AMERICAN UNIVERSITY OF BEIRUT

A FEASIBILITY STUDY ON POTENTIAL POWER GENERATION FROM DISTRIBUTED RENEWABLE ENERGY IN AUB

by
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ABSTRACT
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The Copenhagen conference on climate change in 2009 and the Paris Agreement signed in 2016 have incentivised the Lebanese government to move towards the energy transition and the decarbonisation of the energy mix. Specifically, Lebanon pledged in 2009 at reducing domestic fossil fuel usage by achieving a target of 12% renewables in the energy mix by 2020. This pledge was amended to reach a target of 30% of its energy consumption from renewables by 2030. Characterised by a significant energy supply-demand imbalance, as well as the negative repercussions of the several crises the country has and is witnessing, the Lebanese state has formulated in early 2019 that renewables and energy efficiency should be key to the country's recovery plans.

One way the private sector could contribute to this plan is through the implementation of distributed renewable energy technologies. With the American University of Beirut being considered one of the most notable universities across the region aiming to build a better and brighter future for the upcoming Arab generation, it is essential that AUB takes the lead on the energy transition. Through a conscious and well planned program, AUB's can reduce its reliance on the Lebanese electricity grid and on the local diesel generators. This paper aims to provide a realistic and practical assessment of what AUB can achieve if it amplifies its reliance on renewable energy and, in specific, its reliance on solar photovoltaic power. A case study will be performed on the AUB institution which might later benefit other corporations with similar contexts. In-depth research has been applied by interviewing the AUB's Facility Management unit in order to gather data related to monthly (and yearly) electricity consumptions at AUB, in addition to the electricity bills for both EDL's power and diesel generators. Separate cases were studied to try to make AUB a powerful example in its community for renewable energy powered institution.

Two cases were studied; On-site and Off-site solar PV generation and under each of these two cases three different strategies were estimated: AUB being the sole owner of the investment for a 20-years period, a Power Purchase Agreement (PPA) contract with a third part company for a 10 year period, and finally a PPA for the first 7-years after which AUB will own the solar PV system. The proposed plan has an initial investment cost estimated at 1.36 million USD for case one and 9 million USD for case two, while the annual operation and maintenance costs are estimated at 40,800USD and 270,000 USD for case one and two, respectively. To assess the financial feasibility of the plant, benefits were estimated under two different cases as follows: 400,300 USD for on-site installations and 3 million USD for off-site installations. The results indicate that the project will make the

most benefits when the price of electricity is sold at 0.05 USD/ kWh in the on-site case or if the price of electricity is sold at 0.722 USD/ kWh in the off-site case.

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CHAPTER I

INTRODUCTION

Renewable energy systems are emerging technologies that contribute to meeting the increasing global electricity demand for electricity at lower environmental costs. In 2018, solar panels' total global installed capacity was 480 GW, accounting for the second-largest capacity after wind (Gielen et al., 2019). The International Renewable Energy Agency (IRENA) estimated the globally averaged Levelized cost of electricity (LCOE) for solar panels to have fallen around 77% between 2010 and 2018, making it a competitive technology compared with other generation sources. Renewable energy is progressively becoming a competitive way to meet world energy demands. IRENA shows that bioenergy projects for power, hydropower, and geothermal energy commissioned in 2017 dropped to the range of generation costs of fossil fuel-fired electricity. The global LCOE for these projects is 5 cents/ kWh and 7 cents/kWh for hydropower and geothermal projects, respectively (IRENA,2017). Moreover, solar energy has been competing head-to-head with conventional power sources, as mentioned in the IRENA report of 2020, there was a dramatic fall in solar PV module prices between 2010 and 2019 where the global weighted- average LCOE of newly commissioned utility-scale solar PV fall 82%, to USD 0.068/kWh in 2019 (IRENA,2020).

Until the COP meeting in Copenhagen in 2009, Lebanon never had a tangible commitment to invest in its renewable energy sector. However, after the COP meeting, the Lebanese Government had set a target to have a 12% RE of the country's energy mix 2020, which was recently updated to 30% by 2030 (IRENA, 2020). These commitments were an important part of the policy papers for the electricity sector issued by the MEW in 2010 and 2019. As part to Lebanon's action plan to achieve its target of 12% renewable energy by 2020, and beside the implemented distributed solar PV projects reaching up to 78.65MW in 2019 (LCEC, 2019), several centralized pilot projects were initiated over the past decade. Wind power in Lebanon started taking shape when the first expression of interest (EOI) was launched in 2012 by the Ministry of Energy and Water, and after developing the Wind Atlas of Lebanon by the UNDP, through the CEDRO project, in 2011which has created a growing potential towards developing the renewable energy sector in the country (*The National Wind Atlas of Lebanon*, 2011). The tender process and negotiations phase lasted from 2014 till 2017, as a result of which three companies were awarded the licenses to develop three wind farms in Akkar, northern Lebanon, with a total potential capacity of 226 MW (LCEC,2021). Despite getting some financial approvals from several international financing institutions, the project has not progressed yet and has been halted due to the economic downturn, and Lebanon's default on its debt in March 2020.

CHAPTER II

LITERATURE REVIEW

Different countries are adopting different support policies and schemes to promote renewable energy investments. Support policies can be placed in two categories; investment-based incentives and production-based incentives, with various schemes that can be used for each, as shown in Figure 1

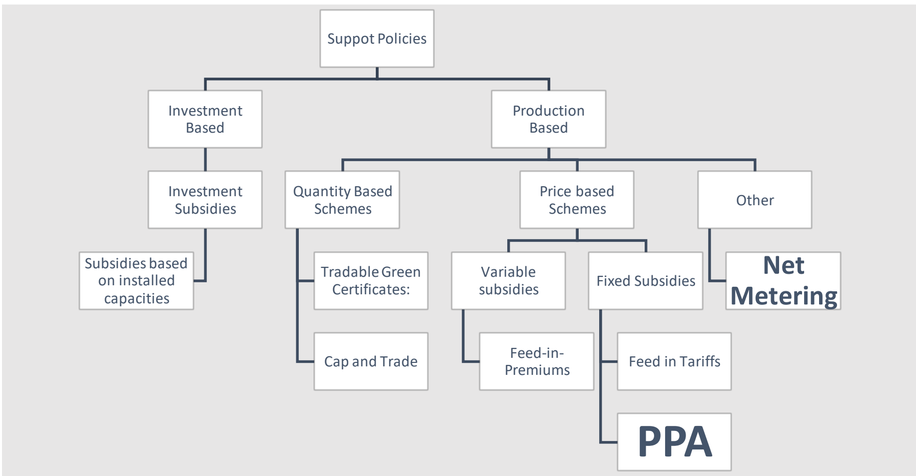


Figure 1: Types of Support Policies

This paper will focus on two production-based support policies; Net metering and corporate PPAs.

A. Net Metering

Net metering offers a favorable investment option for small-scale generation, especially the residential sector. There are various ways to define net metering (NM):

- NM is a regulated arrangement in which utility customers with on-site electricity generators can receive credits for an excess generation fed into the grid, which can be applied to offset consumption (REN21, 2018).
- NM means a methodology under which electric energy generated by or on behalf of a customer-generator and delivered to the Electricity Provider's distribution facilities may be used to offset electric energy provided by the Electricity Provider to the customer-generator during the applicable billing period (IREC, 2009).

Different Net Metering (NM) definitions have one point in common: excess in power generated by renewable energy sources are fed into the utility grid, and then the prosumer is compensated. NM in developed counties and emerging economies are usually accompanied by other regulatory policies such as FiT, tendering, and fiscal incentives. (REN21,2018)

1. Net metering classification:

Net metering has many types that can be deployed by different utilities and clients, as indicated below (adapted from Barnes, 2013 & illustrations adapted from US Dept. Energy *et al*., 2018);

a. Single Owner Net Metering: in this form, the renewable energy source is set by one facility with a single owner that can be residential or institutional. The owner will have one meter where the exchange would take place (See Figure 2).

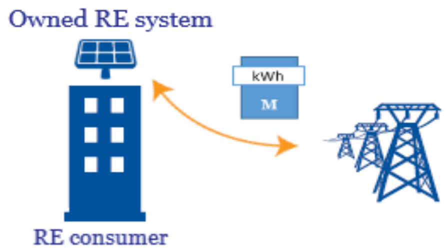


Figure 2 Single Owner NM (US Dept. Energy et al., 2018)

b. Aggregate Net Metering This is an arrangement that allows a single generation system to benefit different customers through offsetting electricity use on multimeters without requiring any physical connection between the system and the meters. Types of aggregate net metering depend on the number of customers and the number of sites allowed. It is grouped into four different categories:

i. Basic Meter Aggregation A single customer may offset electricity use on multiple meters located in the same property with a single renewable energy system (example: a campus with numerous buildings). This arrangement requires the owner to be the same for all meters and the property to be owned or leased by the same customer (See Figure 3).

