TECHNO-FINANCIAL APPRAISAL OF ROOF-TOP PHOTOVOLTAIC (PV) SYSTEMS:
THE CASE OF LEBANON

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Abbreviations

GoL	Government of Lebanon	LCEC	Lebanese Center for Energy Conservation
IEA	International Energy Agency	MEW	Ministry of Energy and Water
NEEREA	National Energy Efficiency and Renewable Energy Action	PV	Photovoltaic
RECREE	Regional Center for Renewable Energy and Energy Efficiency	RET	Renewable energy technology
UNDP	United Nations Development Program	VAT	Value added tax

Abstract

The present work analyses the technical and financial performance of four photovoltaic (PV) systems implemented by the UNDP-CEDRO project. The study builds on actual logged data from the PV sites in order to understand the current challenges and opportunities for microgeneration in Lebanon. Technical analysis focuses on the systems' design that caters for a 'weak' electricity sector and the consequent energy performances achieved. Financial appraisal is then performed on the 1.8 kWp PV systems through the adoption of two possible scenarios in the future. Financial results, in terms of net present value and payback period, are more favorable when assuming, paradoxically, a future with extended reliance on diesel gensets, the use of lower discount rates, and the use of the currently available financial support mechanism in Lebanon. Finally, the applicability of feed-in tariffs (FiTs) for Lebanon is discussed, advising a deferment of FiTs until the presence of 24 hour electricity.

1. Introduction

1.1 General background and objective

Lebanon has set itself a target to achieve 12% renewable electricity within its electricity mix by 2020 (MEW, 2010). However, the expected cash flows of investing in small-scale renewable energy technologies (RETs) in Lebanon are subject to many uncertainties. This is due to the fact that any RET has to confront the unreliability of the existing Lebanese electricity sector (Section 1.2). For many years now, Lebanon has been facing a drastic power shortage that has put the country among the worst three countries in the world with respect to power outages (Nationmaster, 2015). This situation has forced citizens to rely on local diesel generators to compensate a large portion of their electric power needs. Integrating roof-top RET is therefore subject to its performance in relation to the saving on either diesel fuel or diesel genset capacity, within a wider unreliable electricity network.

This paper assesses the financial performance, prospects and possibilities of integrating roof-top photovoltaic (PV) systems in such an environment, building up the case from the measured and calculated energy performances of several implemented PV sites in Lebanon using 2013 as a data logging reference year. The outcome of the financial appraisal is dependent on future scenarios, two of which are assumed and adopted in this paper, particularly related to the future presence of blackouts and the consequent need for backup gensets. A brief analysis discusses the applicability of feed-in tariffs for such RETs, based on the assessed performances of the solar PV systems.

1.2 The status of electricity supply and demand in Lebanon

A detailed description of the current electricity sector in Lebanon can be found in Policy Paper of the Ministry of Energy and Water (MEW, 2010), El-Fadel et al. (2010), Aoun et al. (2013), World Bank (2009), Dagher and Ruble (2010), and Osseiran (2014). The main narrative to note is the demand and supply deficit, where it ranges from a minimum of 600 MW and yet can reach approximately 1 GW in peak summer months (MEW, 2010). This deficit has led and is currently responsible for an average of 6 hour outages across the country, yet with varying degrees between the various Lebanese regions themselves and between the regions and the capital Beirut (MEW, 2010). Most of the power cuts begin early morning and raise steadily to reach a maximum during early night time (see Figure 1). Figure 1 shows the daily demand and supply for four random days per season, and it can be seen that the demand-supply gap intensifies in the months of summer. Power demand in Lebanon is expected to increase annually by 7% (Aoun et al., 2013), and therefore without additional power sources coming online electricity outages are set to worsen. Moreover, the average tariff that Lebanese citizens pay is approximately $c4.6/kWh for residential sector consumers, $c10.4/kWh for the average commercial sector, and $c7.7 for average industrial sector electricity consumption (RECREE & UNDP, 2015), whereas the average cost of generation is at least $c17/kWh and can reach over $c26/kWh, depending on international oil prices (El-Fadel et al., 2010).

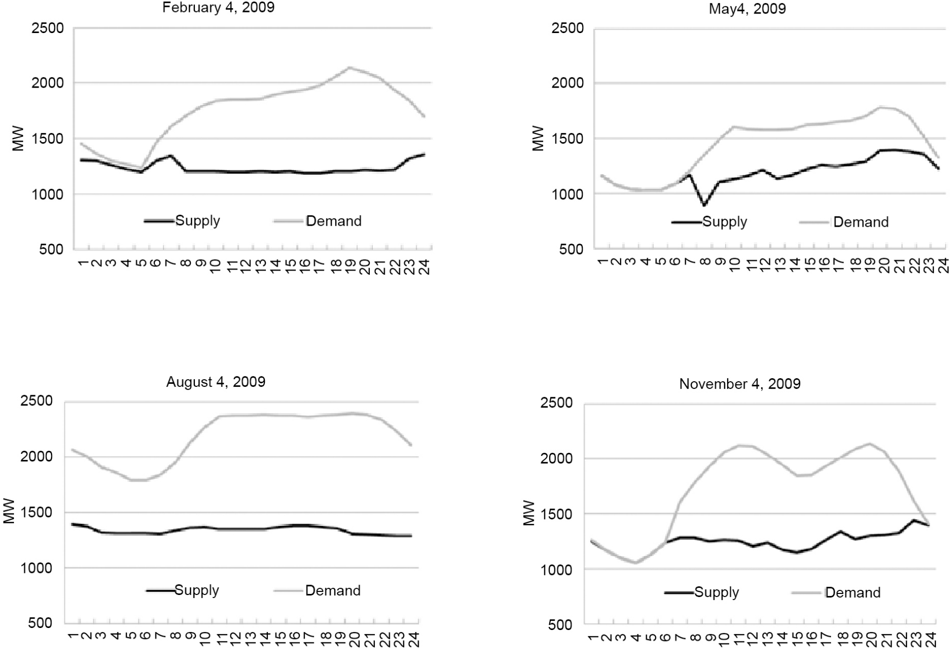


Figure 1. Electricity demand and supply for four selected days in 2009 (EDL Data, 2010)

1.3 PV generation; the dual-mode architecture

Solar PV technology is increasing in importance in Lebanon as an option for the various Lebanese sectors and citizens to overcome the shortfalls of power supply without reverting to costly local diesel generators. The MEW Policy Paper (2010) has indirectly emphasized the importance of microgeneration through enabling a 'net metering' program. Microgeneration can be treated as a category in and by itself (see, for example, Allen et al., 2008). For electricity generation, particular interest in our case is appraising small-scale photovoltaic (PV) microgenerators.

Microgenerators have two known mainstream classical applications, either small autonomous systems with batteries or grid-connected systems without battery storage. In Lebanon there are few remote sites that are not connected to the grid, as electrification rate in Lebanon stands at 99.9% (IEA, 2009). However, given the blackouts, the adapted PV technology must combine aspects of the two classical applications so that buildings with microgenerators can mutually export (or import) electricity to the national grid when it is powered, and deliver electricity from the PV generator to the building in times of black-outs. The schematic of these microgenerators, catered for the Lebanese case, are detailed in Vallvé et al., (2012) and based on the UNDP-CEDRO project's design specifications for small scale PV microgenerators (UNDP-CEDRO, 2014). A brief summary of its operating parameters are specified below.

When grid power supply is present, the PV generation helps to reduce the consumption from the utility grid by supplying the secured load of the facility and charging the battery, as well as potentially back-feeding to the grid any surplus production. Battery charging from the grid is also enabled to allow for times with low solar irradiance (UNDP-CEDRO, 2014). During grid blackouts, power is taken from the DC side (PV generator and battery) to fill the gap and provide back-up electrical supply to the secured priority loads while non-secured loads remain disconnected until the grid is available again. The modes of operation are automatically triggered by the load management and plant supervision strategy and the state of charge of the battery, PV generation and the solar irradiance conditions of the day. The PV generator works independently of the grid supply (UNDP-CEDRO, 2014). Therefore, if there is sufficient solar radiation, the PV will charge the battery or maintain its floating voltage level. The dual-mode inverter, together with the battery's supervisory control, measure the battery voltage and the current to and from the grid and to the priority loads and give priority to consume energy from the PV generator (UNDP-CEDRO, 2014). In case of surplus PV generation, the surplus will satisfy other loads connected on the general feeders, if such a load is present, and if not, the surplus will be exported to the national grid with the 'net metering' arrangement currently in place in Lebanon. If the battery state of charge is abnormally low, the inverter that supplies the priority loads can also be used to charge the battery (UNDP-CEDRO, 2014).

When the national grid has a voltage sag, but it is above 165V AC (which is a common case experienced in some rural regions in Lebanon), the dual inverter is programmed to operate at such a low voltage and continue to charge or inject power (UNDP-CEDRO, 2014).

In times of grid blackouts, defined where grid power is completely absent or has a continuous voltage lower than 165V AC, the supply of the secured loads is done from the battery through the dual-mode inverter (UNDP-CEDRO, 2014). Once the national grid power returns, the plant can restart the interconnection to the grid through the transfer switch. The inverter measures the phase and synchronizes before resuming back-feeding or battery charging. The battery may need to be recharged either from the PV generator or from the grid side. Adequate charging requires a sequence with bulk charge, equalization and floating. The battery supervisory controller and data logger monitor the general conditions of PV availability and the PV battery charger controls the PV duty cycle (UNDP-CEDRO, 2014).

