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
20.8	131	239,401	290	528,280	240	437,953
20.1			314	553,018	418	736,769
19.5					186	317,368
18.0						
17.3						
16.6						

Table 13: Output data of RE technologies for C2 model

Optimal hydro production (existing plants)						
	Low demand case		Medium demand case		High demand case	
Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Kadisha Valley	21.3	76,000	21.3	76,000	21.3	76,000
Litani-Awali	51.1	197,000	51.1	197,000	51.1	197,000
Nahr Ibrahim	32.0	105,000	32.0	105,000	32.0	105,000
Nahr Al Bared	17.2	62,000	17.2	62,000	17.2	62,000
Safa Spring	13.1	23,000	13.1	23,000	13.1	23,000
Hydro (new plants)						
	Low demand case		Medium demand case		High demand case	
Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Nahr Al Bared	1.9	10,319	1.9	10,319	1.9	10,319
Yammouneh	4.7	23,056	4.7	23,056	4.7	23,056
Sir (Sukkar)	7.1	38,304	7.1	38,304	7.1	38,304
Blat (Litani)	21.0	106,697	21.0	106,697	21.0	106,697
Daraya (pointe) (El Kelb)	25.3	84,108	25.3	84,108	25.3	84,108
Chamra (pointe) (El Kelb)	30.7	102,083	30.7	102,083	30.7	102,083
Boustane (Kfar Helda) (El Jouz)	4.5	19,316	4.5	19,316	4.5	19,316
El Ouatie (Nahr Sir)	6.5	35,303	6.5	35,303	6.5	35,303
Sir (Bared sup)	1.8	9,776	1.8	9,776	1.8	9,776
Qattine (Nahr Sir)	4.9	26,613	4.9	26,613	4.9	26,613
Kardaleh barrage (Litani)	9.5	50,087	9.5	50,087	9.5	50,087

Power plant	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
Centrale Qarn	9.7	54,382	9.7	54,382	9.7	54,382
El Mara	11.2	62,792	11.2	62,792	11.2	62,792
Janneh barrage (Ibrahim)	100.0	219,000	100.0	219,000	100.0	219,000
Hdaine (Ibrahim)	24.0	86,198	24.0	86,198	24.0	86,198
Mayrouba (El Kelb)	5.1	23,232	5.1	23,232	5.1	23,232
Dammour barrage	2.2	9,417	2.2	9,417	2.2	9,417
Bchamine (Abou Ali)	5.9	28,426	5.9	28,426	5.9	28,426
Boqaata barrage (El Kelb)	39.0	129,823	39.0	129,823	39.0	129,823
Ibrahim 4 (Ibrahim)	6.0	24,575	6.0	24,575	6.0	24,575
Beit Chlala (El Jouz)	4.1	17,625	4.6	19,616	4.5	19,316
Aval Joun (Awali)	4.3	25,835	4.5	26,593	4.6	27,593
Kfarsir barrage (Litani)	2.8	14,967	3.0	15,837	3.2	16,837
Chabrouh (El Kelb)	0.5	1,035	0.5	1,145	0.5	1,175
Mtaile (Barouk) (Damour)	3.7	16,958	3.8	17,238	4.2	19,238
Centrale Mechmech	2.5	13,964	2.7	15,125	2.7	15,137
El Boum (Damour)	7.7	31,501	8.2	33,826	8.5	35,026
Jezzine (Awali)	0.6	1,632	0.66	1,741	0.79	2,071
Kannoubin (Abou Ali)	0.04	173	0.1	462	0.1	720
Rechmaya (Damour)						
Mseilha barrage (Al Jouz)						
Dachouniye (Beirut)						

Wind (new plants)						
	Low demand case		Medium demand case		High demand case	
Capacity factor	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
42.1	125	460,995	125	460,995	125	460,995
38.4	70	235,912	82	275,240	92	307,888
34.8			52	159,327	57	174,841
31.4						
28.2						
25.1						
22.0						

PV solar (new plants)						
	Low demand case		Medium demand case		High demand case	
Capacity factor	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)	Effective capacity (MW)	Supply (MWh)
20.8	321	585,021	398	725,542	473	861,758
20.1	739	1,302,075	1,086	1,911,468	1,255	2,210,419
19.5			402	686,138	517	883,481
18.0						
17.3						
16.6						

