Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 6 (2020) 420–429
www.elsevier.com/locate/egyr

Tmrees, EURACA, 13 to 16 April 2020, Athens, Greece

Lebanon's electricity from fuel to solar energy production

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Received 31 August 2020; accepted 31 August 2020

Abstract

Since 1924, Lebanon planned to use renewable energy and in particular hydraulic energy to produce the national need of electricity. Until the beginning of the 70, many steps have been achieved by the government where in 1974 around 41.5% of the Lebanese electricity was produced from hydroelectric stations. Unfortunately since then and due to the instability in the political regimen, electric plants and networks suffered from destruction, aging, increased demand, hacking and many other deterioration factors. Therefore and based on all the last mentioned troubles the electric sector in Lebanon transformed to be the major economic and environmental problem.

This paper aims at presenting and analyzing the actual state of the electric sector in Lebanon emphasizing on its impact on air pollution and on the development of factories and small enterprises. Therefore, it will be shown that the problem with the electrical sector is essentially due to the old networks easily hacked, strong reliance on fuel-based electricity, which leads to increased air pollution without meeting the energy consumption demand. This underproduction of electrical energy leads to the development of a parallel electrical private sector also based on fuel burning what worsened air pollution problems despite all the measures taken by the governments to switch to greener electricity production.

A case study on electricity consumption in different locations in Beirut is also presented and used to prove that shifting from fuel to solar production will decrease the economic impact of electricity. Hydroelectric energy was not considered due to a decrease in the precipitation level that made it difficult to produce enough energy from rivers and due to the high cost of rehabilitation and upgrading.

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2020.

Keywords: Solar energy; Fossil fuel burning; Microgrid; Air pollution

1. Introduction

Like most modern countries, Lebanon is suffering from energy problems at the levels of production, consumption, and saving. The leading consequence being environmental degradation and air pollution. Unfortunately, one of the major causes of air pollution in Lebanon after transportation is the electric sector due to the classical and the non-developed way of generation.

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https://doi.org/10.1016/j.egyr.2020.08.061

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2020.

The Lebanese institution for electricity production (EDL, Electricité du Liban) was established in 1964. It assured the distribution of electricity to up to 90% to the Lebanese territory. In 1974, the EDL institution produced 1700 GWH of electricity. 41.5% of this produced power was hydroelectric, meanwhile the production coming from the small private companies was 0.296 GWH which constitute less than 0.02% of EDL production.

This sector, which was expected to turn a part of the energy production in Lebanon to renewable energy resources such as hydraulic power and solar energy [1–5], but unfortunately it has been transformed to be a deadly pollutant weapon [6–8]. In reality, due to the civil war that started from 1975 and lasted to 1990 the military actions have destroyed several thermal power stations and transmission lines. This act pushed people to rely on several pollutant means of energy production, like diesel generators (DG) that do not respect the international norms (bad quality of used Fuel and maintenance) and also the production of thermal energy for water heating by burning pollutant metals (wheels and furniture).

After the 90's the Lebanese electricity generation relied mainly on fossil fuel and suffered from many technical and non-technical losses such as illegal connections and meter manipulations. [5,9–11]. In 2003, the production of electricity reached 10.5 TWH where 87% of this electricity is produced with gas oil, diesel and fuel oil (the last three sources represent 92% of the imported oil derivate while the remaining 8% of the importation are shared between????) and the remaining 13% of the electricity produced with hydropower plants. Good to mention that production from hydropower plants dropped to 4.5% in 2009 due to lack of maintenance and aging in the materials.

Despite the effort made after 1992 to reactivate this sector, the generated power was not able to meet the permanent increase of the society demands. Furthermore, this already old and weakened sector had to face the challenge of meeting the needs of millions of unexpected refugees from different countries who flew to Lebanon in a very short time. Therefore the ministry of energy was not able to organize and implement solutions to the over demand and consumption of energy. The newly imposed problem on the Lebanese government coming from the over consumption created a serious shortness in the supplied hours of electricity where in less than one year the number of population has raised by approximately 25% of the total citizens living in Lebanon [12].

The above-mentioned causes led to having a blackout among the year that could reach in average 13 h per day in many Lebanese regions; that pushed the consumers to find alternative solutions by developing private networks in parallel to the governmental sector (EDL).