2. Methods

Financial appraisal "evaluates the costs and benefits of a technology, in this case, in terms of outlays and receipts accrued by a private entity (household, school, firm, etc.) as measured through market prices" (Hammond et al., 2012). Financial appraisal does not account for environmental externalities, or any costs or benefits that may occur beyond the private individuals and/or institutions that install PV systems, and does not regard the upstream costs of electricity (Hammond et al., 2010), herein embodied in the form of subsidies that the government pays for electricity delivered through the national grid, as mentioned in Section 1.2.

To perform a financial appraisal on PV microgenerators in the Lebanese context, key parameters must be calculated and assumptions adopted, namely, electricity power output, value of displaced electricity, capital costs, and maintenance and operation costs, inclusive of any taxes and/or rebates. Within a 'weak grid' context such as the electricity situation found in Lebanon, appropriately valuing these parameters are not straightforward and yet are instrumental in financial appraisal and subsequent policies that may be deemed necessary to support RETs.

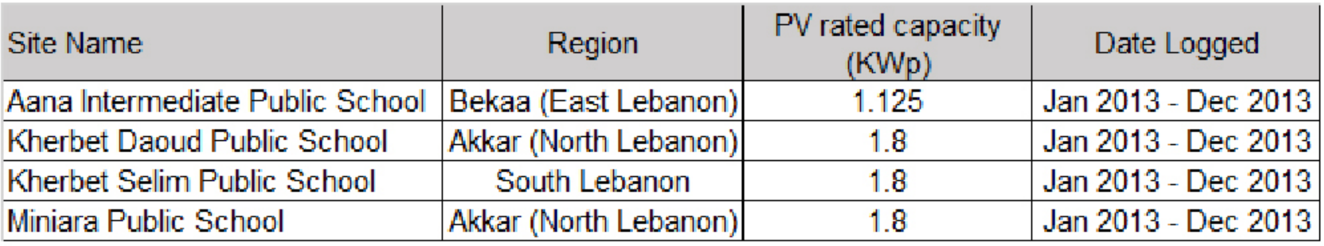
The research will build from these parameters to perform the financial appraisal and levelised cost of energy (LCOE) of the 1.8 kWp PV systems only , as installed by the UNDP-CEDRO project, and based on first-hand data logged from these sites.

3. Results

3.1 Energy output; impacts of blackouts on PV output

As described in Section 1, Lebanon's electricity grid can be considered 'weak' given its' loss-of-load probability of 100% (El-Fadel et al., 2010). Achieving 24 hour electricity by 2015 for the entire Lebanese territory, as indicated in the Energy Policy Paper (MEW, 2010), is, with high probability, subject to several years of delay, given the delay in implementing the required actions of the Policy Paper and given the Syrian refugee crises that has increased the population of Lebanon, and therefore electricity demand, by at least 26% (as of April 2015).

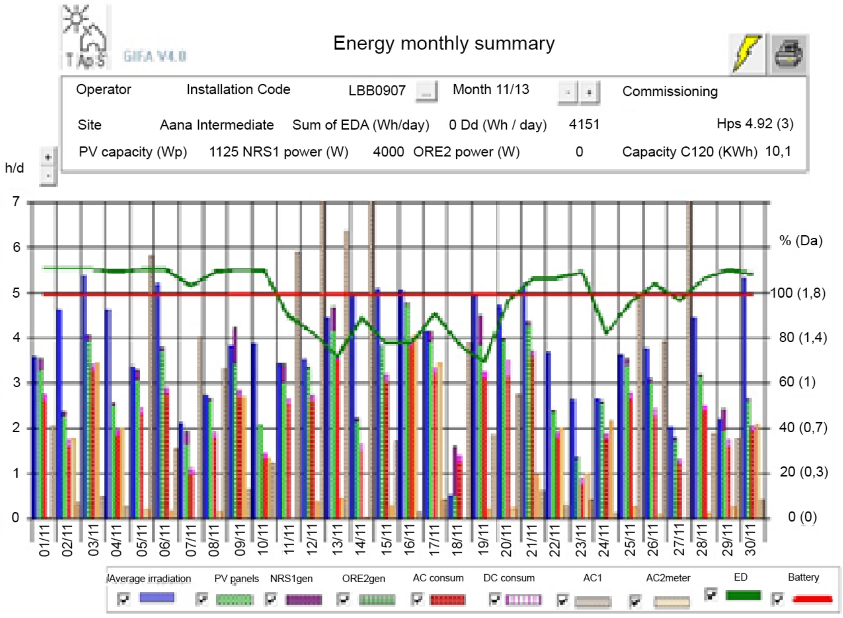
The PV energy performance and implications of blackouts on PV generation is shown through 1 year data from 4 separately logged PV sites implemented on public schools by the UNDP-CEDRO project, listed in Table 1. The UNDP-CEDRO's project mandated that only public sector facilities can be selected to benefit from renewable energy system installations, and in particular public schools across the country were targeted. This limitation is further discussed in Section 4.2.



Site Name	Region	PV rated capacity (KWp)	Date Logged
Aana Intermediate Public School	Bekaa (East Lebanon)	1.125	Jan 2013 - Dec 2013
Kherbet Daoud Public School	Akkar (North Lebanon)	1.8	Jan 2013 - Dec 2013
Kherbet Selim Public School	South Lebanon	1.8	Jan 2013 - Dec 2013
Miniara Public School	Akkar (North Lebanon)	1.8	Jan 2013 - Dec 2013

Table 1: The four analyzed UNDP-CEDRO solar PV sites

The energy management and data logger units control the operation of the PV system, through several sensors installed on site; solar irradiance sensor (reference PV cell), battery and ambient temperatures, DC current and voltage transducers, and AC meters. The logger also allows the checking of the battery voltage, the battery cycles, and the historical index of the days in the last month when the battery equalization has been completed. For the purpose of data analysis, the Gifa software, designed for processing, displaying and analyzing data sets, has been utilized. The software processes and calculates operations and creates a visual graphic permitting the visualization of the data on a daily, monthly and a yearly basis. A display from one logged UNDP-CEDRO site, Miniara Public School, is shown in Figure 2 for the month of November 2013 as an example of the visualized output, accompanied by the corresponding computed parameters that are separated and reassessed through Figures 4 - 9.



Energy monthly summary

Operator Installation Code LBB0907 Month 11/13 Commissioning

Site Aana Intermediate Sum of EDA (Wh/day) 0 Dd (Wh / day) 4151 Hps 4.92 (3)

PV capacity (Wp) 1125 NRS1 power (W) 4000 ORE2 power (W) 0 Capacity C120 (KWh) 10,1

- Average irradiation: average solar irradiance measured through the irradiance sensor installed at the PV generator's plane
- PV gen.: normalized PV generation
- NRS1 gen. (or EDL gen): normalized energy charged into the battery from the national grid
- AC consum.: normalized AC load consumptions
- DC consum.: normalized internal power consumption of the system
- AC1: normalized total energy received from the grid
- AC2 meter: normalized total energy delivered to the grid
- Battery: showing the "practical" state of charge of the battery
- DD: showing the depth of discharge of the battery

Figure 2. Miniara Public School PV system output parameters – November 2013

Monthly and average annual solar irradiance are shown in Figure 3. The values recorded by the installed pyranometers are consistently lower than those expected across the four sites, as measured through average values indicated by the Solar-Med-Atlas (www.solar-med.atlas). Two reasons can be attributed to this divergence. The first is that the measurement is done at the tilt angle of the PV panels themselves, which in the case of the schools are on a 45 degrees angle. This was done to maximize the available PV power in autumn and winter months, when the schools operate at full capacity, as opposed to the angle in Lebanon which achieves the most aggregate power output over the year. The second reason for this divergence could be attributed to local microclimatic conditions, such as moisture, and/or human-induced conditions, such as dust. This has precedence in the literature (for example, see Jardine et al., 2001). The implication of this divergence is that the calculations for PV power generation for the four sites, from a theoretical perspective, are tailored to the PV system installed for schools and can be considered conservative when generalizing for PV systems on a country-level and for various other sectors. In some limited daily recorded data in the four sites, for example, the performance ratio, or the AC power energy generated from the PV system divided by the theoretical AC power supply (see Table 2), was over 100%, which is not possible and can be possibly explained by underestimated irradiance readings. The calculation of the power yield of the PV systems take into account the irradiation tilt angle losses, however not the irradiation measurements due to local microclimatic conditions, which effectively impact the PV modules as well.

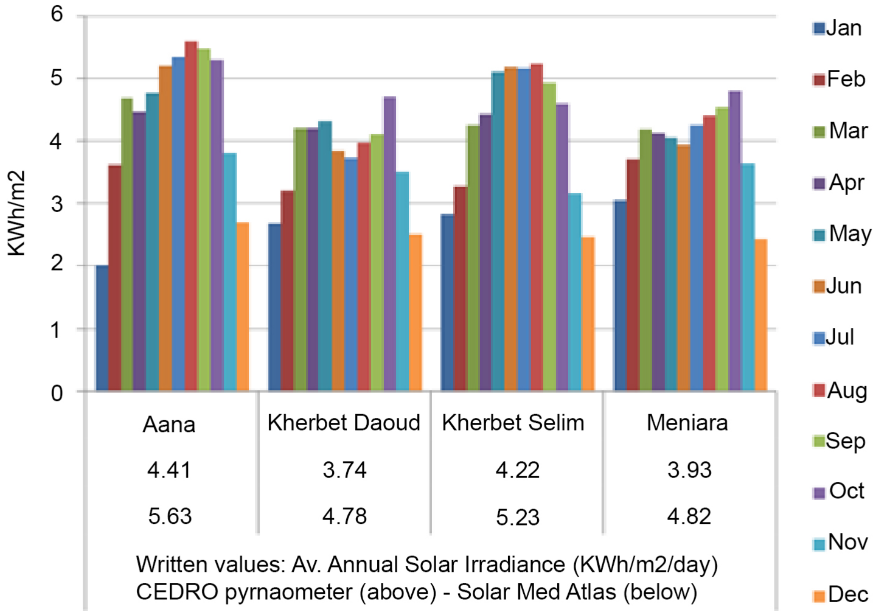


Figure 3. Monthly and yearly average solar irradiance measurements for four sites across Lebanon (2013)

The Nominal Yield “YN”, which refers to annual yield without any losses, is calculated according to Equation 1.