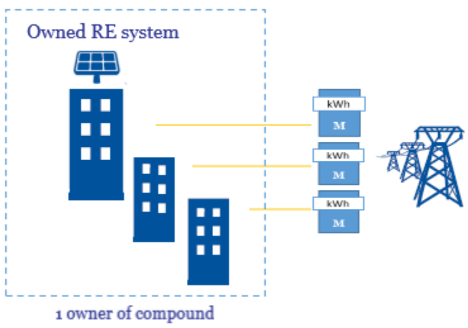


Figure 3 Single customer, Single site basic meter aggregation NM (US Dept. Energy et al., 2018)

ii. Tenant Aggregation This aggregation allows different customers to aggregate meters under the condition that all meters are located on the same property. Including multi-family residential buildings where meters are owned by various customers instead of one landlord (See Figure 4).

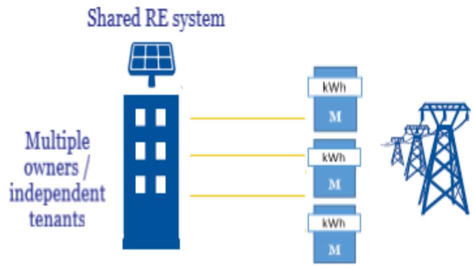


Figure 4 Multiple customers, Single site tenant aggregation NM (US Dept. Energy et al., 2018)

iii. Multi-site aggregation allows a single customer to aggregate meters located in different geographically disconnected places. This is especially useful for facilities that own lands that are rich in RE resources (connected to the grid). They can use this power generated to credit another facility located in areas where it is harder to install renewable energy capacities. This utility may request fees for the use of the distribution network through wheeling charges (See Figure 5).

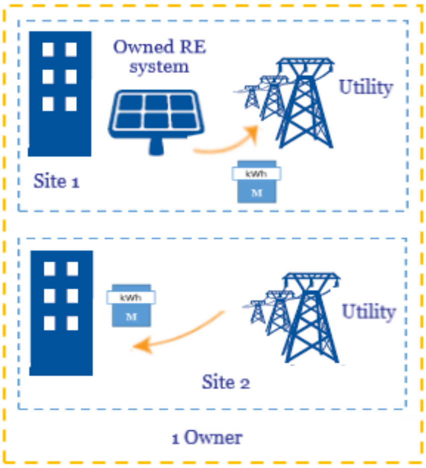


Figure 5 Single customers, Multiple sites aggregation NM (US Dept. Energy et al., 2018)

iv. Virtual Net Metering This is the most flexible type of aggregation, where several customers are allowed to participate in meter aggregation even if they are located in separate properties. This arrangement is subscriber-based with an organization that owns the metered system. VNM may also request fees for usage of the distribution network and other management fees (See Figure 6).

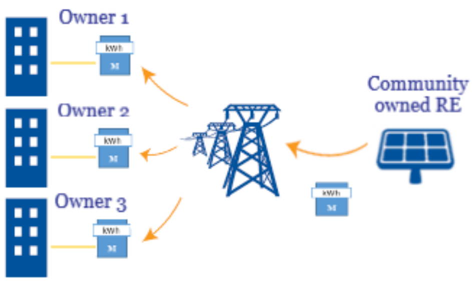


Figure 6 Multiple customers, Multiple sites virtual NM (US Dept. Energy et al., 2018)

B. Corporate Sourcing

The development of renewable energy has led this type of energy to be one of the cheapest energy sources in many parts of the world. In some countries, the investment in renewable energy is outpacing conventional energy sources. Companies in the Commercial and Industrial sectors account for two-thirds of end-use electricity worldwide (IRENA, 2018a). Hence, companies take an essential role in investing in renewable energy to meet global climate targets. The options available for corporations to sources renewable energy depends on the market and the framework in the country where they operate. Reaching full capacity in corporate sourcing is possible when governments are backing through establishing stable and predictable policy frameworks. Although corporate PPA options are showing success in less-regulated markets, implementing a proper policy framework can lead to better sourcing options, whether in vertically integrated or liberalized energy markets. In 2018, more than 130 corporations with operations across 122 different countries joined the RE100 initiative. RE100 is a network of corporations that have pledged to use 100% renewable energy. Figure 7 shows different models for corporate sourcing of renewable electricity

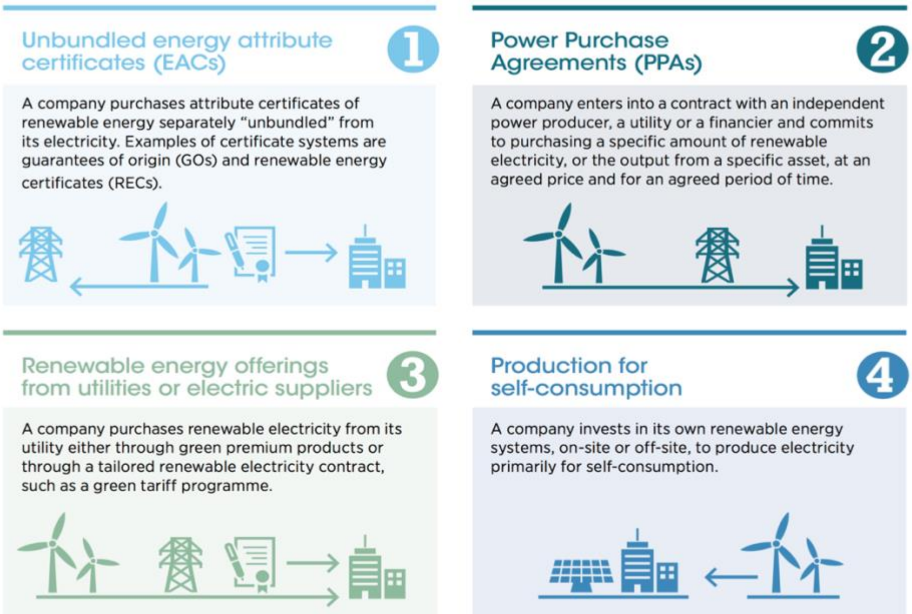


Figure 7 Models for Corporate Sourcing of Renewable Energy (Source: IRENA 2018)

The specific models that promote corporate sourcing of RE, as shown in Figure 7, are further elaborated in Table 1. (Bird et al., 2017).

OPTION	POLICY MEASURES
UNBUNDLED ENERGY ATTRIBUTE CERTIFICATES	• Provide credible tracking of renewable energy attribute certificates • Allow corporations to buy electricity certificates directly
CORPORATE PPA	• Allow third-party sales made directly between corporate buyers and the power producers. • Provide clear rules for transmission and grid access in addition to wheeling arrangements that allow on-site and off-site PPAs
UTILITY PROCUREMENT	• Support market-based renewable energy pricing • Support large corporation with customized long-term contracts
PRODUCTION FOR SELF-CONSUMPTION	• Provide a precise mechanism for on-site and off-site systems to feed excess electricity to the grid • Provide a precise wheeling mechanism

Table 1 Policy measures that promote corporate renewable energy (Bird et al., 2017)

C. Corporate PPA

Corporates proceed to seek corporate PPAs for their economic advantages such as long-term price certainty and the capacity to hedge against future cost increments from the grid. Corporate PPAs are progressively being utilized in rising markets to provide reliability and resilience against grid outages. Common definitions of Corporate PPA are:

- Power Purchase Agreements (PPAs) are performance-based contracts that aim to create a "fair" and risk-controlled agreement for the purchase and sale of energy between an energy consumer (Buyer) and a Producer (Seller) (Mendicino. et al., 2019).

- Corporate PPA is a ‘long-term contract (typically 15 – 20 years) under which a business agrees to purchase electricity directly from an energy generator…, as opposed to buying electricity from licensed electricity suppliers (DLA Piper, 2016).
- In Corporate PPA, a customer or "off-taker" buys from a renewable generator all the generated power at a pre-determined rate ($/kWh) (Bird, et al., 2017). The prices can be fixed or adjustable throughout the contract. Usually, corporate PPA may include a third party that takes on financial responsibilities and investment risks. A third-party developer 'handles all aspects of the project development, including site assessment, system configuration, procurement, installation, financing, and is typically charged with the operation and maintenance (WRI, 2009).

1. Types of Corporate PPAs:

There are two types of Corporate PPAs; physical PPAs and virtual PPAs.

a. <u>Physical PPA</u>

On-site PPAs are also known as "Physical" PPAs, where the off-taker can directly receive power since electricity is connected to the consumer’s meter. This contributes to reducing the purchase of power from the utility (as shown in Figure 7.