Power generation in Lebanon in terms of capacity, efficiency and productions has been investigated by many organizations such as the united nations, the World Bank, the International Monetary Fund, Greenpeace, [3,8,12–15] and it has been proven that this sector needs rehabilitation, reorganization and servo by renewable energies. In addition, it was agreed by the local and international investigators that last mentioned reforms are strictly necessary to achieve the below targets:

- Decrease air pollution therefore reducing its destructive impact on human health, animals, plants, soil, building materials in other words on the entire ecosystem of the country that has seriously been damaged by the non-responsible practices over a period of 20 years.
- Promote enterprises and revive the industrial sector, a step that will open the door to new work opportunities, competitions and productions that fit the international norms

In order to help in the planning and the solution proposal for the above recommendations submitted by the investigators we have realized a case study for the electric consumption of Lebanese foyers for March, April and May 2020 that almost correspond to spring semester. A numerical analysis was done based on a real data measurement for electric consumption taken along a 24 h for sixteen houses. A comparison between the Diesel generators supply and the likely alternative clean source, in our case we have targeted the microgrid, was carried to verify the possibility of covering the shortage of the EDL supply. Obtained results showed clearly the benefit and advantages of switching to microgrid energy production.

2. Present situation of electric sector in Lebanon

Electricity is a major and painful problem in Lebanon which consequences reached levels that start to pose a serious damage on the public finances.

This dysfunctional sector at many scales, managed by the government, became a burden on public finance, on households and on public health and the total Lebanese ecosystem. Furthermore, it is still unable to supply the reliable electricity needed by industry, commerce and houses therefore imposing a significant economic and social cost.

2.1. Challenges

Electricite du Liban (EDL) is the state owned company in charge of the generation, distribution and transmission of electricity is facing four important challenges [11,14–17]:

- First, EDL's generation capacity is well below consumers' demand especially in the last ten years where an increase in the living population of about 1,500,000 persons have suddenly landed in the country without any preliminary preparations or planning [12].
  In fact, after the war (1975–1990) EDL infrastructure was damaged and disregarded which reduced the production capabilities. A reconstruction and rehabilitation plan for the power sector master was developed and implemented since 1992 but it was inefficient and insufficient since the gap between EDL's power production and the total electricity consumption is still growing every year. According to a report published by the international monetary fund, electricity demand increases by 500MW each five years in Lebanon, moreover the negative effect of this number on the society is aggravated by the reduction in the electricity supply. The gap between production and consumption was around 22% in 2008 and is expected to reach 56% in 2025 [18]. It is due to aging power plants with high maintenance cost and operating below their rated capacity what leads to power outages of at least three hours per day in Beirut and up to twelve hours outside Beirut.
  Some solutions have been implemented such as the rehabilitation of power plants, creation of photovoltaic and windmill farms and temporarily renting power barges. However, the green energy stations are still under construction and power outages remains the same across the country. This is because of the sudden increase in the number of population and its subsequent consequences on the increase of electric consumption estimated to be around 500 additional megawatts. A capacity increase that is required from on a generation system already suffering from a big gap between demand and supply. This burden deprives the Lebanese citizen from five additional supply hours at peak times that additionally degrade the industrial sector and the economy of the country.
  To compensate the outages of the electricity the Lebanese citizens developed a networks of supplying composed of expensive private generators placed in the basements of buildings, parking lots and in alleyways near residential units. Those networks are extremely polluting, noisy and do no obeyed to international norms.
- Second, EDL suffers from technical and non-technical losses on the transmission and distribution grids. EDL estimates technical losses to be around 19% when non-technical losses are due to illegal connections to the network and reach 21%.
- Third, though there is an agreement that the electricity sector needs to be reformed, implementing a reform has proven difficult. Many reform plans have been elaborated but were never implemented. The most recent attempt was in 2019 when the ministry of energy and water updated the Policy Paper for the Energy Sector developed in 2010. Cabinet and Parliament both approved this reform in April 2019. They agreed on four points that must reduce EDL deficit that are:

  1. Reducing losses by improving the Distribution Service Provider (DSP) framework and the distribution grid, installing smart meters and temporarily decreasing the subscription price.
  2. Increasing the capacity by building new power plants.
  3. Decreasing the production cost by using gas input instead of fuel.
  4. Increasing the tariffs after supplying 24/7 electric power and adopting an automatic fuel indexation mechanism.

- Fourth, EDL is facing a financial problem since most of the power produced is based on heavy fuel and diesel oil, which leads to high operational cost. A cost that is not entirely collected because EDL is currently applying a low cost outdated tariffs structure where the rates are unchanged since 1996 and because of the unpaid bills that constitute 5% of the total losses of the firm.