Equation 1. $YN\ (\text{KWh}) = \text{PV Active Area} * \text{Yearly Irradiance} * \text{PV Conversion Efficiency}$

The PV active area is calculated using the dimensions of the installed PV modules “Suntech 75Wp”, and accounting for 15 panels for the 1125Wp system and 24 panels for the 1800Wp systems. The yearly irradiance is measured on site for the different system locations (Figure 4), and the PV conversion efficiency is as set in the Suntech 75Wp datasheet (indicated as approximately 13.1%). Table 2 indicates the nominal yields in row 5.

For the losses, the module tolerance and inverter losses are as defined in the datasheets for the Suntech 75Wp module and the installed Studer Xtender 4000/48 inverter, respectively. Whereas the PV losses due to irradiance level is calculated using the PVGIS software for the optimum angle and azimuth, then compared to the implemented ones that have been designed to generate relatively more power in the winter time (to coincide with the schools’ schedules). The PV losses due to temperature are calculated through Equation 2 and shown for monthly values in Figure 4, showing that summer months are responsible for relatively more module losses.

Equation 2. $\text{Percentage loss due to temperature} = TC * (T\ \text{yearly average} + 2)$ *(Renac, 2014)*

T yearly average stands for the yearly average temperature which is measured on site for the different systems’ locations.

Finally, the losses from the system’s own consumption are calculated using the measured system’s own consumption compared to the total system’s generation.

The Theoretical Yield (YT) is calculated through the equation hereafter:

Equation 3; (Ayompe et al., 2011)

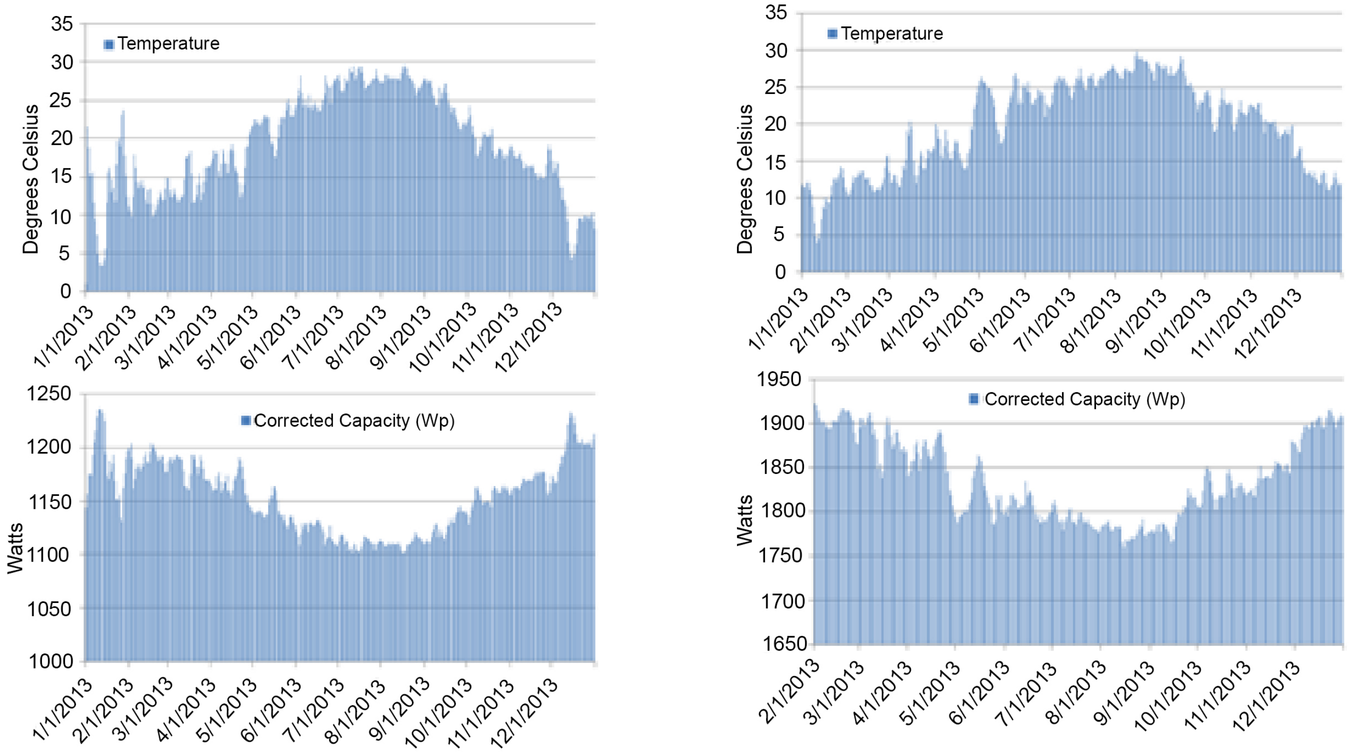
$$YT = \text{PR initial} * \text{Nominal Yield}$$

$$\begin{aligned}\text{PR initial} &= \eta\ \text{irradiance level} * \eta\ \text{temperature} * \eta\ \text{module tolerance} * \eta\ \text{inverter} * \eta\ \text{system consumption} \\ &= (1-\text{Loss irradiance level}) * (1-\text{Loss temperature}) * (1-\text{Loss module tolerance}) * (1-\text{Loss inverter}) \\ &\quad * (1-\text{Loss system consumption})\end{aligned}$$

The measured annual Yield (YM) is the one measured on site for the different systems.
The final PR (PRfinal) is calculated through: $PRfinal = YM/YN$ to assess the performance of the PV systems in Lebanon accounting for the grid availability losses.

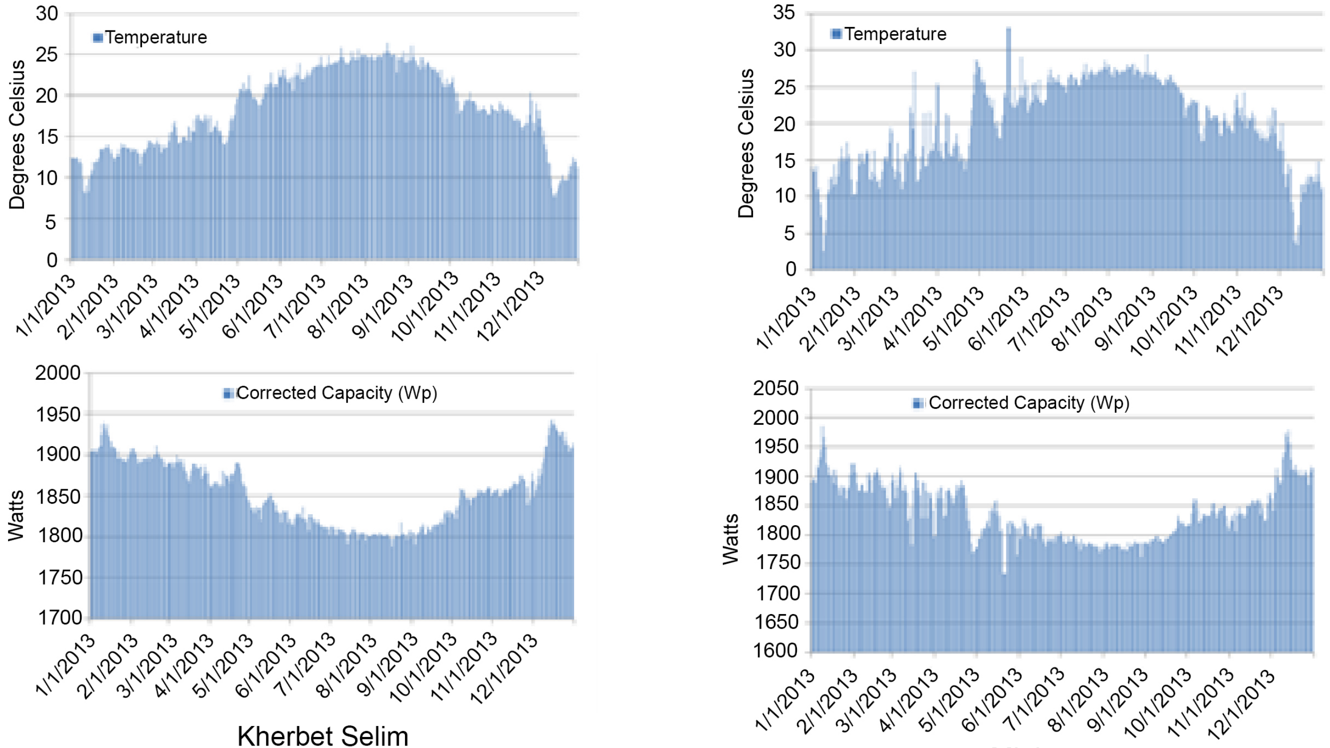
Figures 5-8 show the results of PV power generated in 2013 for the four sites, per month, respectively, revealing the theoretical generation versus the actual logged energy performances.