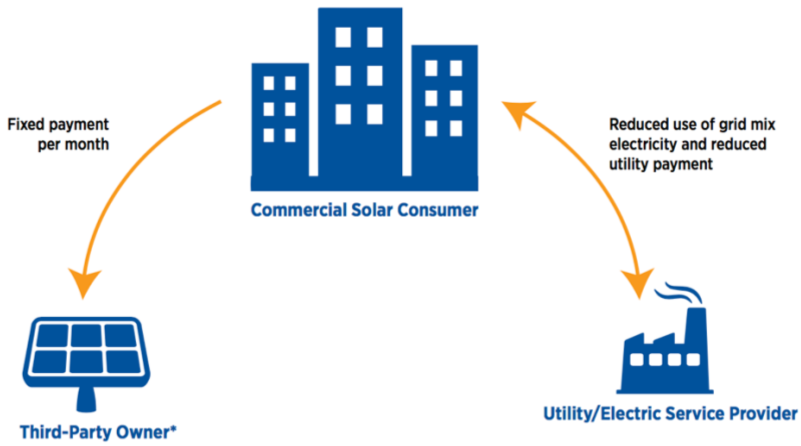
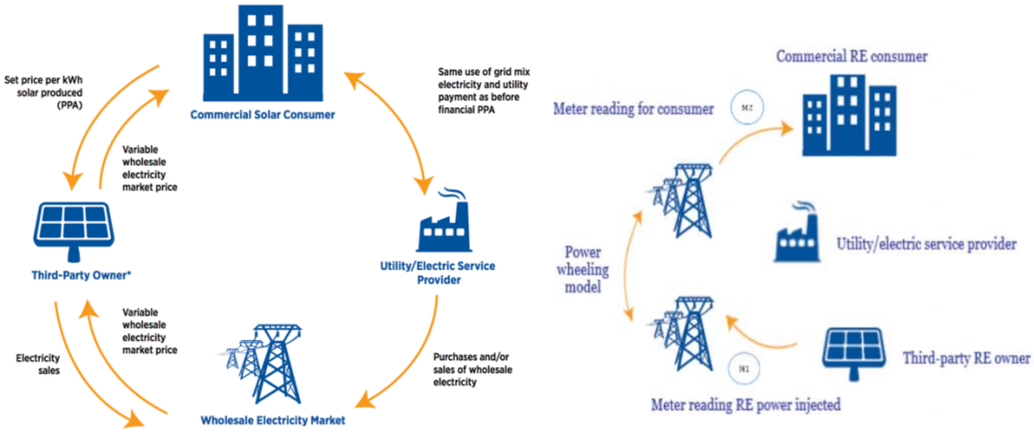


Figure 8 Overview of On-site PPA (adapted from US Dept. of Energy et al., 2018)

2. Virtual PPA (Financial)

In Virtual PPAs, the off-taker buys all generated power at a previously agreed-on rate and duration. The delivery of power between the off-taker and the renewable energy source is not physical. Liberalized power markets allow the RE source owner sells the electricity to the wholesale power market. The off-taker and the owner then settle on a price between the wholesale price and the agreed-upon PPA price (strike price) (NREL, 2017). If the wholesale price was greater than the strike price, the generator settles by paying the off-taker's overage. However, if the wholesale price was lower than the strike price, the off-taker must settle by paying the RE generator's difference (Baker and McKenzie 2015). In a vertically integrated market, this type of PPA should follow a mechanism that sets an agreement between RE generator, utility, and off-taker to allow the RE power to be wheeled to the designated off-taker. According to Kirchhoff's Laws, electric currents move in the direction with the least electrical resistance; thus the electricity generated by the RE source is not going to end up at the end user's site (Studebaker, 2001). For this reason, the utility will take management, transmission, distribution charges, wheeling charges, and other additional fees. Virtual PPAs with off-site models in both liberalized and vertical markets are illustrated in Figure 9.



Liberalized Market Mode Vertically Integrated

Figure 9 Virtual PPAs with off-site models in both liberalized and vertical markets (adapted from US Dept. of Energy et al., 2018)

D. Wheeling Power

Electric power networks are divided into transmission and distribution networks. Transmission lines are used for the transmission of power from the electricity generating facilities to substations that are usually located near population centers. Electrical power is moved from substations to the end consumers via the distribution network.

Not all generating facilities are required to own transmission and distribution lines, as long as they are connected to the utility grid. For this reason, wheeling is an important concept where electrical power is transported from buyers to sellers through the utility's transmission facilities (Baji & Ashok, 1998).The exact conditions for power wheeling change depending on the market structure and circumstances of each country. Thus, the conditions of charges for administering and using the transmission and distribution network are set through a contractual wheeling agreement between the parties involved. There are several methodologies to calculate wheeling charges, but regardless of the approach used, the charges will be composed of Operation & Maintenance Costs and network losses and congestion. (OUR, 2012). The O&M component is determined yearly and includes personnel that maintains the transmission lines and administrative costs (Raftelis, 2014).

E. Distributed Renewable Energy in the MENA region

Despite the fact that the Arab region has abundant renewable resource levels, it remains untapped, and this region still mainly depends on fossil fuels. The countries in this region experience high levels of energy insecurity. As a result, some countries started setting policies to scale up private investment to accelerate RE sources' implementation. Among other countries in the MENA region, Egypt and Jordan have shown major progress in their renewable energy generation. These countries are the only countries in this region, to date, that allow corporate sourcing through direct PPA in specific cases, excluding investment in renewable energy for self-consumption. The country's performance for distributed renewable energy will be indicated below (IRENA data online):

1. Jordan:

Jorden is a middle-income Arab country in Western Asia's Levant region, on the East Bank of the Jordan River. Jordan's GDP in 2019 was around 44.5 Billion USD, or an average of 4,405 USD per capita GDP. Unlike bordering countries, Jorden's fossil energy resources cover 4% of its domestic demand, and the remaining 96% has to be imported. In 2014, electricity was mainly produced from imported heavy fuels at world market prices due to the intermittent gas supply interruption from Egypt facing its events of the Arab Spring in 2011. This led to an increase in electricity costs for generation and distribution for the National Electric Power Company (NEPCO). The combination of high electricity costs from conventional power plants and subsidized electricity rates of around 0.16 USD/kWh, led to a significant deficit in NEPCO. From an economic point of view, it was important for Jordan to look for a cheaper electricity supply option. Other energy options such as nuclear or shale oil need many years of exploration and development before implementation. A quick solution was required to generate additional electricity capacities that compensate for Jordan's growing population and lifestyle where electricity consumption is increasing.

For this reason, in 2007, the Government of Jordan had set a strategy to increase RE's share in electricity production from 0 to 10% until 2020 (EMRC 2014). In 2012, the Renewable Energy and Efficiency Law 13 (REEL) as well as by-laws allowed Independent Power Producers (IPP) to provide NEPCO with electricity from renewable energy resources through long-term Power Purchase Agreements (PPA). Different residential and public sectors are committed to installing on-grid PV projects that will feed the excess electricity produced to the grid. Renewable energy systems can be connected on-site if space was available, or consumers can connect using a wheeling scheme allowing net metering aggregation. Aggregate net metering allows consumers to generate electricity on one site and consume it on another. Table 2 shows the rates Jorden applies for different wheeling charges and expected grid losses:

Type of Connection	Electricity Losses (%)	Charge (JD/kWh)
Connection to transmission system for a user connected to the transmission system	2.3	0.0045
Connection to distribution system for a user connected to the distributed system	6	0.007
Connection to transmission system for a user connected to the distribution system	8.3	0.0115

Table 2 Jordan’s Connection fees

Two primary laws organize the RE sector in Jordan are as follows:

With the General Electricity law No. 64/2002, the electricity market in Jordan has been updated over the years to reach a state of a competitive wholesale market operating under a multiple-buyer business model. This law is a general framework that regulates the generation and distribution of electricity.

Renewable Energy and Energy Efficiency Law No. 13/2012: According to this law, all Jordanian companies responsible for distributing energy are required to purchase all the power produced by licensed renewable energy power plants. Article 10 of this Law states, "prices of electricity to be sold to the licensed distribution companies shall not be less than the purchase price determined by the licensed distribution companies."

- Article 8 of law 13/2012 states that the electrical power generated by RE licensed facilities should be sold to the Bulk Supply Licensee or the Retail Supply Licensee according to the PPA concluded under this law.
- Article 10 of law 13/2012 states any person, no matter how small the facility is, may sell the generated electrical power to the Bulk Supply Licensees and the Retail Supply Licensees. The selling price should be set under the Commission's instruction, but it should not be lower than the tariff set by the licensees.

- Article 11 of law 13/2012 states that all equipment used in renewable energy sources and its production will be exempted from all customs and sale tax.

a. Examples of Jordan's PV system installments:

Jordan's investment in the Renewable Energy sector has created 10,900 jobs. By the end of 2015, distribution companies received more than 2000 applications and about 35 MW were installed. The target is to reach 11% of their total energy generated from renewables by 2025 (UNDP, 2017).

Different institutions in Jordan had their contributions to use PV installations for electricity production. For example, mosques in Jordan have high electricity bills; 400 mosques took the initiative to shift to RE to produce electricity by installing PVs on rooftops. This led the Renewable Energy and Energy Efficiency Fund (JREEEF) to launch a project that would include more mosques relying on PVs for electricity. In collaboration with the Ministry of Energy and Mineral Resources and the Ministry of Awqaf and Islamic, this project which was funded with about 5.6 Million USD, and aims to install systems ranging between 2 to 3 kW on each mosque (Tsagas, 2016b). Other institutions, such as universities, joined the transition to PVs under the Renewable Energy and Efficiency Law 13 (REEL). Jordan has 30 universities under which ten are public, all of which pay 0.37 USD/kWh for conventional electricity, making PVs an attractive investment. The majority of Jordanian universities have either implemented PVs or in the process of implantation. For example, in 2014, Philadelphia University (PHU) installed a 1.5 MW solar PV on its campus premise dividing its installment into 3 equal phases (Philadelphia University, 2014). Moreover, in 2013, the Hashemite University had set a bid for domestic and international companies to design and build a

5 MW photovoltaic park on its campus. This system started producing electricity in 2017.

Philadelphia University and Hashemite University are not an exception; Table 3 shows a list of universities that are adopting solar PV systems.

