Lifecycle Assessment of Solar Pumping for Pumping Stations in Bekaa

Topic 10: Sustainability of Solar Pumping for Pumping Stations

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2021 -2022

Acknowledgments

Appreciation goes to:

- The Bekaa Water Establishment (BWE) for providing hydraulic data (flow, pump head, operating hours...) for the three stations;
- Nassrieh Municipality for providing the operating and maintenance costs of the Nassrieh Water Pump Station;
- Kherbet Qanafar Municipality for providing the operating and maintenance costs of the Kherbet Qanafar Water Pump Station;
- Kfardinis Municipality for providing the operating and maintenance costs of the Kfardinis Water Pump Station;
- Technical Supervisors at ACTED for reviewing the diesel and solar Lifecycle Cost Assessment calculations and solar system Bill of Quantities (BOQs).

List of Acronyms

WASH: Water, Sanitation, and Hygiene

NGO: non-governmental organization BWE:

Bekaa Water Establishment

l/p/d **:** Liter per person per day

LCC: Life Cycle Cost

EDL: Electricity Of Lebanon

kVA (kilo-volt ampere) : unit for generator power

DC: direct current

AC : alternating current

Hp (horsepower): unit for pump power

m^3/hr : unit for hourly flow rate m :

unit for pump head

l/hr : Liter per hour (unit for diesel consumption of generator)

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Abstract

Host communities and refugees in Bekaa are relying more on private water supply such as water trucking, incurring additional costs twice as much as high as that of public supply, where the demand exceeds supply. Hence, the purpose of this research paper is to explore the challenges of domestic water supply to host communities and Syrian refugees in the Bekaa Governorate, including the high prices of diesel due to the current economic crisis, which decrease the purchase ability of diesel, affecting diesel water pumps, and, thus; resulting in water shortages. As a result, this study will aim to display a life-cycle cost assessment and environmental impact assessment of solar water pumping for pumping stations, as an alternative to diesel pump systems, and as an approach for host communities and Syrian refugees in the Bekaa Governorate to have access to quality Water, Sanitation, and Hygiene (WASH) services.

Introduction

Water is a vital requirement for survival. Nothing is more essential to human health and well-being than water, whether for drinking, irrigation, cattle, or residential use. Every day, millions of cubic meters of water are pumped for rural uses all over the world, with electricity and onsite generators serving as the primary sources of power. Given the combination of high energy prices and lowering costs of renewable, especially solar PV technologies, renewable energy has started to become a more viable solution in recent years, providing farmers and rural residents with environmentally friendly power sources to pump water with competitive advantages over traditional diesel-driven generators.

In the Bekaa governorate, Lebanese host communities and Syrian refugees rely on a mix of public and private water sources to suit their needs, in which refugee households use around a third of the water that Lebanese households utilize. The major water sources in Bekaa are surface water, springs, and underground aquifers. Because few springs are located at elevation, water storage reservoirs must rely on pumping. Due to high diesel prices required to operate diesel pumps, power outages and unpredictable electricity, and consequently water shortages, this can be a concern. Thus, Bekaa region has a daily water supply of five hours on average, and there are days when there is no power supply, where 60 to 80 percent of linked households indicate that demand exceeds supply throughout the year, with the water deficit persisting (Machayekhi, et al., 2017). Since domestic water demand is not being met by public supply, households must rely on private sources (water delivered by truck). Consequently, Bekaa households are incurring additional costs by spending twice as much on private water purchases as they do on public water (200 to 300 percent higher than public water costs), weakening the regulation of public water providers (Oxfam, 2017). As a result, the economic impact of water scarcity might be deemed significant, particularly among lower socioeconomic classes (Machayekhi, et al., 2017). When compared to diesel generators, solar pumping is considered a more economically viable solution due to lower operating expenses related to diesel supply and maintenance costs, as well as a lower carbon footprint, meeting consumption needs especially in areas without power lines and operating best during sunny seasons when there is a demand for water peaks (UNDP, 2015).