The best performance ratios were slightly above 50% for Aana and Miniara Public Schools. The impact of the presence of blackouts, which forbids the export of solar power, is particularly acute in the schooling sector. The reason being that, as can be seen in Figures 5-8, the summer months that are endowed with the most solar irradiance (and therefore most expected PV generation) also coincide with limited educational activity, where often only the administration is present and working for half the day. Power is thus curtailed in the absence of the grid.



Aana

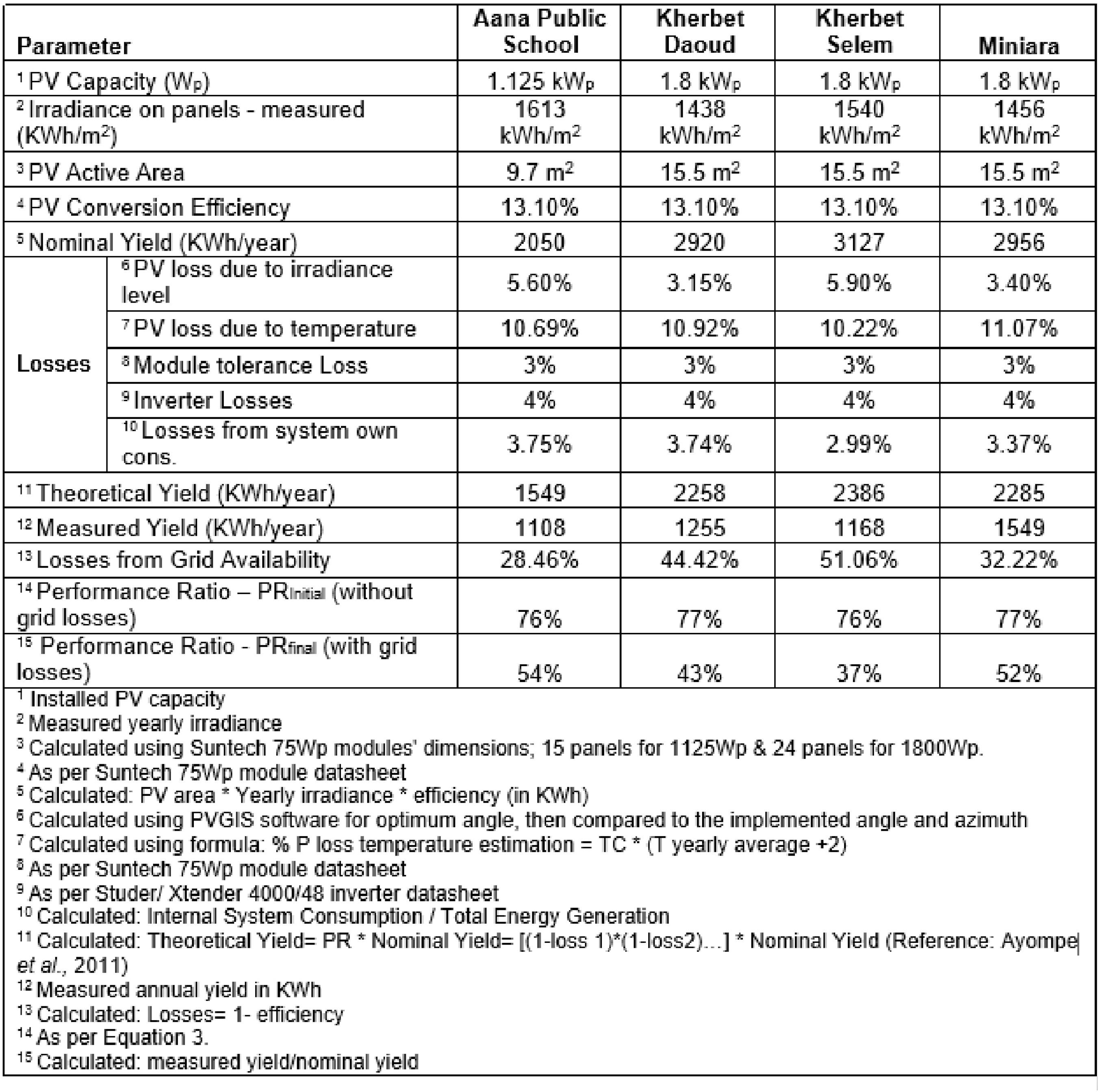
Kherbet Daoud



Kherbet Selim

Miniara

Figure 4: Power losses attributed to temperature divergence from STC for all systems



Parameter		**Aana Public School**	**Kherbet Daoud**	**Kherbet Selem**	**Miniara**
[1] PV Capacity (W_p)		1.125 kW_p	1.8 kW_p	1.8 kW_p	1.8 kW_p
[2] Irradiance on panels - measured (KWh/m^2)		1613 kWh/m^2	1438 kWh/m^2	1540 kWh/m^2	1456 kWh/m^2
[3] PV Active Area		9.7 m^2	15.5 m^2	15.5 m^2	15.5 m^2
[4] PV Conversion Efficiency		13.10%	13.10%	13.10%	13.10%
[5] Nominal Yield (KWh/year)		2050	2920	3127	2956
Losses	[6] PV loss due to irradiance level	5.60%	3.15%	5.90%	3.40%
	[7] PV loss due to temperature	10.69%	10.92%	10.22%	11.07%
	[8] Module tolerance Loss	3%	3%	3%	3%
	[9] Inverter Losses	4%	4%	4%	4%
	[10] Losses from system own cons.	3.75%	3.74%	2.99%	3.37%
[11] Theoretical Yield (KWh/year)		1549	2258	2386	2285
[12] Measured Yield (KWh/year)		1108	1255	1168	1549
[13] Losses from Grid Availability		28.46%	44.42%	51.06%	32.22%
[14] Performance Ratio – $PR_{Initial}$ (without grid losses)		76%	77%	76%	77%
[15] Performance Ratio - PR_{final} (with grid losses)		54%	43%	37%	52%

[1] Installed PV capacity
[2] Measured yearly irradiance
[3] Calculated using Suntech 75Wp modules' dimensions; 15 panels for 1125Wp & 24 panels for 1800Wp.
[4] As per Suntech 75Wp module datasheet
[5] Calculated: PV area * Yearly irradiance * efficiency (in KWh)
[6] Calculated using PVGIS software for optimum angle, then compared to the implemented angle and azimuth
[7] Calculated using formula: % P loss temperature estimation = TC * (T yearly average +2)
[8] As per Suntech 75Wp module datasheet
[9] As per Studer/ Xtender 4000/48 inverter datasheet
[10] Calculated: Internal System Consumption / Total Energy Generation
[11] Calculated: Theoretical Yield= PR * Nominal Yield= [(1-loss 1)*(1-loss2)…] * Nominal Yield (Reference: Ayompe *et al.*, 2011)
[12] Measured annual yield in KWh
[13] Calculated: Losses= 1- efficiency
[14] As per Equation 3.
[15] Calculated: measured yield/nominal yield

Table 2. Nominal vs. calculated yield of the 4 PV systems; the performance ratios