	University name	PV capacity [MW]
Operating systems	Al-Ahliyya Amman University	0.276
	Al-Zaytoonah University	0.164
	Amman Arab University	1.5
	Applied Science University	1.5
	Arab Open University	0.25
	Petra University	1.5
	Philadelphia University	0.7
	Balqa Applied University	0.079
	Jadara University	0.5
	Tafila Technical University	0.03
	Zarqa University (private)	1.89
	Total	**8.39**
Under construction	Al Quds College	1.06
	Al-Zaytoonah University	1.6
	Applied Science University	0.57
	Irbid National University	0.25
	Jerash University	0.5
	Tafila Technical University	1
	Hashemite University	5
	Total	**9.98**
Awarded	Al-Hussein Bin Talal University	53
	Jordan University of Technology and Science	5
	Total	58

Table 3 PV systems in Jordanian Universities

2. *Egypt*

The Arab Republic of Egypt is a low-middle income country surrounded by the Mediterranean Sea from the north and the Red Sea from the east; it's a country spanning between northeast Africa and southwest Asia. The majority of Egypt’s landscape is desert with a few scattered oases. It has 100 million inhabitants in 2019, making it a heavily populated country and home for one of the rapidly growing populations globally (CAPMAS, 2020). Due to this rapid increase in population, power demand is increasing by 6% annually (MOERE, 2017). Even though Egypt is considered the biggest non-

OPEC oil producer, its oil consumption outpaces its oil production. The energy sector in Egypt is considered one of the major contributors to its GDP, making its growth dependent on the energy supply's stability (Trading Economics, 2017). In 2007, Egypt started experiencing a shortage in energy supply and domestic depletion in its hydrocarbon resources, changing the countries status from a net exporter to a net importer. This bought up a set of obstacles to the energy sector, namely electricity shortage and the subsidized electricity price. This urged the Egyptian government to take a major step towards a diversification strategy that secures the energy supply stability by 2030, known as the Integrated Sustainable Energy Strategy (ISES). The target of the ISES is to reach 20% RE in the electricity mix by 2022 and 42% by 2035 (EU, 2015). This strategy includes the development of renewable energy, and energy efficiency should be deployed in parallel with reforms and maintenance of the power sector. In parallel, in July 2014, the Egyptian government started its five-year plan to phase out its subsidies in the power sector.

On the other hand, Egypt's abundance of renewable energy resources comes as an advantage for the ISES 2030 to be accurately deployed by the government. Egypt enjoys an average of 9 -11 hours of daily sunshine with a global horizontal radiation intensity of about 2000-3000 kWh/m^2 per year (IRENA, 2016). Moreover, Egypt is endowed with substantial wind resources that can be used in the generation of electricity. The average annual wind speeds reach 8-10 m/s by the Red sea coast and 6-8 m/s along the Nile banks and the Western Desert (IRENA, 2016). Egyptian Electricity Authority (EEA) had full authority over the generation, transmission, and electricity distribution. The new Electricity laws in 2015 ended the transmission and distribution monopoly aiming to secure a competitive power market through bilateral contracts. The electricity sector is currently managed by the Ministry of Petroleum and Mineral Resources and the Ministry of Electricity and Renewable Energy (MOERE) and with the Supreme Energy Council's overall governance (SEC). This sector is regulated by the Egyptian Electric Utility & Consumer Protection Regulatory Agency (EgyptERA), which manages licenses and implanting policy decisions. Also, the MOERE gave EgyptERA the authority to set tariff prices and remove this burden from the government (EgyptERA, 2015).

Egypt has set several laws and regulations to govern the electricity sector and promote investment in renewable energy. The below summarizes some of these laws:

- Electricity law – Law No. 87/2015: The Electricity Law provides restructuring of the electricity utility roles and the Consumer Protection Regulatory Agency (EgyptERA). The law also emphasizes opening up the Egyptian electricity market for competitiveness and contributes to the production of distributed "clean energy." This can be done by setting a framework to liberalize the market by demonopolizing the generation and distribution activities and integrating the private sector in the electricity generation process.
- Renewable Energy Law (Decree No.203/2014): This law aims to encourage the private sector's participation in producing energy using renewable energy sources. This law will allow a gradual shift from government-administered projects into privately financed projects through several established schemes such as (Article 2):
    - Private-to-Private: Under Egypt's electricity law, this scheme allows private producers of electricity to self-consume electricity or sell it to

third parties. This motivated some local and international investors to start developing IPPS businesses. The projects can be either on the investors' land or land leased by the NREA for 25 years. The negotiation between the investor and off-takers is set through a bilateral PPA, which EgyptERA embeds.

- Power wheeling: The Egyptian law allows the self-production of power on an external site. The excess energy generated will be injected into the national grid, which is subjected to wheeling charges that differ depending on the level of voltage of the network. Egypt has set its wheeling charges as follows:

Type of distribution network	**Piasters/kWh**	**$c/kWh***
Medium distribution network	7.21	0.42
High voltage	5.53	0.32
Extra high voltage	1.96	0.11
* Using exchange rate between Egyptian Pound and US Dollar of 1 Egyptian Pound = 0.058 USD		

Table 4 Egypt ERA sets power wheeling fees

- Net Metering: In January 2013, Egypt took the first step of integrating electricity produced by IPPs into the national grid. Through circular No. 1/2013, EgyptERA adopted the net metering scheme that allows small-scale RE projects, less than 10 KW, to feed in the national utility grid. All system owners should apply for a meter and get the engineering approval of Egypt Electric Cooperative Association (EECA). Each month the meter is monitored for production and consumption. If the system owner has excess production, the net metering credits can be kept for an annual period with the ability to rollover. However, if the owner used more electricity than produced, they must pay the deficit to the utility.

These reforms encouraged Egypt to install 4813 MW of renewable energy power, which created an additional 4200 jobs in the sector by the end of 2018. Moreover, Egypt has installed 60 MW of solar power connected to the utility grid under a net-metering mechanism and 80 MW under a solar feed-in tariff regime (NREA, 2018).

Egypt’s implementation of solar power system projects is still a relatively small market funded mainly by international donors. However, one of the massive projects currently under construction is the Benban 1.8 GW solar Park which is considered one of the world's largest. This type of project can be considered the first real step for Egypt towards deploying renewable energy according to the ISES 2030. The Benban power plant is located in the western deserts with high radiations and is divided into 41 connected slots. In 2013, the Egyptian government allocated 37.2 KM^2 of land to the NREA for the purpose of renewable energy production (NS Energy, 2018)However, under Presidential Decree Number 274, the land ownership was transferred to the New and Renewables Energy Agency (NREA). The project was funded by major international lenders such as the European Bank for Reconstruction and Development, the African Development Bank, the Asian Infrastructure Investment Bank, and the Dutch Development Bank. The solar park will contain 32 individual solar power projects operated by 45 different companies. The first phase with a 50 MW solar power plant came into operation in March 2018, and the whole project was completed by the end of 2019. With the Benban solar park project's completion, it will be producing 1650

MW of electricity, which can power thousands of Egyptian homes and businesses. Mohamed Orabi, a professor of power electronics at Aswan University, mentioned in one of his interviews that the Benban solar park played a major role in decreasing solar panels' prices in Egypt. In addition, he pointed out that around 3000 Egyptian workers who worked on the site have gained experience in installing solar PV systems and are now ready to share their expertise with other countries.

Jorden and Egypt have put RE on the rise and have strived to develop their RE sector further. The two selected countries have managed to do the aforementioned by combining their efforts to expand this sector. By establishing applicable laws that clearly dispense each institution's duties, these countries have incentivized the entire RE sector. Setting the necessary regulations in Lebanon related to net metering and bilateral RE trade (on-site or off-site) would give citizens incentives to start investing in RE systems and consume their self-produced electricity, which is needed progress in our times.

F. Lebanese Electricity Sector and Regulations

Lebanon has been suffering from power shortages ever since the Civil War (1975 to 1990). As a result, Lebanon's electricity sector fell behind, compared to other countries, due to the lack of a clear policy that sets goals for the sector's development. Since then, minimal investment in the power plants and infrastructure have been made. In addition, the Syrian refugee influx in 2011, led to a significant impact on the generated capacities which resulted in enlarging the electricity deficit. The Lebanese power sector is facing major challenges which are impacting the end-users, the government, and the entire economy. As stated by the IMF in 2019, Lebanon's consumer peak demand was estimated at 3,200 MW, which is much higher than the national electricity utility EDL's capacity to generate (IMF, 2019). In 2018, EDL delivered between 55-64% of Lebanon's electricity need despite production barriers (World bank, 2020). This deficit in electricity supply has led to daily outages which were compensated for through environmentally harmful private generators. EDL is currently applying a tariff structure that has been used since the 1990s, using rates that have not been changed since 1996, which are well below the EDL's production costs. The average production cost by EDL varies between $c16-22/kWh depending on the prices of oil (Ahmad et al. 2020). For EDL to break even, tariff costs must increase significantly. The average break-even tariff for EDL, including technical and non-technical losses, is estimated at $c23/kWh , of which, only $c0.9/kWh is paid by the end-user (Ahmad, 2020). Over the decades, these subsidies have led to Lebanon's major fiscal imbalances. According to a recent Byblos Bank publication, treasury transfers to EDL were equivalent to 3.2% of GDP in 2018 and 2.8% of GDP in 2019.[1] Aggregate transfers from the treasury to cover EDL’s losses totaled around $43 billion between 1993 and 2020 - or around 46% of Lebanon’s public debt[2] (Audi Bank, 2021). Renewable energies offer Lebanon the opportunity to decentralize installations and electricity production as a means of replacing diesel generators until reaching the targeted energy mix.