Objectives

This research paper will tackle the subsequent questions in response to the water crisis in Bekaa:

1. What is the population and water demand for host communities and refugees in Bekaa?
2. What is the cost of diesel pumps in Bekaa?
3. What is the cost of diesel per liter in Bekaa?
4. How much does water trucking cost per month in Bekaa?
5. How does a solar system work?
6. What is the optimal design system for solar system?
7. What is the cost of a solar system in Bekaa?
8. How cost-effective and environmentally friendly is to install a solar system for pumping stations in Bekaa?

Advocacy plan

Our research paper explores the lifecycle assessment of solar water pumping stations in the Bekaa Governorate, as an alternative to current diesel systems, so as to render water supply and WASH services accessible to host communities and refugees, with a special focus on Informal Tent Settlements (ITS), which will be our water axis.

Stakeholders of the project include the Ministry of Energy and Water, Nassrieh, Kherbet Qanafar, and Kfardinis municipalities, the targeted population, and the NGOs/donors. Opponents of the project can be the Ministry of the Energy and Water, as it may impose the purchase of government diesel, and in turn decline solar energy, and the municipalities, as they may possess private diesel stations, and in turn reject the project to avoid losses to their profits. On the other hand, the targeted population and NGOs can be allies to the project, as they can exert pressure on the Ministry and municipalities, and influence them to accept the project due to the numerous benefits it can provide the region with.

The tools deployed are using diplomacy and lobbying to communicate with the Ministry of Energy and Water and the municipalities, where meetings and discussions can be held with official representatives, preparing online and in-person workshops and uploading posts about them on social media to inform the population about the project after negotiating with stakeholders and receiving their consent to publicize them, and contacting the NGOs and donor agencies via email or in-person meetings to discuss the importance of implementing the project.

Methodological Approach

1. Study area

The region under study is the Bekaa Governorate (33°50′N 35°54′E) in Lebanon, having an area of 1,433 km^2 (Wikipedia, 2022).

Figure 1. Location of the Bekaa Governorate (Wikipedia, 2022)

2. Population

2.1. Lebanese Host Communities

The Bekaa Governorate encompasses a Lebanese population of 150,838 in West Bekaa, 47,122 in Rachaya, and 336,382 in Zahle, a total of 534,342 since 2017 (UNHR, et al., 2019).

Table 1. Population of Bekaa Governorate in 2017 (UNHR, et al., 2019)

Name	Status	Population (2017)
Bekaa	Governorate	534,342
West Bekaa	District	150,838
Rachaya	District	47,122
Zahle	District	336,382

2.2. Syrian Refugees

According to the Ministry of Environment, the Bekaa Governorate hosts the most registered refugees in the country (34.6%), where, according to the UN, they count up to 275,000 in Bekaa Governorate since 2015. Syrian refugees are considered a vulnerable population, where over 54 % are living in poor shelters, including around 37% in informal settlements (Machayekhi, et al., 2017).

3. Water Demand

3.1. Lebanese Host Communities

According to a survey by Oxfam and EDESSA conducted in 2015 in different districts of Chtoura, the Lebanese host communities use 170 l/p/d. Also, Pierpaoli in 2016 estimated that the average water usage per capita for Lebanese communities is roughly 145 l/p/d in rural areas of North Bekaa (Machayekhi, et al., 2017).

3.2. Syrian Refugees

World Vision and its partners (Intersos, Sawa, and Oxfam) conducted an Emergency Market Mapping Assessment (EMMA) in 2014 in North, West, and Central Bekaa, focusing on Syrian refugees in all sorts of shelters and host communities (Machayekhi, et al., 2017):

3.2.1. Informal Tent Settlements

In Informal Tent Settlements (ITS), households' water needs were 33 l/p/day, but households receive 20 l/p/d instead, due to a lack of purchasing power, a lack of water storage tanks, and seasonal variations in the water provided by trucks or the municipal system. In terms of drinking water, ITS households have a shortage, with 2.5 l/p/d instead of the minimum 3 l/p/d (Machayekhi, et al., 2017).