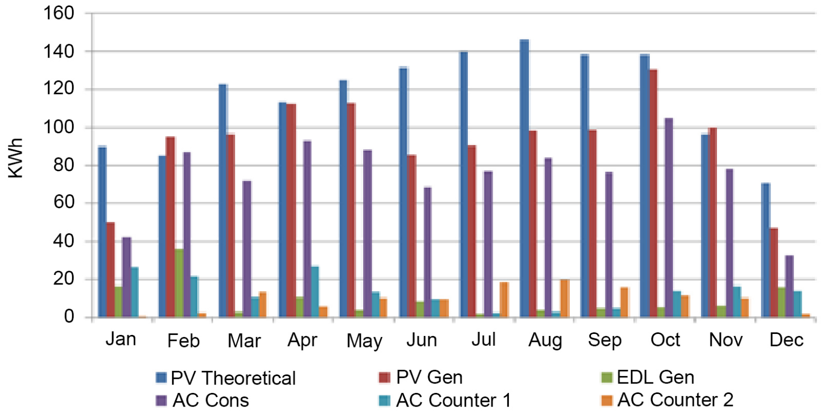


Figure 5. Aana Intermediate Public School 1.125 kWp PV system

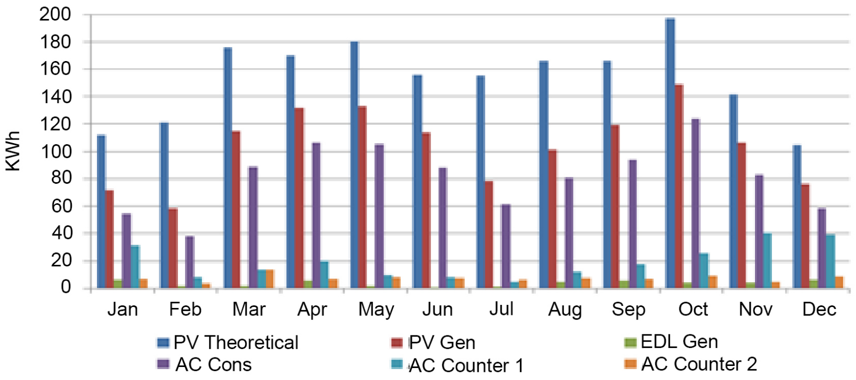


Figure 6. Kherbet Daoud Public School 1.8 kWp PV system

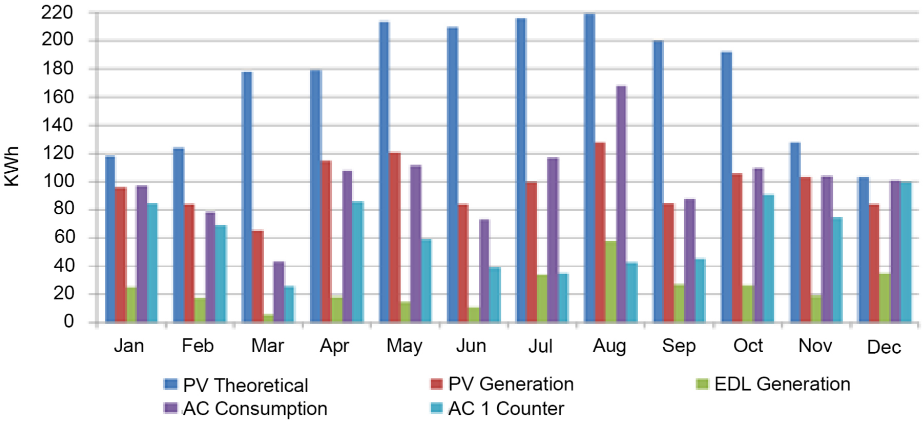


Figure 7. Kherbet Selim Public School 1.8 kWp PV system

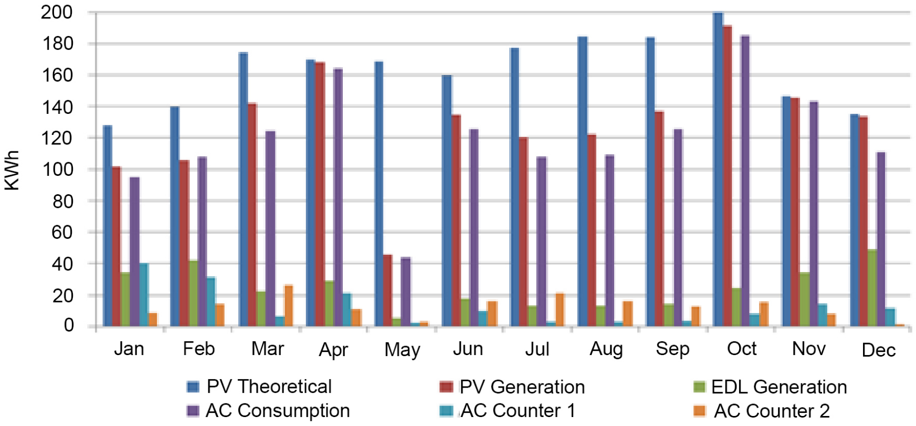


Figure 8. Miniara Public School 1.8 kWp PV system

3.2 Capital and maintenance costs

Capital costs of systems may vary depending on specifications, types, and suppliers. The UNDP-CEDRO project implemented several bidding processes, particularly for PV systems within the configuration outlined in Section 1.3, over the course of six years, which has led, together with the sharp decline of international prices of PV panels, to a reduction of price for the standard 1.8 kWp PV system, as shown in Figure 9.

The supply and installation costs of a 1.8 kWp PV system was approximately $9800 by 2014 (inclusive of 10% value added tax, and 5% customs duty on products), however this price is also inclusive of a data logger. Excluding the data-logger, the costs of the fully installed 1.8 kWp PV system is approximately $9,370. The total costs of the 1.8 kWp PV system in Lebanon has dropped more than 60% since 2009.

The higher initial prices of 2009 are attributed to the then lack of a local robust market in Lebanon for renewable energy technology as well as the higher prices of PV modules. The relatively limited opportunities in a start-up market for renewables in Lebanon in 2009 meant that contractors did not have extensive experience in installation and did not have, nor was there an incentive to have, the microgenerators' components, from panels to all the other respective balance of system parts, in stock, increasing thereby the unit costs as most components are imported in limited quantities. In the early phases of the CEDRO project (2009-2010), contractors took approximately 5-7 working days to install the PV systems, whereas the latest installations (after 2011) took the winning contractors less than 2 days. In this respect, the absence or presence of a market for such systems have large implications on price. Consecutive bidding rounds, as done by the UNDP-CEDRO project, assist in establishing the market and ready it for more commercial-oriented support, such as feed-in tariffs (see Section 4.1), as expressed in the S-curve (Hammond et al., 2012). A discussion of the implications of 'local' versus 'global' learning effects on RETs' costs can be found in, for example, Huenteler et al., 2014, validating the larger significance of 'local' learning on costs.

It is important to highlight that capital cost differences for PV systems between nations are not uncommon and can be quite marked. Table 3 shows this divergence and attributes it to 'soft costs' that includes, among other parameters, customer acquisition, inspection and interconnection, installation labor, and financing costs (IEA, 2014).

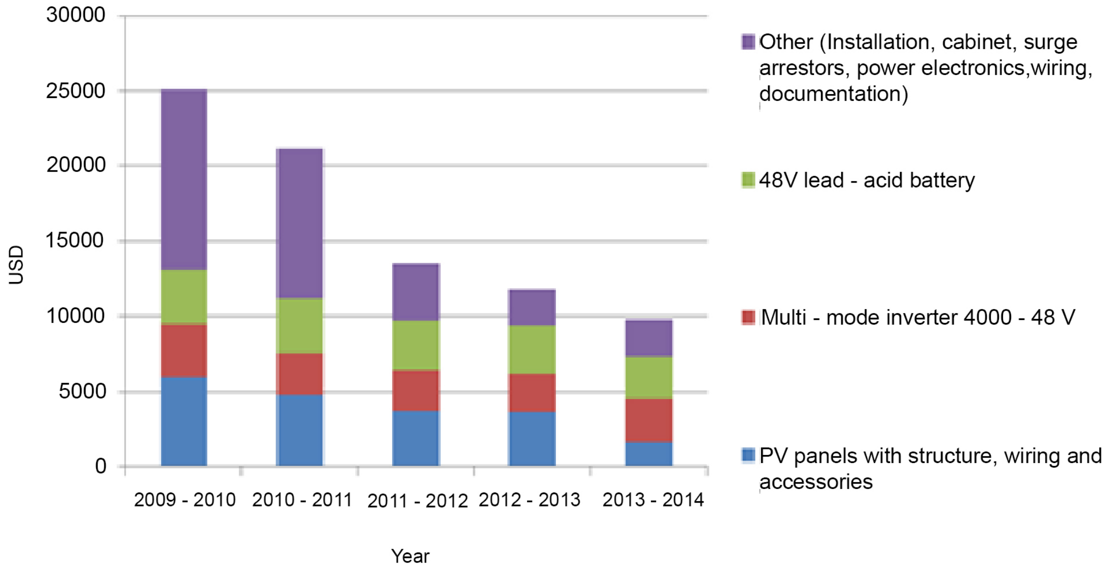


Figure 9. Investment cost evolution of 1.8 kWp PV back up plants developed by the UNDP-CEDRO project

	Australia	China	France	Germany	Italy	Japan	UK	USA
Residential PV Systems (USD/W)	1.8	1.5	4.1	2.4	2.8	4.2	2.8	4.9

Table 3. Typical 2013 PV system prices across select countries (without batteries) (IEA, 2014)

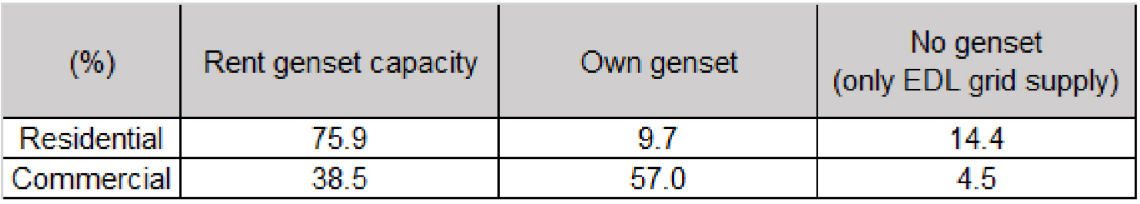
Maintenance costs are more difficult to ascertain because they are subject to future circumstances and scenarios. The bulk of the maintenance costs involve the replacement of the battery (should one be similarly required) and the inverter, currently costing approximately $3000 each (imported and installed), sometime over the 20 year assumed lifetime of the PV. The installed lead-acid battery is designed and expected to last a maximum of 8 years, subject to proper care and maintenance, while the inverter can be expected to be changed once over the PV system's lifetime from 10 to 15 years of operation. Maintenance costs are thereby impacted by future changes in the Lebanese electricity situation, where 24 hour delivery of power from the national grid, which is assumed to occur at the latest by year 2022 (see Section 3.4), will displace the need for battery replacement and will entail a grid-connected inverter, a cheaper option than a dual-mode inverter. At year 13, a grid-tied inverter is assumed to cost approximately $1,300 (as per expectation of growth and cost reduction of grid-tied inverters – Hammond et al., 2012).