All those energy challenges affect negatively the society in different ways and at different echelons. Impact of caused drawback and consequence from the above described challenges on enterprises and air pollution was investigated in the below paragraphs.

2.2. Impact on enterprises

Nowadays all businesses depend on a supportive environment that reinforce the companies' ability to develop i.e. to survive, create jobs, invest, innovate and be competitive. A reliable electricity supply is of major importance for economic growth. Therefore, electricity shortages, bad performance and the necessity to rely on high cost private generators affect the competitiveness of businesses in Lebanon due to huge economic losses [19] and lead to lost economic opportunities. This is shown by a survey conducted by the World Bank [20] in which electricity shortages are listed as the second constraint to competitiveness after political instabilities.

2.3. Impact on air pollution and health

High reliance of EDL on heavy fuel oil and diesel oil not only increases the production cost but also leads to air pollution since burning such types of fuel generate particulate matter as well as toxic gases such as NO_x and CO_2. Moreover, the electric outages obliged the citizens to rely on private diesel generators. The emissions of such generators increase air pollution problems to the point at which Greenpeace classified the city of Jounieh located near Zouk's thermal power plant as the 5th most air polluted town in the Arabic word [13].

Those pollutants that we breathe lead to adverse physical and mental health problems such as anxiousness, depression, attention problems, increased premature death, asthma, cardio vascular disease, lung cancer and other pulmonary diseases. [7,21]

Electric sector in Lebanon has reached a critical situation and needs efficient and fast solutions.

3. Experimental study: household energy consumption

3.1. Energy consumption before and after COVID19

The solution to Lebanese electric sector problems must include besides energy saving a strategic plan that involves renewable energy sources especially solar energy. In fact, Lebanon enjoys around 3000h of sunshine during a year that correspond to an average solar irradiation varying between 1520 KWh/m^2/year and 2148 KWh/m^2/year with the majority of the areas receiving above 1900 KWh/m^2/year[1].

Renewables integration in parallel to the fuel sector will decrease the production cost from 0.17$ per KWH to around 0.06$ per KWH, a 35% of gain that may be invested in the maintenance and improvement of the present exciting sector which will lead to more efficient production by fuel at lower cost.

Furthermore, using solar energy will avoid fuel burning at high amount therefore, decreasing carbon footprint, air pollution and health cost. To prove the efficiency of switching to micro grid produced electricity a survey was conducted to study the cost difference between diesel and solar electricity for two sets of households. The first was chosen in a town to the east of Beirut (Block of flats I noted B1) and the second in a town to the south of Beirut (Block of flats II noted B2). Measurements of the consumed power were recorded during the month of March 2020, where people had a regular life style, and during lockdown. Those changes in living styles will allow us to study the consumption during all conditions. Both cities suffer from 10 h electricity shortage compensated by private diesel generators.

- Fig. 1a represents the curves of the power consumption for the eight apartment in a Block-flat 1 (B1) for the period extended over March 2020. B1 is geographically located in the east side of Beirut.
- Fig. 1b represents the power consumption for the same apartments in Block-flats 1 for the period extended over April and May 2020.
- Fig. 2a represents the power consumption for the eight apartments of a second Block-flat 2 (B2) located in the south district of Beirut and for March 2020.
- Fig. 2b shows the power consumption for the same eight apartments founded in Block-flats 2 for March, April and May 2020.

Figs. 1.a and 2.a correspond to the profile of energy consumption of habitants in two different area in Beirut. It is obviously concluded that during March 2020 period, people had a synchronized life style and the use of household electricity is directly related to the presence of persons between work and home. In more details, since schools start at 8:00 AM as well as most of the jobs, the first consumption peak extending from 5:00 to 10:00 AM corresponds