3.2.2. Host Communities

As for host community contexts, the average water usage is higher, ranging from 80–160 l/p/d in metropolitan regions to 40–80 l/p/d in rural areas, but Syrian refugees residing in rented or owned host community housing receive only 70 liters per day instead of the standard 160 liters per day (Machayekhi, et al., 2017).

3.3.Available Water Resources

Surface water, springs, and subterranean aquifers are the main water sources in the Bekaa Governorate, where groundwater accounts for the majority of the sources of the public water network and public reservoirs. It is also the major water source for private water vendors and agricultural consumers. According to the Ministry of Energy and Water and UNDP, geological structures as pervasive fault networks NNE/SSW and diffuse karstic rocks are the major markers for water bearing formations, where these rocks have good water quality features and are mostly used as residential water resources via boreholes or springs (Machayekhi, et al., 2017).

The Bekaa Water Establishment (BWE) provides water to the area via 148 wells and 28 springs. Around 70% of the wells have a yield of less than 15 liters per second. Because few springs are located at elevation, water storage reservoirs must rely on pumping. Because of the unreliability of electricity, this can present issues (Machayekhi, et al., 2017).

4. Public and Private Water Supply Costs

A survey was posted to collect opinion polls of host communities and refugees about the causes of water shortages in the Bekaa Governorate. The results of this survey concluded that:

- The majority of households are not paying the monthly tariff for public water supply services as water demand is not being met, where water pumping is done only once a week.
- An average of 50 $/month is paid for private water-trucking services.

5. Studied stations

The study area (Bekaa Governorate) is large to be treated entirely. Thus, in order to represent the situation of water pumping stations in this area we will take 3 stations, each one refers to one of the three districts in the Bekaa Governorate.

Within each district, choosing a station was based on the following criteria:

- adequate area is available to install a solar system;
- no other projects of solar system installation are ongoing in these stations;
- the pumping stations suffer from severe scarcity of power.

After contacting the BWE, we specified some stations which were then filtered into 3 after contacting the referring municipality. In each of the three stations, water is pumped from a groundwater well to a water storage tank of about 1000 liters by a submersible pump, which is the pump under study in this paper, and whose hydraulic data (power, flow rate, pump head, operating hours…) were provided by the BWE. Then the water is pumped from the tank to the distribution network by a surface pump of a smaller size, which is neglected in this study. The three chosen stations are as follows:

5.1. Nassrieh Water Pump Station (Zahle District)

Nassrieh is located in the Zahle District of the Bekaa Governorate. It is 867 m above sea level, 14 km from the Zahle District and the Bekaa Governorate, and 50 km from Beirut (Lebanese Ministry of Interior, 2014).

The following data were attained from the BWE and Nassrieh Municipality for the Nassrieh Water Pump Station. The major power source is the EDL, but is not sufficient for the water pump to operate at the recommended rate of 6 hours per day. Being unstable (less than 3 hours per day), the EDL service line was eliminated from the design, and the water pumping system was considered to be completely dependent on solar energy.

Table 2. Nassrieh Water Pump Station

Station name	NASSRIEH 1 WELL
Main power source	EDL
Connected to electricity service line	YES
Availability of Generators on site	YES
Generators KVA	400
Operating Hours of Generator since Installation	>30,000
Current supply hours per day using EDL	3
Recommended operating hrs	6
Water Pump	
Available at Site?	Yes
Type of Pump	AC
Pump Power (Hp)	150
Operating Hours per Day	8
Flow rate (m^3/hr)	85
Pumping Head (m)	200

5.2. Kherbet Qanafar Water Pump Station (West Bekaa District)

Kherbet Qanafar is located in the West Bekaa District of the Bekaa Governorate. It is 949 m above sea level, 8 km from the West Bekaa District, 34 km from the Bekaa Governorate, and 67 km from Beirut (Lebanese Ministry of Interior, 2014).