3.3 Financial benefits

Financial benefits are in the form of displaced electricity consumption from the grid (and/or exported), as well as displaced electricity consumption from the diesel genset. The Ministry of Energy and Water sets the upper limit for prices charged by privately run generators. The latest (April 2015) prices were set at $c17 for every hour blackout for a 5 Ampere subscription and $c34 for every hour blackout for 10 Ampere subscriptions, in addition to $c17/kWh electricity consumption (MEW, 2015). Expected increases in electricity tariffs, as prescribed by the MEW Policy Paper, are marked to become $c13.75/kWh by 2015, although this issue could be subject to several years of delay given the delay of actions prescribed by the Energy Policy Paper.

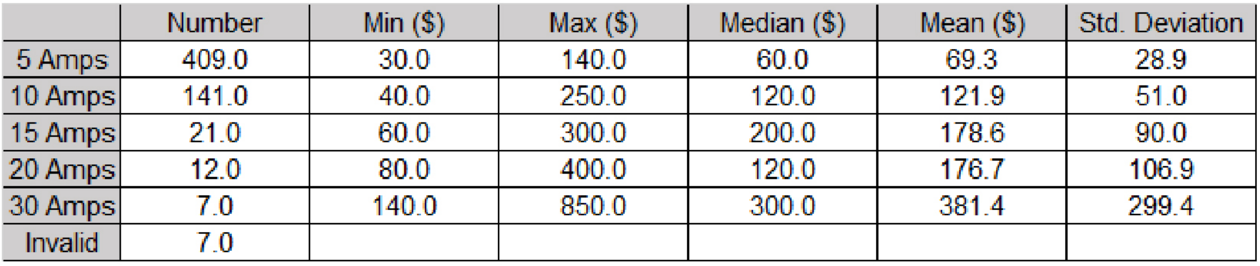
The problem with setting gensets' power tariffs by the Ministry of Energy and Water is that genset power is charged , mostly, by power capacity and not per unit energy consumed (i.e., a charge per 10, 20, 30… amperes as opposed to a charge per kWh of consumption), or is owned (i.e., generator purchased by facility or household). Table 4 shows the percentage distribution of these categories through a representative survey questionnaire of 600 samples for the residential sector and 200 samples for the commercial sector undertaken by CEDRO in 2013.

On the ground, the subscription paid to rent genset power is done for capacity, and this subscription fee ranges depending on the genset power providers' area and discretion, as detailed in Table 5.



(%)	Rent genset capacity	Own genset	No genset (only EDL grid supply)
Residential	75.9	9.7	14.4
Commercial	38.5	57.0	4.5

Table 4. Sample distribution of action to counter blackouts in Lebanon's residential and commercial sectors



	Number	Min ($)	Max ($)	Median ($)	Mean ($)	Std. Deviation
5 Amps	409.0	30.0	140.0	60.0	69.3	28.9
10 Amps	141.0	40.0	250.0	120.0	121.9	51.0
15 Amps	21.0	60.0	300.0	200.0	178.6	90.0
20 Amps	12.0	80.0	400.0	120.0	176.7	106.9
30 Amps	7.0	140.0	850.0	300.0	381.4	299.4
Invalid	7.0					

Table 5. Statistics on monthly rent payments for diesel gensets capacity in 2013

The difficulty in assessing the generalized financial benefits of the solar PV is due to its site-specificity, given that each site's load and blackout hours schedule and magnitude defines the ability of the PV system to displace the diesel genset capacity and, importantly, dictates how much electricity power from the grid is reduced, if any. Typically, black-out hours in Lebanon follow certain on-off patterns; in some regions the patterns constitutes of 3 hours of electricity supply versus 3 hours of electricity black-out (recurrent once or twice a day), other regions have 4 hours and still other regions have 6 hours of on-off grid electricity. The battery storage of the 1.8 kWp PV system is of 13.44 kWh capacity as per the system's design. The depth of discharge is specified at 75%. Thus, if the battery is at a 100% state of charge, the maximum capacity that can be used on site is reduced to 10.08 kWh. The operating voltage is 220V AC. Taking into account the above mentioned three black-out patterns, and using the direct power formula, the current capacity of the secured loads at full charge for 3 hours black-out is at 15.2 Amps, for 4 hours it stands at 11.45 Amps, and for 6 hours it is 7.6 Amps. Therefore in the best case scenario, the PV system will displace 15 Amperes while in the worst case it would displace 5 Amperes capacity (given that genset ampere capacity is rented in blocks of 5 amps). Therefore, 10 amperes of displaced genset capacity is the average value to be adopted, non-withstanding the fact that in some situations and/or under certain conditions 5 or 15 Amperes would be displaced.

With respect to reducing the electricity imports from the utility, experience with the implemented UNDP-CEDRO sites has given mixed results. Some sites identified that they have reduced their utility bill, while other sites have indicated a slight increase in their bill, the latter due to the charging of the batteries from the grid. Therefore a generalized assumption would be that the PV system would only displace the 10 Amperes diesel generator capacity and will not impact the intake of utility electricity until 24 hour electricity is provided by the utility (see next Section).

3.4 Adopted scenarios

To undergo a financial appraisal of the 1.8 kWp PV system, different scenarios need to be adopted to take into account current and expected future situations and schedules in line with the expected lifetime of the PV system. The scenarios are based on the latest actions and prospects on the energy sector in Lebanon.

Two scenarios are set to best reflect possible future possibilities in the electricity sector, as shown in Figure 10. The first scenario, S1, assumes that EDL tariffs remain constant at $c9.8/kWh until the end of 2017, built on the assumption held by some policy makers that no tariff increase can take place without first providing 24 hour electricity and eliminating the need for local diesel gensets. S1 assumes the provision of 24 hour electricity at the beginning of 2018 (eliminating therefore Gensets), a possible outcome if the government puts the Energy Policy recommendations back on fast-track, and therefore average electricity tariffs are immediately increased to $c13.75/kWh, as per the Policy Paper recommendations. From 2018 and up to the end of 2034, electricity prices increase according to either a ‘High Oil Price Case’ or a ‘Low Oil Price Case’. The former assumes a 2.1% increase in primary energy consumption for the Middle East, while the latter assumes a 1.4% increase (EIA, 2013), and these increases are assumed to translate into analogous electricity price increases.

The second scenario, S2, adopts a more pessimistic view of the reliability of the electricity system of Lebanon, assuming that 24 hour electricity will only be delivered by the end of 2021. Tariffs are adjusted to $c13.75/kWh in 2022, when gensets are eliminated. As in S1, electricity prices increase according to the ‘High Oil Price Case’ or a ‘Low Oil Price Case’, yet assumed post 2022.

Once 24 hour electricity is delivered in both respective scenarios, S1 and S2, the theoretical annual PV generation (see ‘theoretical yields’ in Table 2) would be taken into account as opposed to the actual power output as measured in Section 3.1 for the three 1.8 kWp sites.

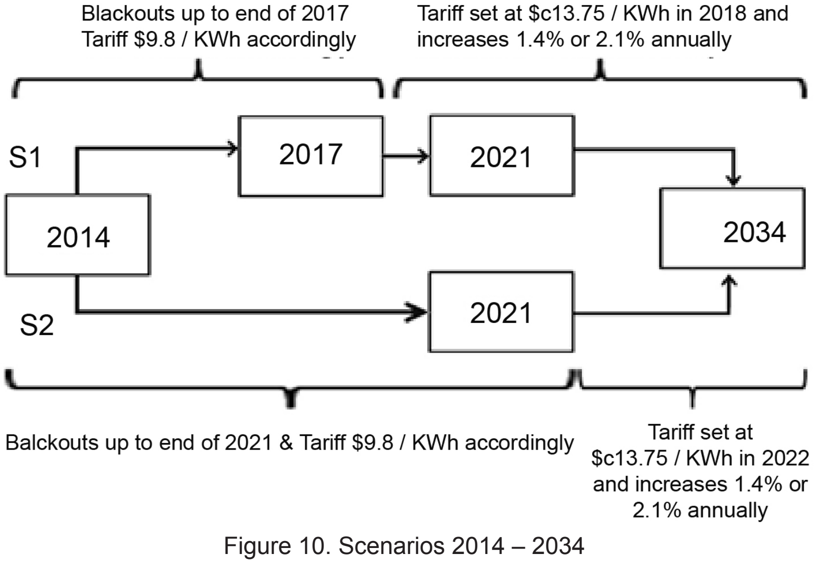


Figure 10. Scenarios 2014 – 2034

3.5 Existing Financial Mechanism for renewable energy support in Lebanon

The financial appraisal adopts a private individual or institution perspective, and therefore available financial mechanisms for renewable support in Lebanon have to be taken into account. Currently (as of end of 2014), a mechanism known as NEEREA (National Energy Efficiency and Renewable Energy Action) can be tapped into. NEEREA is a national financing mechanism initiated by the Central Bank of Lebanon in collaboration with the Ministry of Energy and Water, the Ministry of Finance, the United Nations Development Program (UNDP), the European Union (EU), and the Lebanese Center for Energy Conservation (LCEC). NEEREA allows private sector entities (individuals, small and medium sized enterprises, or corporate bodies) to apply for subsidized loans for any type of energy efficiency or renewable energy projects. NEEREA covers loans by any Lebanese commercial bank with a 0.6% interest rate and a repayment period of up to 14 years, in addition to the possibility of a 15% grant amount released after the project is implemented (Khoury, 2013). Effectively, for the purpose of the 1.8 kWp PV system, this mechanism reduces the discount rate used in the analysis to 0.6% and offers the possibility of a grant for the amount of $1405 to be deducted from the capital costs of $9370, as identified in Section 3.2.