~~Until the COP meeting in Copenhagen in 2009, Lebanon never had a tangible commitment to invest in its renewable energy sector. However, after the COP meeting,~~

[1] Compared to 5.1% of GDP in 2012, 4.3% of GDP in 2013, 4.4% of GDP in 2014, 2.3% of GDP in 2015, 1.8% of GDP in 2016, and 2.5% of GDP in 2017

[2] $23.1 billion between 2001 and the end of August 2020 (Byblos Bank, 2021)

~~the Lebanese Government had set a target to have a 12% RE of the country's energy mix 2020, which was recently updated to 30% by 2030 (IRENA, 2020). These commitments were an important part of the policy papers for the electricity sector issued by the MEW in 2010 and 2019.~~ On the policy level, the Lebanese government did not favor renewable energy over traditional resources. The law that currently governs the Lebanese electricity sector is Law 462/2002. This law established a new structure of the energy sector and sets a legal framework for its unbundling. It divided the sector into three: production, transmission, and distribution where production and distribution becomes partially privatized. Nonetheless, Article 5 of Law 462/2002, keeps EDL the sole institution responsible for electricity transmission. Moreover, this law initiates the appointment of the Electricity Regulatory Authority (ERA), which becomes responsible for ensuring competition in the sector, adjusting non-competitive tariffs, and issuing long-term licenses for IPPs to generate electricity and feeding it into the grid. Although Law 462 came into force in 2002, it was never implemented, and no licenses were granted at that stage since the ERA has not been achieved yet (IFI,2020).

Law 288 (2014) came to temporary amend law 462/2002, and issue exceptional licenses for power purchase agreements between 2014 and 2016 until the ERA is appointed. The government did not grant any permits under law 288; thus, the amendment of Law 288 (under Law 54/2015) came to extend the period the first time till 2018 and under law 129/2019 extend it another time till April 2022, to allow IPPs to generate electricity and feed it to the grid via PPAs. Under law 54/2015, one power purchase agreement for 3 wind farms/projects in Akkar were signed; these projects' combined capacity is over 226 MW (ERBD, 2019).

Based on the aforementioned, Decree 16878 Article 4 indicates that "natural and legal persons are eligible to produce electricity for their consumption and to cover their personal needs only." In this context, in 2011,based on the decision No. 318-32 of EDL's board of directors, net metering was introduced to inject excess power produced on consumer's premise into EDL's grid credited against their monthly bills. Due to the novelty of the net metering scheme, EDL has established a Net Metering Committee responsible for the implementation process's supervision.

On the other hand, a draft law for the Distributed Renewable Energy Generation is currently being prepared to set a basis for establishing projects that promote peer-to-peer distributed renewable energy generation through net metering in all its forms, trading through direct power purchase agreements and/or renewable energy equipment leasing. All what was previously mentioned would be effective immediately once ratified by the parliament and announced in the official newspaper. At another level as well, is the Energy Efficiency Law that is targeted to promote behavioral changes and the usage of more efficient appliances and equipment through a combination of economic policies and incentives.

CHAPTER III

METHODOLOGY

A. AUB Background

The American University of Beirut (AUB) is a private and independent university located in Beirut, Lebanon, and founded in 1866. AUB currently has around 800 faculties and about 8000 students with leading bachelor's, master's, MD, and Ph.D. degrees. The AUB campus is approximately 250,000 m^2 consisting of 64, buildings including four libraries, three museums, and seven dormitories. Figure 10 below shows how faculties and buildings are located on AUB campus.

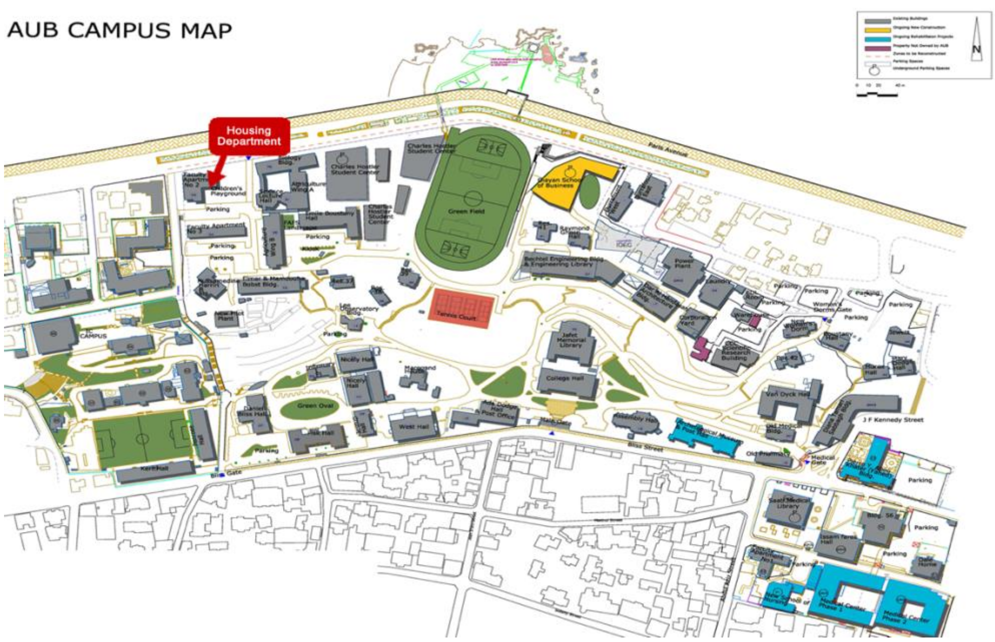


Figure 10 Shows AUB building

B. Model Specification

AUB is the leading university in the Middle East aiming to provide excellence in education, promote advanced knowledge through research, and contribute to the development of the local and national community. In order to achieve these objectives, AUB needs to be a leader in sustainability and a case in point for others to follow. We took AUB as a case study that can be later generalized for other corporations. This paper aims to undertake a techno-financial viability for various scenarios of increased solar PV penetration at AUB, subject to various policies available for corporate sourcing of renewable energy systems. This will be done by analyzing quantitative data collected from AUB facility mangers and calculation done through excel sheets.

C. Measures

During the meeting with AUB's Physical Plant Department manager, Mr. Khaled Bechara, the needed data and information related to AUB's monthly electricity consumptions, in addition to their electricity costs for both EDL's power and the diesel generators was gathered. In addition, an interview was conducted with Dr. Mohamad Khaled Joujou, assistant to the Dean for Operations at AUB, who supported us with a study previously conducted showing potential buildings on AUB premise for solar PV installation and buildings that solar panels are already implemented with their specified capacity.

According to data provided by Dr. Mohmad Khaled Joujou, we evaluated all the capacities and locations of potential solar PVs or that are already installed on-premise.

Building on Dr. Joujou's data, this strategy will be using solar PVs meter-aggregation net-metering to combine AUB's consumption. Using the global solar atlas, the capacity factor for the areas under study was calculated using the following formula:

$$\text{Capacity factor} = \frac{Actual\ Energy\ Produced\ (MWh)}{Capacity\ (MW) x\ Time\ (hrs)}$$

Two different cases were considered; on-site and off-site solar PV systems with three strategies in each case. To study all possibilities that AUB could use to receive maximum generation capacity from solar PV systems.

1. In both cases the following formulas will be used for:

Initial investment of the project

*Cost of solar PV ($/KW) * Total Number of solar PVs installed (KW)*

Operation and Maintenance Cost is considered as 3% of Capital cost:

*O&M = 0.3 * Initial investment*

Benefits are defined as the amount of money saved in installing PVs instead of conventional electricity i.e the difference between current cost of kWh (assumed to be approximately 0.24 USD per kWh) and the cost of kWh after PV installation:

*Benefits = 0.24*Produced KWh[3] – LCOE*Produced KWh*

Dynamic payback period is the amount of time it takes to recover the cost of an investment, inclusive of the time value of money:

Dynamic Payback Period= $- I_o + \sum_{t=1}^{T} \frac{(R_t - A_t)}{(1+i)^t} = 0$

[3] Produced kWh= Nb of kWh produced by the system*8760* Capacity factor

2. ***Case one is considered as On-site power generation with 3 different strategies:***

a. Strategy One:

AUB is given sole ownership of the solar power system; it would pay initial investment costs and the cost of operation and management. This case will use solar PVs with meter-aggregation net-metering since according to Dr. Joujou AUB power meters are set per building to collect building consumption.