The following data were attained from the BWE and Kherbet Qanafar Municipality for the Kherbet Qanafar Water Pump Station. The major power source is the EDL, but is not sufficient for the water pump to operate at the recommended rate of 6 hours per day.

Table 3. Kherbet Qanafar Water Pump Station

Station name	KHERBET QANAFAR WELL
Main power source	EDL
Connected to electricity service line	YES
Availability of Generators on site	YES
Generators KVA	250
Operating Hours of Generator since Installation	>30,000
Current supply hours per day using EDL	3
Recommended operating hrs	6
Water Pump	
Available at Site?	Yes
Type of Pump	AC
Pump Power (Hp)	125
Operating Hours per Day	8
Flow rate (m^3/hr)	36
Pumping Head (m)	230

5.3. Kfardinis Water Pump Station (Rachaya District)

Kfardinis is located in the Rachaya District of the Bekaa Governorate. It is 1,133 m above sea level, 10 km from the Rachaya District, 41 km from the Bekaa Governorate, and 83 km from Beirut (Lebanese Ministry of Interior, 2014).

The following data were attained from the BWE and Kfardinis Municipality for the Kfardinis Water Pump Station. The major power source is the EDL, but is not sufficient for the water pump to operate at the recommended rate of 6 hours per day.

Table 4. Kfardinis Water Pump Station

Station name	KFARDINIS WELL
Main power source	EDL
Connected to electricity service line	YES
Availability of Generators on site	YES
Generators KVA	175
Operating Hours of Generator since Installation	>30,000
Current supply hours per day using EDL	3
Recommended operating hrs	6
Water Pump	

Available at Site?	Yes
Type of Pump	AC
Pump Power (Hp)	100
Operating Hours per Day	8
Flow rate (m^3/hr)	29
Pumping Head (m)	580

As for the chlorination system employed by the three pumping stations before the water is pumped to the distribution network for domestic use, 500 g of sodium hypochlorite (bleach) are manually added to the 1000 |L water storage tank for disinfection, in which the chlorine solution is left for 24 hours before flushing it out from the tank.

6. Lifecycle cost analysis

The life cycle costing method is used to evaluate different systems that provide the same service. This approach compares systems on an equal level by lowering all future expenses that occur at different periods of the system's life to a single value known as the Life Cycle Cost (LCC) of a project. Future costs comprise operating costs, maintenance costs, and replacements.

This method gives a realistic picture of the expenses incurred during the lifetime of the project that delivers a certain service and may be used for comparison. The LCC approach is especially significant in renewable energy projects, which typically startle investors due to high startup costs. The traditional alternative, which is frequently dependent on a fossil energy, looks to be less expensive due to lower initial capital costs, however the running costs can build up to a significant sum throughout the project life - cycle.

6.1. Formula

The money spent today in relation to the money that will be spent in the future is fairly balanced by life cycle cost analysis. For each indicated alternative, the costs should be converted into dollars, added together, and then expressed as a total cost in today's money. The net present value is another name for this amount. The comparison is simple since units are constant when the net present value for the alternative is determined. The alternative with the highest net present value or lowest life cycle cost is the best choice.

The formula used is:

$$LCC = C + \sum_{n=1} \left(\frac{C_n}{1+d}\right)$$

Where

LCC: the life cycle cost

C: the capital cost at year 0 C_n

: costs at year n

d: discount rate

n: number of periods

6.2. Capital Cost

The initial capital costs of a project only occur once at its start. They include the price of the tools and supplies, the price of installation, and the price of transportation.

6.2.1. Diesel System

Nassrieh, Kherbet Qanafar, and Kfardinis stations have on-site generators of 400, 250, and 175 kVA, respectively. However, all these generators exceeded the needed operating hours for replacement (30,000 hours). Thus, a new generator for each station will considered at the beginning of the project.