3.6 Financial appraisal; net present value and payback period

A financial appraisal is undertaken for the standard 1.8 kWp PV system, adopting the two scenarios (S1 and S2) indicated above and their respective parameters on diesel genset rent, the expected year that 24 hour electricity will be delivered by the utility, and annual production of PV power (actual and theoretical). The assumptions on electricity price increase had negligible impact on overall financial appraisal results and therefore the average of the electricity tariff level increases' was adopted.

Results are shown in Figure 11 for the three 1.8 kWp sites, assuming a 5% and 10% discount rate. The discount rates selected are in line with those used by the IEA for costing renewable energy sources (IEA, 2010). With the NEEREA scheme, the discount rate assumed is 0.6%.

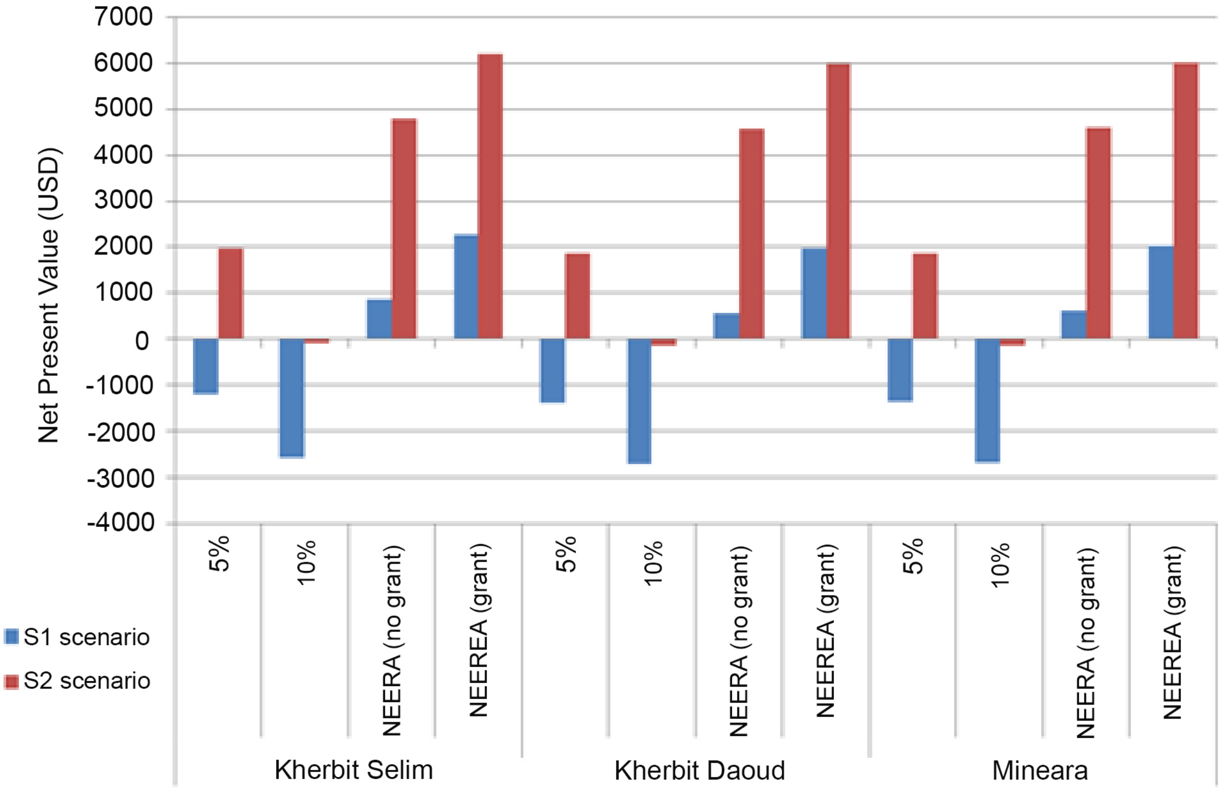


Figure 11. Net present value for the 3 selected 1.8 kWp PV sites under two scenarios (with and without NEEREA support mechanism)

Figure 11 shows that, paradoxically, the presence of diesel gensets, prevalent in Scenario 2 up to the end of 2021 (as opposed to the end of 2017 as per Scenario 1), presents an opportunity for PV systems in Lebanon, as the PV systems' displacement of genset capacity provides significant financial savings to the customer. Moreover, the NEEREA mechanism nulls, to a considerable extent, the impacts of discount rates, and when coupled with NEEREA's grant component, presents a significant positive return on investment. This can be further highlighted in the discounted payback period, shown in Figure 12.

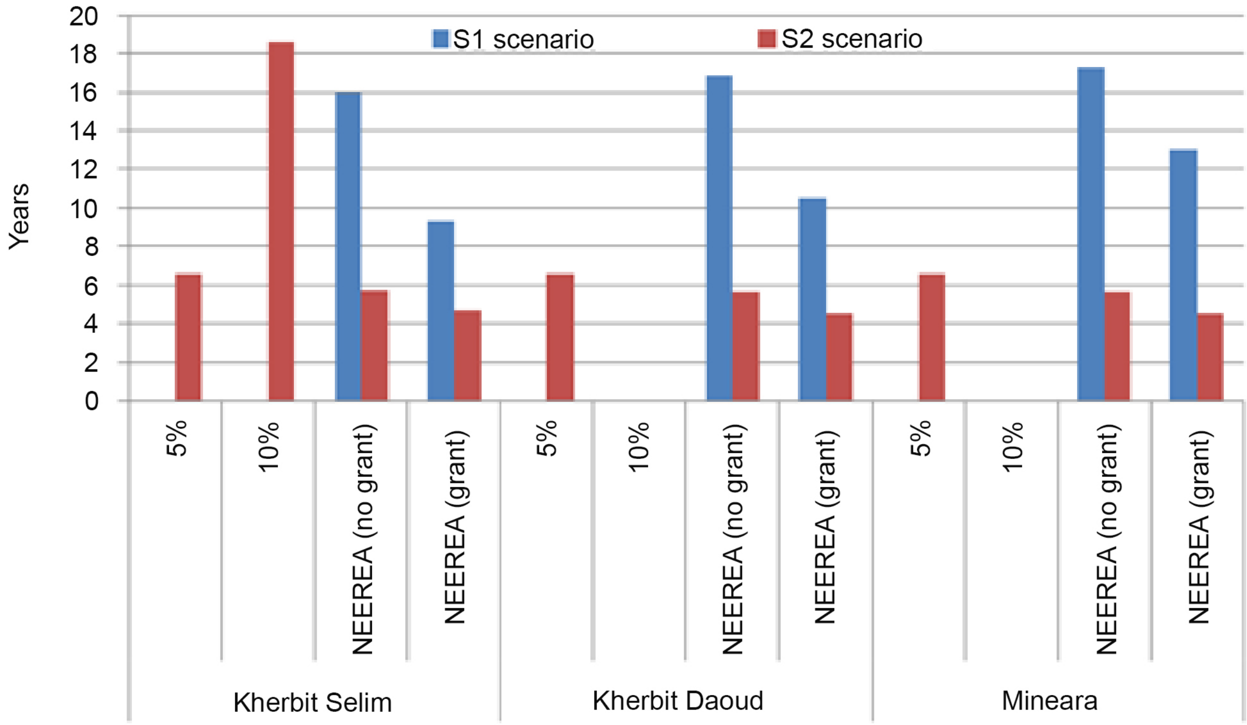


Figure 12. Payback period for the 3 selected 1.8 kWp PV sites under two scenarios (with and without NEEREA support mechanism)

The bars in Figure 12 appear only when the payback period is within the assumed 20 year lifetime of the PV system. Utilizing the 10% discount rate renders the PV system's payback period beyond its' assumed lifetime for both Scenarios (with the exception of Kherbit Selim where the payback period just under 19 years), therefore the system will never return its investment. In agreement with Figure 11, the PV systems would similarly not payback if 24 hour electricity supply from the grid is achieved by the end of 2017 (therefore Scenario 1 is absent from Figure 12 unless the NEEREA grant scheme is introduced, and favorably with the grant component). If Scenario 2 is realized, the payback period can reach 6.5 years without the NEEREA mechanism and approximately 4.5 years with the NEEREA grant scheme.

It is important to note that VAT and customs make up, approximately, 15% of the project costs, and therefore, the NEEREA grant scheme yields almost similar results to if the VAT and custom duties are removed for renewable energy systems and installations. A more favorable scenario would be to couple the removal of all taxes on renewable energy systems coupled with the NEEREA grants.

3.7 Sensitivity analysis; reduced genset rent values

As mentioned earlier, oil prices have dramatically fallen by the end of 2014 to approximately half the levels they were at in 2013-2014. Although this reduction has yet to take full effect in the local Lebanese market, a sensitivity analysis where genset rent values for the 10 Ampere subscriptions are halved is shown in Figure 13.

Figure 13 shows the significant impact on the financial performance of the PV systems if the genset values fall in line with, and to the extent of, the fall in international oil prices. The implication of this price drop could be drastic for the nascent decentralized renewable energy market in Lebanon, and may require increased and wider financial support to keep the market growth maintained.