To estimate the profitability of the investment in solar PV systems, the Levelized Cost of Electricity (LCOE) was other indicator to be calculated. The LCOE gives the present value of building and operating this project over an assumed period taken as 20 years. The target is to have an LCOE for these systems lower than the current price of electricity.

$$\text{LCOE} = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}$$

where: Io is initial investment cost in $
A is estimated Annual costs
i: discount rate
E: annual expected electricity generation

Strategies two and three are similar, in considering a third-party private company that develops, owns, operates, and maintains the PV system for a pre-determined period and leases them to AUB through a *Power Purchase Agreement* (PPA). A PPA, as afore-mentioned, is a a long-term electricity supply agreement between two parties; the power producer and a off-taker or customer (in this case AUB). The PPA is tailored to specific applications, but mainly includes the amount of electricity to be supplied, negotiated prices, accounting, and penalties for non-compliance. PPAs are convenient to reduce risks and investment costs encountered with planning or operating renewable energy systems.

b. Strategy Two:

This strategy considers a PPA contract of 10 years duration, where the investor will be leasing electricity for AUB. In addition to the LCOE formula mentioned above, the following formulas were used to show the project's profitability and feasibility.

The NPV formula shows the future cash inflows and outflows and are discounted to the present value. A positive NPV indicates that the project's expected earnings would exceed its anticipated costs both in present value.

$$\text{NPV} = -I_o + \sum_{t=1}^{n}\left(\frac{R_t - A_t}{(1+i)^t}\right)$$

where: Io is initial investment cost in $
A : estimated Annual costs
i: discount rate
R: Estimated annual Revenues

To estimate the profitability of this project, the Internal Rate of Return (IRR) was calculated. The IRR is the discount rate that equates the NPV to 0. For the project to be taken for further analysis, the IRR should be greater than the hurdle rate, which is equal to the firm's capital cost. If otherwise, then the project must be rejected.

$$\text{IRR: } I_o + \sum_{t=1}^{n}\left(\frac{R_t - A_t}{(1+IRR)^t}\right) = 0$$

where: Io is initial investment cost in $
A : estimated Annual costs
i: discount rate
R: Estimated annual Revenues

The Hurdle rate is obtained by applying the Weighted average Capital Costs (WACC) formula

$$\text{WACC} = \frac{Debt}{Total\ Capital}\ x\ Debt\ Interest\ Rate + \frac{Equity}{Total\ Capital}\ x\ Required\ Return\ on\ Equity$$

c. Strategy Three:

This strategy calculates the LCOE of the third-party private company for seven years PPA contract. After this period this strategy assumes that AUB will regain the system's ownership and thus calculates the NPV of all benefits from years 8 through 20. Taking into assumption that AUB currently pays only 0.11 USD per kWh for EDL, this strategy will calculate the NPV of this amount over 13 years and compare it to the NPV of the benefits of this strategy.

In brief, using an excel sheet, we input the aforementioned equations to calculate the NPV, compare the WACC to the IRR, and most importantly, calculate the LCOE to show how much AUB would be saving in implementing solar power systems. The three strategies will be compared to AUB's current electricity bill to EDL and diesel generator costs to enable a comparative analysis of the economic situation with and without solar PV interventions.

3. Case two is considered for off-site power generation with 3 different strategies:

The second case focuses on solar power systems installed off-site: This case will be using multi-site aggregate net-metering. Similar to the first case concerning determining the local capacity of electricity production, the possibility of off-site power generation from a large solar PV system will be assessed using multi-site aggregate net metering. This case is focused on installing the system in the Beqaa valley, where according to the Global Solar Atlas, has a higher capacity factor than Beirut. Simulations on the net metering implications, including wheeling charges, will be undertaken.

This case also includes three strategies the first being AUB as sole owner of the PV system, the second being a 10-year PPA with a third-party private company, and the third being a combination where the PPA is for seven years after which AUB gains the ownership over the system. Similar to the first case, LCOE, NPV, IRR, and WACC will be calculated. One major difference is that the three strategies is that power has to be transported from Beqaa to Beirut (AUB), thus additional wheeling fees are administered for the use of the 66 KV transmission lines. The below Figure 11 shows Lebanon's electricity transmission network including major load centers.

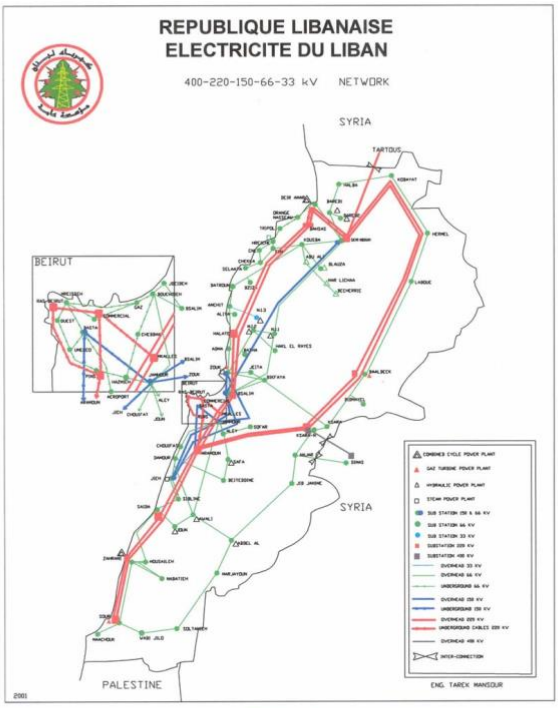


Figure 11 Electricity Transmission Network of Lebanon showing major load centers

Several indicators were missing for calculating wheeling fees, which created a barrier to calculate a definite number for Lebanon. For this reason, the case of Jordan was taken into consideration, and wheeling fees were extracted from the literature (shown in Table 2). According to the World Bank report in 2018, the technical losses on the transmission and distribution lines are estimated to be 18%. Thus to calculate the incurred losses, the total number of electricity produced (kWh) will be multiplied by 0.18. To get the final total wheeling charges; electricity produced after accounting for the losses will be multiplied by wheeling fees adopted from the Jordanian case.

CHAPTER IV

RESULTS

One way to enhance AUB's environmental performance is through decreasing their dependence on the Lebanese electricity grid and on the locally AUB-owned diesel generators. This would have a further importance contribution to lowering AUB's operating and maintenance costs at a time when it is most needed. For that, AUB can benefit from its multiple facilities to reach its target of low emission campuses.

During our interviews with Mr. Khaled Bechara, *Coordination Center Engineer*, data showed that AUB's total annual electricity consumption is 36,965,982 kWh from EDL Mreisse readings and 13,899,605.6 kWh from its on-premise power plant diesel generators adding up to 50,865,588 kWh annual consumption. This is equivalent to 6,285,035 million USD paid for electricity per year, of which 2,218,777 million USD are the cost of fuel for the generators. Taking the assumption from data observation, AUB is getting 70% of its electricity from EDL and 30% from generators, thus AUB will be an average of 0.24 USD per kWh, as shown in Table 5.

	2019	2018	2017	2016
Cost of Electicity from EDL in $/KWH	4066258.02	3956190.04	3684191.94	3416837.82
Amount of Oil gas Consumed LTS	4023236.1	4146308.4	3697140.4	4482886.25
Cost of Gas Oil for Gen in $/LTS	2218777.17	2286650.4	2038938.436	2472269.941
Total Costs	6285035.19	6242840.44	5723130.376	5889107.761

Table 5 Shows total costs AUB pays annually for electricity for years 2016-2019

Moreover, Dr. Mohmad Khaled Joujou provided data that includes all AUB buildings with potential for PV systems installations, in addition to data about current AUB solar PV system deployed on SRB and BRB Buildings. The data showed that an average of 1700 KW (with associated 2,680,560 kWh of approximate annual production) can be produced only from solar PV systems installation on AUB premise. Table 6 below shows the location and the capacity of solar PVs on AUB buildings.

AUB Buildings		
Building	# Panels	Total KW
Architecture	192	63
Biology	288	95
Chemistry	166	55
Corporation Yard	54	18
Hariri	182	60
Hostler	872	288
IFI	164	54
IOEC	378	125
Jafet	184	61
Jewett Hall	94	31
Kerr Hall	322	106
Murex Hall	66	22
New Women	72	24
OSB	376	124
Penrose	170	56
Physics	316	104
Pilot Plant	108	36
Agriculture Wing A + SLH	318	105
Agriculture Wing B	368	121
SRB+BEB	474	150
Total	5164	1698

Table 6 Showing the location and Capacity of AUB Building

These roof tops installation of PVs that generate electricity will displace part of AUB's need for power from diesel generators and the Lebanese grid. This will lead AUB to be generating electricity at lower costs and with lower carbon emissions. This paper aims to provide a realistic and practical assessment of what AUB can achieve if it maximized its reliance on renewable energy and in specific, solar photovoltaic power.

A. Case One Analysis

All data collected and analyzed in case one show that electricity cost from renewable energy sources is much lower and has more economic and environmental benefits. To start with, the calculation of case one's initial investment cost is based on the assumption (with reference to Dr. Harajli) that the cost of solar PV is 800$/kW. This is based on latest UNDP procurement of such systems (reference Dr. Harajli). Thus, the initial investment for case one is 1,360,000 USD, in addition to annual O&M costs of 40,800 USD.

Strategy 1 considers AUB a sole owner of the PV systems though out the assumed 20 year lifetime of the system. In this strategy the LCOE was calculated in addition to the payback period. According to the calculations, the LCOE of implementing this plan is 0.055 USD per kWh. Considering that AUB currently pays an average of 0.24 USD per kWh for EDL and generators combined, it will be saving 0.185 USD per kWh. Table 7 shows detailed calculations of the LCOE.