Table 14: RE mixes for BAU_{12} and BAU_{20} models – medium demand case

Optimal hydro production (new plants)		
Power plant	**BAU_{12} supply (MWh)**	**BAU_{20} supply (MWh)**
Nahr Al Bared	10,319	10,319
Yammouneh	23,056	23,056
Sir (Sukkar)	38,304	38,304
Blat (Litani)	106,696	106,696
Daraya (pointe) (El Kelb)	84,108	84,108
Chamra (pointe) (El Kelb)	102,083	102,083
Boustane (Kfar Helda) (El Jouz)	19,316	19,316
El Ouatie (Nahr Sir)	35,303	35,303
Sir (Bared sup)	9,776	9,776
Qattine (Nahr Sir)	26,613	26,613
Kardaleh barrage (Litani)	50,087	50,087
Centrale Qarn	54,382	54,382
El Mara	62,792	62,792
Janneh barrage (Ibrahim)	219,000	219,000
Hdaine (Ibrahim)	86,198	86,198
Mayrouba (El Kelb)	23,231	23,231
Dammour barrage	9,417	9,417
Bchamine (Abou Ali)	28,426	28,426
Boqaata barrage (El Kelb)	155,651	129,823
Ibrahim 4 (Ibrahim)	20,684	24,574
Beit Chlala (El Jouz)	11,640	17,380
Aval Joun (Awali)	18,963	27,086
Kfarsir barrage (Litani)	13,792	15,872
Chabrouh (El Kelb)	856	1,061

Power plant	BAU_{12} supply (MWh)	BAU_{20} supply (MWh)
Mtaile (Barouk) (Damour)	1,347	17,694
Centrale Mechmech	10,573	13,904
El Boum (Damour)	24,665	33,641
Jezzine (Awali)	1,162	1,703
Optimal windpower production		
Capacity factor	**BAU_{12} supply (MWh)**	**BAU_{20} supply (MWh)**
42.1	429,165	460,995
38.4	92,690	214,846
Optimal photovoltaic production		
Capacity factor	**BAU_{12} supply (MWh)**	**BAU_{20} supply (MWh)**
20.8	0	627,376
20.1	0	906,374
19.5	0	183,541
Total production from new RE sources		
	BAU_{12} supply (MWh)	**BAU_{20} supply (MWh)**
	1,774,577	3,673,810

Annex VI: Limitations and assumptions of the models

It is important to state all the limitations of the models in this study that may have an impact on reading and acting upon the results of this report. However, the focus was on delivering precise and realistic results of a number of simplistic models. Mainly, the limitations are:

i. The models employed to determine the optimal energy mix rely on a single criterion: the cost represented by the LCOEs of various technologies. Environmental and risk criteria, as well as the benefit from diversifying sources of energy were not embedded at this stage.

ii. All the models hold many assumptions; for example, regarding the distributions of LCOEs, the constraints, the RE targets and the electricity demand by 2020. However, as in any modeling exercise, making assumptions was inevitable for simplification and reliability.

iii. A number of factors that can have a great influence on the results were not represented by the model, either due to the absence of data, or resulting from their non-connectedness to the model. For instance, technological (absence of skilled-labor), political (impacting the infrastructure) and macroeconomic (business and land permits) risks and barriers could not be accounted for.

iv. The LCOE ranges for the PV technology do not reflect the size (1 MW, 50 MW, or 100 MW), but rather are based on general experts' estimates.

v. There are certain obvious drawbacks associated with RE supply that were not accounted for, such as the stochastic behavior of power generation, policy uncertainty, etc., which can seriously expose the future of RE development.

vi. Dynamic constraints are also not included, such as the cost of shutting down existing plants or units, for replacement with RE sources.

vii. The simulation optimization model uses a genetic algorithm to search for optimum solutions which has a number of limitations as mentioned in Annex II. Most importantly, the solution provided may be at the local minimum where the ability of the algorithm to continue to search for better solutions is effectively eliminated.

viii. A proper FIT scheme with decreasing tariffs over a contact period could not be constructed due to the lack of data on potential LCOE reductions resulting from higher expected technical capacities and economies of scale in the future.