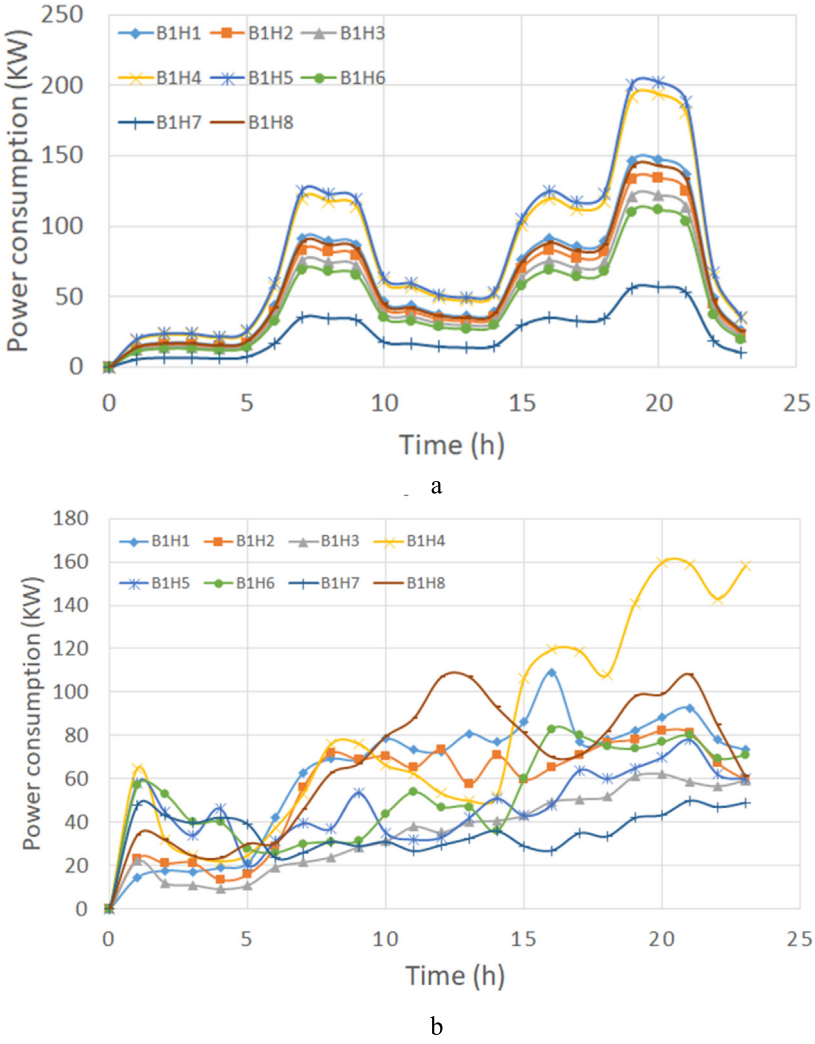
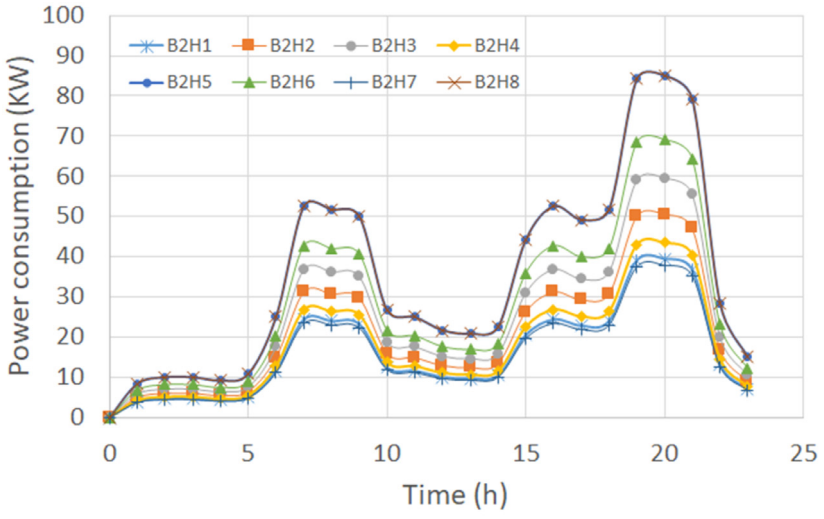


Fig. 1. (a) Electric power consumption as a function of daytime for the eight apartments forming Block of flats I (BI) for March 2020; (b) Electric power consumption as a function of daytime for the 8 apartments forming Block of flats I (B1) for April and May 2020.