Case 1: S.1	Benefits	Costs (A)	R-A	(1+i)^t	AC/Dis	AP/ DIS
1	495903	**40800**	455103.00	1.050	38857.14	2552914.3
2	495903	**40800**	455103.00	1.103	37006.8	2431346.9
3	495903	**40800**	455103.00	1.158	35244.57	2315568.5
4	495903	**40800**	455103.00	1.216	33566.26	2205303.3
5	495903	**40800**	455103.00	1.276	31967.87	2100288.9
6	495903	**40800**	455103.00	1.340	30445.59	2000275.1
7	495903	**40800**	455103.00	1.407	28995.8	1905023.9
8	495903	**40800**	455103.00	1.477	27615.05	1814308.5
9	495903	**40800**	455103.00	1.551	26300.04	1727912.9
10	495903	**40800**	455103.00	1.629	25047.66	1645631.3
11	495903	**40800**	455103.00	1.710	23854.91	1567267.9
12	495903	**40800**	455103.00	1.796	22718.97	1492636.1
13	495903	**40800**	455103.00	1.886	21637.11	1421558.2
14	495903	**40800**	455103.00	1.980	20606.77	1353865
15	495903	**40800**	455103.00	2.079	19625.5	1289395.2
16	495903	**40800**	455103.00	2.183	18690.95	1227995.4
17	495903	**40800**	455103.00	2.292	17800.9	1169519.4
18	495903	**40800**	455103.00	2.407	16953.24	1113828
19	495903	**40800**	455103.00	2.527	16145.95	1060788.6
20	495903	**40800**	455103.00	2.653	15377.09	1010274.9
TOTAL			9102060	34.72	508458.2	33405703
			LCOE	0.05593		
				5.5 cents		

Table 7 LCOE calculation of Strategy 1, Case 1

The LCOE of solar PVs calculated are compared to the present value of benefits from integrating solar power. In all cases, these benefits include and are not limited to: the reduced consumption of conventional capacity, savings on fuel for generators, and emissions through the project's lifetime. Thus, if the LCOE of 2,680,560 kWh is 0.055 USD/ kWh, then the cost of electricity per year will be 147,430.8 USD compared to 643,334.4 USD at the current rate of 0.24 USD/kWh; resulting in total benefits of 495,903 USD per year. On the other hand, the Internal Rate of Return for this strategy is 33% taking into consideration a WACC of 5% (IRR > Hurdle rate). This shows the high profitability and attractiveness of this investment, in addition to its payback period of 3 years.

In the second strategy, a third-party private company will be leasing AUB electricity for 10 years through a PPA; the LCOE, IRR, and benefits were calculated. These are the levelized costs, should not be mistaken with the (PPA) 'price' that the solar PV developer will ask from the government of Lebanon. The PPA price is expected to be higher than the LCOE as it will integrate risks and profits. The LCOE was calculated to be 0.097 USD/KWh considering a WACC of 10% as shown in the below table.

Case 1: S.2	Benefit	Costs (A)	R-A	(1+i)^t	AC/Dis	AP/ DIS
0	-1360000					
1	383320.08	**40800**	342520.08	1.100	37090.91	2436872.7
2	383320.08	**40800**	342520.08	1.210	33719.01	2215338.8
3	383320.08	**40800**	342520.08	1.331	30653.64	2013944.4
4	383320.08	**40800**	342520.08	1.464	27866.95	1830858.5
5	383320.08	**40800**	342520.08	1.611	25333.59	1664416.9
6	383320.08	**40800**	342520.08	1.772	23030.54	1513106.2
7	383320.08	**40800**	342520.08	1.949	20936.85	1375551.1
8	383320.08	**40800**	342520.08	2.144	19033.5	1250501
9	383320.08	**40800**	342520.08	2.358	17303.18	1136819.1
10	383320.08	**40800**	342520.08	2.594	15730.17	1033471.9
TOTAL			LCOE	17.53	250698.3	16470881
			9.7 Cents			

Table 8 LCOE calculation of Strategy 2, Case 1

The benefits for this strategy are 383,320.08 USD which is definitely less than the first strategy taking the same amount of produced kWh. This is due to higher risks the third part company is accounting for as it will be responsible for securing the required investment. In addition, the IRR for this strategy is 25% which is still much higher than the hurdle rate (WACC), taken as 10%. This shows that this strategy is still profitable and AUB will be saving 0.143 USD/ KWh.

For strategy three, LCOE is calculated for the first seven years where the company will be leasing AUB electricity through the PPA as shown in the below table (Table 9).

Case 1. S3	Benefit	Costs (A)	R-A	(1+i)^t	AC/Dis	AP/ DIS
1	1688752.8	**40800**	1647952.80	1.100	37090.91	2436873
2	1688752.8	**40800**	1647952.80	1.210	33719.01	2215339
3	1688752.8	**40800**	1647952.80	1.331	30653.64	2013944
4	1688752.8	**40800**	1647952.80	1.464	27866.95	1830859
5	1688752.8	**40800**	1647952.80	1.611	25333.59	1664417
6	1688752.8	**40800**	1647952.80	1.772	23030.54	1513106
7	1688752.8	**40800**	1647952.80	1.949	20936.85	1375551
Total	11821269.6			10.44	198631.49	13050089
		LCOE	0.12	/ 12 cents		

Table 9 LCOE calculation of Strategy 3, Case 1

Even though this strategy shows the highest LCOE for PV systems , AUB will still be saving 0.12 USD for every kWh generated. This gives an annual average benefit of 321,667.2 USD which AUB could allocate for other pressing academic enhancements and needs

However, after year seven (8 through 20), the NPV will be calculated for the benefits AUB will be having in producing its own electricity with no costs other than O&M. Table 10 shows the net present value (NPV) from year 8 through 20.

Year	Benefits	Costs	B-A	(1+i)^t	(R-A)/(1+i)^t
8	707667.84	40800.00	666867.84	1.10	606243.49
9	778434.62	40800.00	737634.62	1.21	609615.39
10	856278.09	40800.00	815478.09	1.33	612680.76
11	941905.90	40800.00	901105.90	1.46	615467.45
12	1036096.48	40800.00	995296.48	1.61	618000.81
13	1139706.13	40800.00	1098906.13	1.77	620303.86
14	1253676.75	40800.00	1212876.75	1.95	622397.55
15	1379044.42	40800.00	1338244.42	2.14	624300.90
16	1516948.86	40800.00	1476148.86	2.36	626031.22
17	1668643.75	40800.00	1627843.75	2.59	627604.23
18	1835508.12	40800.00	1794708.12	2.85	629034.25
19	2019058.94	40800.00	1978258.94	3.14	630334.26
20	2220964.83	40800.00	2180164.83	3.45	631516.09
Total	**17353934.73**				8073530.27
		NPV	6713530.27		

Table 10 NPV of Benefits

The total benefits (saving) is 17,353,934.73 USD which gives a net present value of 6,713,530 USD. If an assumption is taken that during the period between year 8 and year 20 AUB will be buying its electricity from EDL at the rate of 0.11USD/ kWh. Results show that the net present value AUB will be paying for electricity in this period is around 32 million USD, compared to net benefits of around 17 million USD. As a conclusion, if AUB were to implement this project, it would lessen its electricity budget and in turn use the saved money to compensate for its other expenses on campus.

EDL Case		Consumption	EDL Cost of KWh	Cost on AUB
	1	50865588	0.11	5595214.68
	2	50323142	0.11	5535545.62
	3	46254334	0.11	5087976.74
	4	46600527	0.11	5126057.97
	5	48510897.8	0.11	5336198.75
	6	48510897.8	0.11	5336198.75
	7	48510897.8	0.11	5336198.75
	8	48510897.8	0.11	5336198.75
	9	48510897.8	0.11	5336198.75
	10	48510897.8	0.11	5336198.75
		NPV	$32,858,827.97	

Table 11 NPV of Paying EDL at 10 cents/ KWh

B. Case Two Analysis

For the three strategies in this case, a 10 MW system is assumed to be implemented, thus taking initial investment costs at 800$/KWh, the total initial investment assumed is $9,000,000 and annual maintenance and operational costs are assumed to be approximately $270,000.

In this case, the solar PVs will be implemented in the Beqaa valley where the capacity factor is 21%. However, this requires the implementation of additional wheeling fees since the national transmission and distribution will be used. The wheeling fees are extracted from Jordanian literature and their pricing methodology of net-metering; in our case wheeling fees will be accounted for as 0.0063 USD per kWh (as shown in table 2). According to MEW, the power losses in Lebanon are accounted for 18%.

As aforementioned, this case is a 10 MW (18 396 MWh) solar PV system and accounts for 18% technical losses; thus AUB will be only billed for 15 084 MWh by EDL. This means that the meter in Beqaa will read 15 084 MWh but the PPA contract will based on 18 396 MWh, hence, wheeling charges paid will be an average of $95,000 year.

In the first strategy of this case the LCOE was calculated to be 0.07 USD/kWh. The benefits of implementing the solar PV system is 2,530,598.38 USD per year which means that AUB can displace this amount for other university investments. In addition, the IRR for this strategy is 31% which is still much higher than the hurdle rate (WACC) taken as 5%. This shows that this strategy is still profitable and AUB will be saving 0.17 USD/ kWh. Moreover, the discounted payback period for this strategy is 4 years.