After checking different supplier and technician, the following tables were prepared for the capital cost of the diesel system for each station.

Table 5. Capital cost of the diesel system

Nassrieh Station			
Component	**Unit**	**Qty**	**Total Price (USD)**
Generator	kVA	400	$50,000
Installation and Accessories	$		$1,500
Total Capital Cost			**$51,500**
Kherbet Qanafar Station			
Component	**Unit**	**Qty**	**Total Price (USD)**
Generator	kVA	250	$45,000
Installation and Accessories	$		$1,500
Total Capital Cost			**$46,500**
Kfardinis Station			
Component	**Unit**	**Qty**	**Total Price (USD)**
Generator	kVA	175	$15,000
Installation+ Accessories	$		$1,000
Total Capital Cost			**$16,000**

6.2.2. Solar System

A reliable solar pumping system is one that is appropriately sized and constructed to meet the needs of the task. There are numerous designs for numerous applications, necessitating technical design and study to prevent system underperformance or irrational cost increases. Solar PV pumping requires more austerity because system components are very expensive and efforts need to be made to reduce system setup costs as opposed to traditional utility or private generator powered systems, where large pumps are typically installed to pump water in large volumes whenever power is available.

1- Water storage

Because the water pump in the three stations only operates during the day, there is no need to install batteries for power storage and charge controllers for voltage control at night, which eliminates their high initial and maintenance costs.

Since battery storage is a huge burden due to its high capital and maintenance costs, water storage is more feasible as enough solar power is adequate during the daytime, where the system can deliver sufficient water more than the daily demand. The pumped water can be stored in water tanks, which should be sized according to the climate and water usage patterns to guarantee enough storage volume.

2- Orientation

Installing solar panels with a maximum tolerance of 35 degrees from the flat surface towards the south in an unshaded area must be done in order to maximize their performance.

3- Tilt Angle

The solar radiation should strike the panel's surface at a perpendicular angle, so as to attain the maximum amount of solar rays into a given area.

4- Pump type

The PV panels provide DC form of electricity; thus, the use of an inverter is required since the existing pumping system is of AC form. However, it must be taken into consideration that the inverter will cause a reduction in efficiency.

Thinking of changing the pumping system to DC will not be suitable in our case, since the DC pumps are only applicable for compact situations where a modest flow need exists. Also, it will not be feasible since the AC system is already installed.

6.2.2.1. Solar system components

The solar system is composed of the following components:

1- Solar Panels

The photovoltaic panel captures solar radiation and transforms it into electrical energy is a photovoltaic panel. Solar panels lose their efficiency according to weather conditions, and efficiency losses should be taken into account to properly size solar systems. To calculate the required number of solar panels, 30% losses were considered in our design.

2- Mounting Track

Depending on the site conditions, solar panels can be mounted on the ground, a roof, or a post. The panels are held in place by metallic frameworks that are made to endure strong winds and unexpected weather. The mounting track should be adequately coated and shielded from elements like rain, humidity, and other conditions.

3- Inverter

An inverter is an electronic control system that converts direct current (DC) to alternating current (AC), and is mainly used in large solar water pumping projects where the required flow is relatively high.

4- Electrical Accessories

The electrical accessories of a solar system include: cables, junction boxes, connectors, switches, earthing kits for safety against lightning, and short circuits.

5. Installation Components

The installation components of a solar system include fittings and pipes as plumbing requirements to connect the pump to the system.

6.2.2.2. Solar system design

The following section elaborates the method used in order to design the solar system for the three stations.

Solar Panels

The most common types of solar panels in the Lebanese market are monocrystalline and polycrystalline panels, with monocrystalline as the most efficient type.

Monocrystalline 545 Watt high power solar panels was considered, as recommended by the municipalities.