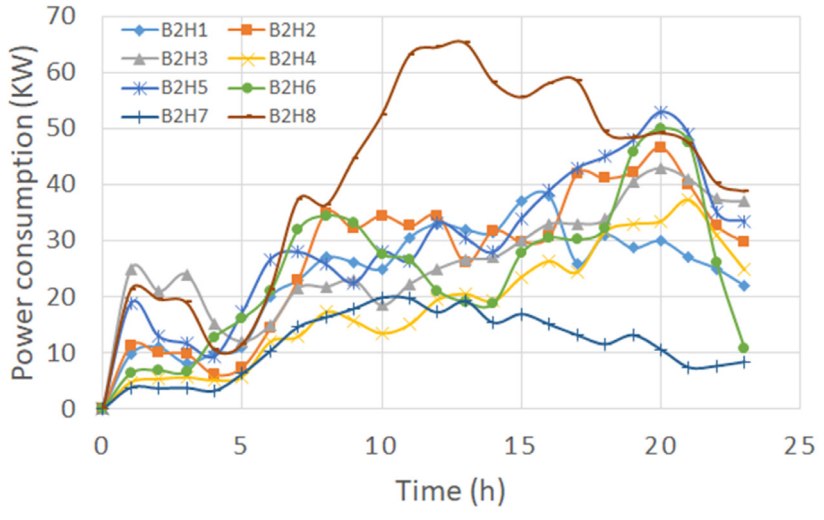
to the morning use of electric current (light bulbs, heater, small and large home appliances). The two other peeks correspond to the time when children are back from school (03:00 PM) and when people are back home from work, (06:00 PM) considered as the time of evening activities (Studies, TV, use of home appliance). Therefore, Figs. 1.a and 2.a present typically the same pattern and daily routine.

Figs. 1.a and 2.a correspond to the behavior of habitant during April and May 2020, where during this period, home-based activities were less synchronized and do not follow a periodic schedule. Actually, during this period in some foyers works were conducted remotely from homes, children studied online and presence of people at their residence led to net increase in the energy use, or other families have left the capital to the villages due to the high risk of COVID19 Contamination in the Capital. Therefore, the increase in the household's electricity needs and the behavior of each block of flats consumption differed depending on the residents' life style, their presence in the flat and their activities.

Before lockdown (March 2020), an identical and typical behavior of energy use is noticeable in both households of the Blocks I and II, where electric energy consumption increases during three time windows that all are considered within the common time of people's presence at their homes.



a



b

Fig. 2. (a) Electric power consumption as a function of daytime for the eight apartments of Block of flats 2 (B2) during March 2020; (b) Electric power consumption as a function of daytime for the same eight 8 apartments of Block of flats 2 (B2) during April and May 2020.

- The first time slot was identified between 5:00 and 9:00 AM that corresponds to early morning electricity usage before leaving to schools and works.
- The second slot is found between 3:00 and 6:00 PM, a time that matches the returns from schools and the evening assembly of the foyers members.
- The third peak starts at 7:00 and 11:00 PM, where probably individuals perform the missing tasks at home.

To estimate the total cost of consumed energy as well as the benefit gained from switching to micro grid a home-developed simulation program was used. A home-developed simulation program calculated the total cost of fuel based electricity generation and solar electricity production for the two block of flats presented in the preceding sections.

3.2. Numerical analysis to validate the feasibility of employing micro grid as alternative solution for diesel generators

Diesel generators (DG) replacement by Micro grid (MG) Energy Management systems (EMS) is expected to have many advantages. To verify this improvement at the level of the total cost that takes into consideration impact on public health, economy and environment a numerical analysis study was realized that allowed us to make a comparison between the cost paid for energy production by DG and MG.

Data input were implemented in a mathematical model that allow an exploration for energy needed for each hour of a day and all data related to the maintenance and consumption according to Diesel generators and Micro-grids system (MGS).

In the used model, the mathematical equation of the total cost of energy produced by Diesel Generator is given by:

$$TC_{Di} = IC_D + EC_{Di} + CC_{Di} + MC_{Di} \tag{1}$$

where,

IC_D: Investment cost of Diesel generator/hour = constant

EC_{Di} = environmental cost incurred when using Diesel at the hour i according to the energy Wi

CC_{Di} = consumption cost of Diesel generator at the hour i according to the energy Wi

MC_{Di} = Maintenance cost of diesel generator at the hour i taking into account maintenance costs, reliability data of Diesel generator and the real energy Wi needed

In the economy terminology, the investment cost is defined as the funds paid in order to produce profit or income, in our study the income was defined as how much an individual has to pay for installing the system and to make it operational. Good to mention that there will be a cost loss with these systems, e.g: efficiency reduction with time coming from aging and probably other dysfunction.

Maintenance cost is considered as the money paid before failure happened or to extend the operation life-time of the Micro-grid.