Case 2. S1	Benefit	Cost	B-C	(1+i)^t	AC/ Dis	AP/Dis	(B-C)/(1+i)^t
1	2530598.4	365033.74	2165564.65	1.10	331848.85	13713381.82	1968695.13
2	2530598.4	365033.74	2165564.65	1.10	331096.36	13682285.71	1964230.97
3	2530598.4	365033.74	2165564.65	1.16	315329.87	13030748.3	1870696.16
4	2530598.4	365033.74	2165564.65	1.22	300314.16	12410236.48	1781615.39
5	2530598.4	365033.74	2165564.65	1.28	286013.48	11819272.83	1696776.57
6	2530598.4	365033.74	2165564.65	1.34	272393.79	11256450.32	1615977.68
7	2530598.4	365033.74	2165564.65	1.41	259422.66	10720428.87	1539026.36
8	2530598.4	365033.74	2165564.65	1.48	247069.2	10209932.26	1465739.39
9	2530598.4	365033.74	2165564.65	1.55	235304	9723745.011	1395942.28
10	2530598.4	365033.74	2165564.65	1.63	224099.05	9260709.534	1329468.84
11	2530598.4	365033.74	2165564.65	1.71	213427.67	8819723.366	1266160.8
12	2530598.4	365033.74	2165564.65	1.80	203264.44	8399736.539	1205867.43
13	2530598.4	365033.74	2165564.65	1.89	193585.18	7999749.085	1148445.17
14	2530598.4	365033.74	2165564.65	1.98	184366.84	7618808.652	1093757.3
15	2530598.4	365033.74	2165564.65	2.08	175587.47	7256008.24	1041673.62
16	2530598.4	365033.74	2165564.65	2.18	167226.16	6910484.038	992070.116
17	2530598.4	365033.74	2165564.65	2.29	159263.01	6581413.37	944828.682
18	2530598.4	365033.74	2165564.65	2.41	151679.06	6268012.733	899836.84
19	2530598.4	365033.74	2165564.65	2.53	144456.24	5969535.936	856987.467
20	2530598.4	365033.74	2165564.65	2.65	137577.38	5685272.32	816178.54
Total		LCOE	0.07	7.22	4533324.9	187335935.4	

Table 12 LCOE Calculation of Strategy 1, Case 2

Strategy two includes a 10-year PPA agreement with a third-party private company. The LCOE for this case was calculated at 0.1085 USD/ KWh, detailed calculations are shown in table 13 below, compared to 0.24 USD/ KWh, consequently saving around 2 million USD from implementing a 10 MW solar PV system. Furthermore, the IRR is calculated at 28%, lower than that in the first strategy, yet it is still a profitable investment with IRR> WACC (taken at 10% for this case).

Case2. S2	Benefit	Cost	B-C	(1+i)^t	AC/ Dis	AP/Dis
1	2958077	335033.74	2623043	1.10	304576.1	13713381.82
2	2958077	335033.74	2623043	1.21	276887.4	12466710.74
3	2958077	335033.74	2623043	1.33	251715.8	11333373.4
4	2958077	335033.74	2623043	1.46	228832.5	10303066.73
5	2958077	335033.74	2623043	1.61	208029.6	9366424.3
6	2958077	335033.74	2623043	1.77	189117.8	8514931.182
7	2958077	335033.74	2623043	1.95	171925.3	7740846.529
8	2958077	335033.74	2623043	2.14	156295.7	7037133.208
9	2958077	335033.74	2623043	2.36	142087	6397393.826
10	2958077	335033.74	2623043	2.59	129170	5815812.569
Total					2058637	92689074.31
		LCOE	0.109	10.85		

Table 13 LCOE Calculation of Strategy 2, Case 2

For the third strategy, the LCOE was calculated for the first seven years, while the NPV was calculated for years 8 till 20 to estimate the present value of the benefits to AUB when it owns the PV systems. The LCOE for years 1 through 7 was the highest in all six strategies at around 0.13 USD/ KWh as shown in table 14. This is due to higher risks taken by the company, shorter contract period, costs of wheeling, and losses in the transmission. Nonetheless, AUB will still be saving 0.11 USD/ KWh with total benefits of 1,659,319.2 USD per year.

Case2. S3	Benefit	Cost	B-C	(1+i)^t	AC/ Dis	AP/Dis
1	5430499.2	335034	5095465.5	1.10	304576.1236	13713381.8
2	5430499.2	335034	5095465.5	1.21	276887.3851	12466710.7
3	5430499.2	335034	5095465.5	1.33	251715.8047	11333373.4
4	5430499.2	335034	5095465.5	1.46	228832.5497	10303066.7
5	5430499.2	335034	5095465.5	1.61	208029.5906	9366424.3
6	5430499.2	335034	5095465.5	1.77	189117.8097	8514931.18
7	5430499.2	335034	5095465.5	1.95	171925.2815	7740846.53
Total					1631084.545	73438734.7
		LCOE	0.13	13.11		

Table 14 LCOE Calculation of Strategy 3, Case 2

Since after year seven (8 through 20), AUB will be having in producing its own electricity with no costs other than O&M, Table 15 shows that NPV of benefits is around 35 million USD.

Year	Benefit	Cost	B-C		(B-C)/(1+i)^t
8	3982366.08	365034	3617332.344	1.10	3288483.949
9	4380602.688	365034	4015568.952	1.21	3318652.026
10	4818662.957	365034	4453629.221	1.33	3346077.551
11	5300529.252	365034	4935495.516	1.46	3371009.847
12	5830582.178	365034	5465548.442	1.61	3393675.57
13	6413640.396	365034	6048606.66	1.61	3755708.85
14	7055004.435	365034	6689970.699	1.77	3776314.052
15	7760504.879	365034	7395471.143	1.95	3795046.055
16	8536555.366	365034	8171521.63	2.14	3812075.148
17	9390210.903	365034	9025177.167	2.36	3827556.142
18	10329231.99	365034	9964198.257	2.59	3841629.773
19	11362155.19	365034	10997121.46	2.85	3854423.982
20	12498370.71	365034	12133336.98	3.14	3866055.082
Total					47246708.03
		NPV	$35,471,361.75		

Table 15 NPV for benefits years 8-20

Assuming that EDL would be able to fully supply electricity with a tariff of 0.11 USD/KWh, will implementing solar PVs still be profitable? For this reason table

16 shows the present value of AUB paying its bills at 0.11 USD/ KWh for the next 10 years, compared to Table 15 where AUB would producing its own electricity. Results show that the NPV for paying 0.11 USD/kWh is around 42 Million USD while of AUB produces its electricity off -site it will be saving around 35 million USD.

EDL Case		Consumption	EDL Cost of KWh	Cost on AUB
	1	50865588	0.11	5595214.68
	2	50323142	0.11	5535545.62
	3	46254334	0.11	5087976.74
	4	46600527	0.11	5126057.97
	5	48510897.8	0.11	5336198.75
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	7	48510897.8	0.11	5336198.75
	8	48510897.8	0.11	5336198.75
	9	48510897.8	0.11	5336198.75
	10	48510897.8	0.11	5336198.75
		NPV	$32,858,827.97	

Table 16 NPV for AUB paying 11 cents/KWh

CHAPTER V

CONCLUSION

In conclusion, Lebanon is a country abundant with renewable energy potential, such as wind, solar and hydropower. Renewable energies offer Lebanon the opportunity to decentralize installations and electricity production as a means of replacing diesel generators until reaching the targeted energy mix. Our ultimate aim is to show that in being a “prosumer”, AUB could benefit financially from this action and help to contribute to Lebanon’s Nationally Determined Contributions (NDCs) under the Paris Climate Change Agreement. This will also be an incentive for decision makers to take needed measures enhance the installation of distributed renewable energy sources to be a step towards a solution to one of Lebanon’s major complication: the Lebanese Electricity Sector.

This study conducted a techno-financial viability for various scenarios of increased solar PV penetration at AUB, subject to various policies available for corporate sourcing of renewable energy systems. The key findings (in Table 17) show that this project is technically viable and economically feasible even if EDL set a low tariff of 0.11 USD/ KWh. If AUB were to implement any of the two cases presented in this study, it would be contributing to producing 41% of its electricity from a renewable energy source.

Case One				
	LCOE	IRR	PBP	NPV
Strategy 1	0.055USD/ kWh	33%	3 Years	2,812,855.67 USD

Strategy 2	0.0097 USD/ kWh	25%	-	744,637.62 USD
Strategy 3	0,12 USD/ kWh	-	-	6418385.55 USD
Case 2				
Strategy 1	0.072	28%	4 Years	17,987,722.14 USD
Strategy 2	0.109	17%	-	2,013,549.48 USD
Strategy 3	0.13	-	-	37843079.89 USD

Table 17 Summary of Study Results

It is important the upcoming months which will make distributed renewable energy more affordable than conventional electricity sources and power plants. Moreover, this study did not integrate the current situation of the country and the depreciation of the LBP nor the adjustments in the price of electricity that may happen in the near future (increase in the price of electricity or tariffs).Also, this study assumes 18% losses for 20 years which is a worst case scenario, and the GoL can actually improve this in the future. Finally one major short-coming of this study is not calculating the exact wheeling charges due to the lack of information. This can pave the way for future studies on these topics.

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