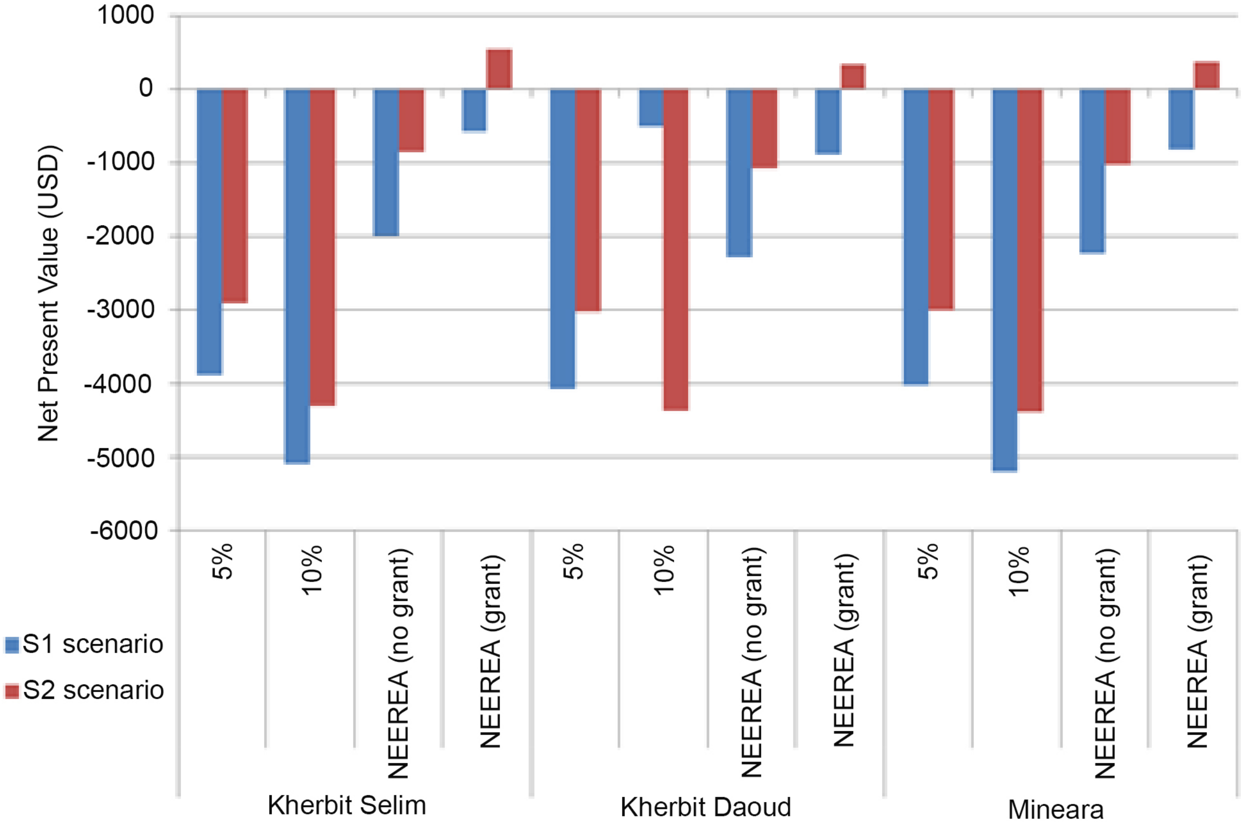


Figure 13. Net present value for the 3 selected 1.8 kWp PV sites under two scenarios (with and without NEEREA support mechanism) with halved genset rent values

4. Discussion

4.1 Financial appraisal's implication on Feed-in tariffs: can the shoe fit?

A feed-in tariff (FiT) refers to an explicit monetary reward for producing electricity using renewable energy technologies at a rate per kWh (Ayompe & Duffy, 2013). The FiT scheme allows electricity producers to obtain a fixed price for RE electricity for a determined period of time or, alternatively, the FiT can be paid in the form of an additional premium on top of the electricity market price (Klein, 2008). Del Rio (2012), Mendonca et al. (2010), Klein (2008), Poyry & Element Energy (2009), and Sovacool & Gilbert (2013) provide comprehensive assessments and reviews with the advantages and disadvantages of various FiT features and design. These studies focus on major design parameter choices, such as; eligible technologies and their maximum capacity, the choice of fixed tariff or premium tariff; the choice of stepped tariff or flat tariff; the choice of tariff setting and adjustment mechanisms; appropriate length and term of policy (time frame of support), cost-containment mechanisms (for example whether or not to impose a capacity cap), purchase and forecast obligation of renewable energy systems, and how to fund the FiT support.

FiT are performance based instruments, i.e., they are implemented to incentivize the production of power (Moner-Girona & Szabo, 2012). In Lebanon however, as the case of the four sites assessed in this paper, the actual measured PV systems' power outputs and their respective performance ratios, as indicated in Table 2, have shown the dramatic loss of power due to grid availability. The dual-mode PV system architecture, the presence of batteries and gensets, and the presence of blackout hours make the introduction of feed-in tariffs in Lebanon, as applied in various European Union countries, for example, problematic, unless a wide ranging and more in-depth assessment is carried out across the country in Lebanon. This assessment will have to test or model for various RETs, including solar PV, including a representative sample of their various respective sizes, in various sectors and sub-sectors (residential, commercial, and industrial), and areas or regions of the country (that are impacted differently by the current blackouts in the electricity sector).

Taking the three 1.8 kWp systems as a case in point, the 3 separately measured power outputs varied due, mainly, to the losses from grid availability. Setting feed-in tariff remuneration that is uniform, even across the same type, size and cost of technology, cannot thus translate into certainty of cash flows for investors, even with the presence of programs that assist in the mitigation of risks, such as the GET FiT program (DBCCA 2010), or other globally managed or supported FiTs (see, for example, Huentler 2014 and UNEP (2012) for a discussion on globally managed and/or supported FiTs and other international funding options).

Until the problem of blackouts in Lebanon is resolved, net metering has been introduced in 2011, prior to which the parallel connection of microgenerators to the national grid was not foreseen in the regulation. The adopted net metering text in Lebanon allows the rollover of exported electricity within billing months of any one year yet nulls any exports after the 1 year term and thus provides no financial reward for the excess electricity. This is not the best net metering arrangement (Doris et al., 2009), yet could be an important start. Net metering suffers from the same problem given the lack of grid availability. However the introduction of net metering in Lebanon was important in order to begin to change the existing paradigm of the 'passive' electricity system where one-way flow of power is the norm and given that net metering provides a simple, low cost, and easily administered way to deal with PV systems (and other microgenerators) (Poullikkas, 2013).

4.2 Limitations

The limitations of this study are several. The first limitation is that the study focuses only on one type of institution, public schools, under one sized solar PV system. Given that schooling activity is the least in summer when solar irradiance is at its highest, coupled with poor grid availability, has severely limited the benefits of the PV systems. The load profiles of other institutions and/or households, and for various other locations in Lebanon that experience a lower number of blackouts (e.g. administrative Beirut) can be drastically different, particularly in terms of increased on-site consumption from the RET that will minimize the impacts of grid availability. Furthermore, the analysis of this paper does not cater for larger institutions that require larger RETs that synchronize with the national grid, when electricity is present, and the diesel genset, when there are blackouts, in the absence of battery storage. This architecture is the focus of the new phase of the UNDP-CEDRO project, funded by the European Union, in 2015.

A second limitation is the selection of only one-year data measurements. Acquiring a complete set of data in Lebanon has been problematic due to many reasons such as sensor failures and institutional or behavioral shortcomings, for example in the form of turning off the systems completely for days on end when the school is not being used. Therefore the selection of sites was more due to data availability then representation of various institutions or climatic zones. The 1 year measurement also does not take into account inter-annual solar variability, although for such small solar systems this impact can be rather small.

A third and final limitation is that the assessments of the solar PV systems are purely from a financial perspective and not from an economy-wide perspective. An economy-wide perspective relates to the marginal and average cost of electricity generation that the national utility pays on power through direct tariffs on consumers together with nationally transferred subsidies to the sector, the lifecycle environmental benefits of increased renewable energy integration (including any environmental costs related to disposal at the end of life), and the diversity to the energy sector that RE power provides. These issues were partly discussed in El-Fadel et al. (2010), are recently partially addressed in Kabakian et al. (2015), and are the subject of future research.

5. Conclusion and policy implications

The characteristics of the 'weak' Lebanese electricity sector offer both barriers and opportunities for renewable energy integration. Barriers are in the form of the low final performance ratios of the solar PV systems. Opportunities come from the financial saving due to diesel genset displacement that RETs can provide. The NEEREA program may prove to be sufficient in terms of support for renewables, evident by the positive net present value and attractive payback period that can be achieved only under the NEEREA, and particularly when coupled with NEEREA's grant component that should be encouraged and increased in light of the new reality of reduced oil prices.

Therefore, given the complexity of setting the correct support tariffs required for the Lebanese context, the existing investment subsidies and soft loans of the NEEREA mechanism could be regarded as the only viable option at present to further strengthen and support RET, particularly in light of the recent drop in oil prices, until 24 hour electricity is secured.

The PV systems installed by the UNDP-CEDRO project were among the first microgenerators designed to cater, technically, to the Lebanese electricity grid. The next phase of the CEDRO program is targeted towards larger commercial and industrial PV applications, where battery storage becomes prohibitively expensive, replaced by a design to synchronize the PV systems to the existing diesel gensets when power from the utility is off, and to the national grid when power is on. In this circumstance, feed-in tariff design cannot be, similarly, conventionally set. This complex reality calls for the establishment of a Regulatory Authority that can dynamically, under adequate funding and skilled human resources, better set the targets for renewable energy in terms of types and scale within similar types, set the required support mechanisms to achieve identified RET targets within the existing reliability of the grid, and monitor the results for effective policy feedback.

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