Environmental cost is the bill of damage created in our ecosystem by the CO2 emission, corresponding to amount of CO2 emitted during the operational time of the Diesel generators. Adding to this sum we need to figure in our calculation the heavy charge of the health treatment resulted from the chronic diseases caused by these toxic emissions.

Consumption cost depends on the cost of the fuel needed to run the diesel generators per hour; this cost is subject to the market price list variation.

As a summary and depends on the complexity of the installation the Microgrid costs may vary; but the major expenses is illustrated in Fig. 3:

- Generation, which can rise up to 50% of the total costs
- Microgrid Controller, accounts for closer to 15%
- Remaining costs, up to 35% Includes (maintenance, installing, etc.. . .)

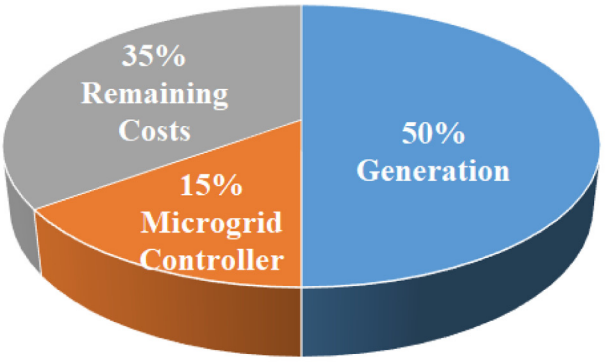
Fig. 3: Illustration of the investment cost for a Microgrid

In Fig. 3a, b, c and d we plot the results obtained by numerical analysis for the Cost Difference of the energy consumption taken from four different flats (B1H1, B1H8, B2H2, B2H5) and over two periods of time (March 2020 before Lockdown and April, May 2020 after Lockdown: 8 weeks). From the curves of Fig. 3 exemplifies the economized value by integrating a micro grid for power generation instead of the Diesel Generators.

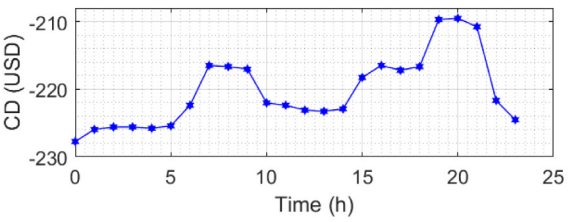
Negative sign in the Cost value results correspond the gain in cost of energy production with micro grid system with respect to the fuel system. Moreover, this cost reduction is valid for all conditions of energy consumptions (times and season). It has been observed from our model that health-care cost play a major role in the total bill reduction due to the consistent quantity of emitted air pollution.

Financial Study for the real paid bills of the Energy consumption (EC) shows a high compatibility with the obtained CD values, e.g if we take the case of B1H1 that has consumed 1446 KW over a period of March 2020 we can identify the following:

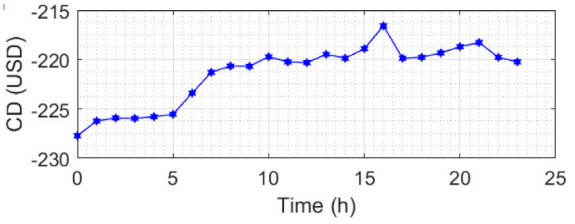
B1H1 has paid a total bill of 249.4 USD for the energy consumed during March 2020, this amount is the equivalence of 1446 KW with an average price of 6 cents per KW. As for the obtained analysis from our Model,



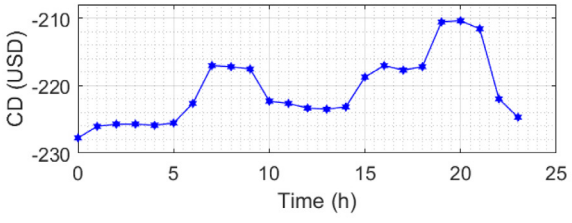
Percentage Distribution for the Investment Cost of a Microgrid



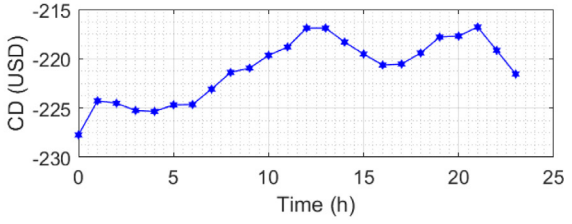
a) B1H1, March 2020



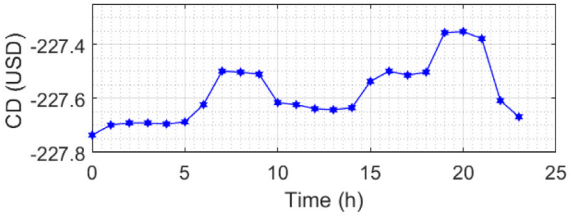
B1H1, April and May 2020



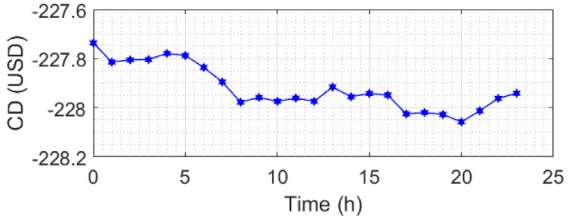
b) B1H8, March2020



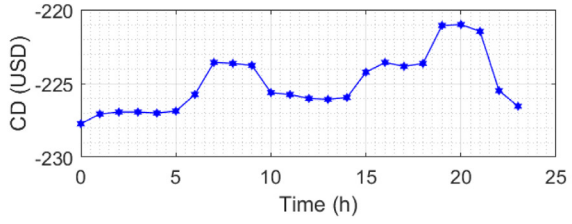
B1H8, April and May 2020



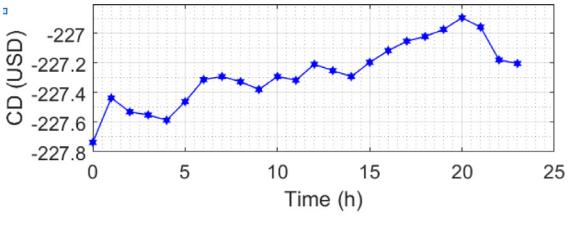
c) B2H2, March 2020



B2H2, April and May 2020



d) B2H5, March 2020



B2H5, April and May 2020

Fig. 3. a, b, c and d: Difference in cost for energy production by micro grid or Diesel Generators. This cost difference CD is in USD.

Table 1. Comparison between Costs and Benefits for a sample of flats in Blocks B1 and B2.

Flat ID	**March 2020**				**April and May 2020**			
	Diesel TC	MG TC	TC difference	Gain	Diesel TC	MG TC	TC difference	Gain
B1H1	249.4	29.1	220.27	88.38	252.6	31.15	221.4	87.6
B1H8	249.14	28.5	220.65	88.56	253.97	32.9	221	87
B2H2	244	16.4	227.57	93.26	248	20	227.92	91.9
B2H5	245.9	20.94	224.98	91.48	247.84	20.57	227.27	91.7

we observe clearly that we can benefits from an average of 220 USD fees saving, equivalent to 88.38% of the total bill, by implementing the proposed Microgrid for backing the Energy generation. For April and May 2020, we conclude obviously the same benefit from the fact of integrating an alternative source of Energy generation.

Table 1 summarizes the Costs and the benefits for randomly chosen four flats from B1 and B2.

4. Conclusion

Power sector in Lebanon requires rehabilitation upgrading and shifting from fossil fuel burning to renewable energy harvesting. Switching to hydraulic power plants is the easiest choice since plants already exists and the country is considered very rich in water sources. However it hydraulic energy generation cannot be alone an effective solution because of climate change we are facing recently, random decreases in the rainfall in some years and because its cost is still high.

Another valuable and very effective renewable resource that can be harvested is solar energy since Lebanon enjoys more than 3000 h of sunshine. Such a step for switching to solar energy necessitate the installation of photovoltaic farms on the national and individual planes, where governmental intervention is strongly needed at financial and Technical levels at the beginning until the solar sector become auto-productive and satisfying in terms of Energy and finance.

The greener solution consist on modifying the present governmental laws and allowing the individuals to sell the excess of energy produced by the renewable sources to the government (on grid solution), a pace that can has mutual benefits either on the economy or on the pollution reduction, environment protection and health advantage.

The costs of energy production simultaneously from fuel burning and from harvesting solar energy have been evaluated based on the investment cost, the consumption cost, the maintenance cost, the carbon footprint and the environmental cost. The cost difference between the electricity produced from fuel and that produced from solar showed without any doubt that government should consider seriously and imminently switching to solar energy production.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

The authors would like to thank the University of Lorraine for supporting and funding their project.

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