The following formulas were used to calculate for each station:

- The PV Power Needed (kW) = $\frac{Pump\ Power}{Inverter\ Efficiency\ x\ Efficiency\ Factor}$

where Inverter Efficiency = 0.85 and Efficiency Factor = 0.8

- The Number of Solar Panels (Considering 30% Losses)

$$= \frac{Power\ Needed\ (Watt)}{545\ Watt} \times 1.3$$

Operating Hours

According to Cedro, 2013, the status of solar energy in Lebanon is around 300 sunny days per year with 8 to 9 hours of sunshine per day. So, 8 operating hours per day on average were considered in the design of the solar system.

6.2.2.3. Solar system capital cost

After checking the local market, we prepared a detailed bill of quantities (BOQ) for the solar system chosen in the three stations (Appendix I). The following table shows the total capital costs for the solar system:

Table 6. Total Capital costs for the solar system

Station	Solar System Capital Cost ($)
Nassrieh	$118,029
Kherbet Qanafar	$98,009
Kfardinis	$78,540

6.3. Operating costs

Diesel system operating costs include: labor cost and fuel consumption costs. The labor cost refers to the salary of the workers responsible of operating the stations. For the fuel consumption costs, the type of generator as well as the loading factor affect its fuel consumption. The following table provides the oil consumption of the engines in each station.

We will consider that the generator will operate for 6 hours a day in order to fulfill the daily needs for each station. However, this value doesn't consider the safe yield of pumping.

Table 7. oil consumption of the engines in each station

Station	Nassrieh	Kherbet Qanafar	Kfardinis
Generator Power (kVA)	400	250	175
Load (%)	50%	70%	75%
Operating hours per day	6	6	6
Fuel consumption (l/hr)	42	41.6	41.4
Fuel consumption (l/day)	252	249.6	248.4

The solar system operating costs only include the labor cost. The workers are responsible of operating and managing the station.

For both diesel and solar systems, the labor cost in each station is taken to be 400 $/month.

6.4. Maintenance and replacement costs

Both Diesel and PV systems are subject to maintenance and replacement.

Diesel system

To ensure the diesel generator set's long-term trouble-free operation, proper maintenance is required. Minor and major maintenance services include engine oil and filters changing, wiring system inspection, cooling system flushing, labor, transport…

Furthermore, it's primarily to restore the dynamic performance, economical performance, and fastening performance of diesel engine parts. With an overhaul, the core components are kept while replacing only the major engine components. Even with the additional labor costs, a lot of money will be saved compared to replacing the engine. The areas of the engine with poor performance will determine which parts should be replaced during the overhaul. Boring out the cylinders and installing new piston rings, bearings, and gaskets are standard components of a generator set refurbishment.

The lifespan of a generator is a crucial aspect to take into account during the study period. A diesel generator's lifespan is primarily influenced by its engine size, quality, and environmental considerations. When the generator reaches its theoretical lifespan, it will be replaced and, in our case, no residual value will be considered.

The following tables show the frequency of change in hours for each maintenance type and replacement as well as their average costs.

Table 8. Frequency of change for each maintenance type and replacement for the Diesel system as well as their average costs

Station	Nassrieh station		Kherbet Kanafar station		Kfardinis station	
Generator Maintenance	Good Quality Engine		Good Quality Engine		Good Quality Engine	
Maintenance and Replacement	Frequency of change (h)	Price (USD)	Frequency of change (h)	Price (USD)	Frequency of change (h)	Price (USD)
Minor & Major Service	520	2,000	520	1,500	520	1,000
Overhaul	13,000	30% Generator cost	13,000	30% Generator cost	13,000	30% Generator cost
Replacement	30,000	Generator Cost	30,000	Generator Cost	30,000	Generator Cost

Solar system

Solar system requires only some preventive and minor services (panels cleaning, wiring system inspection). Generally, solar panels should be cleaned from two to four times per year to ensure that dirt, leaves, and other debris aren't blocking the sun's radiation. The following table indicates the expected cost of the preventive and minor services costs for the solar system in each station.

Table 9. Preventive and minor services costs for the solar system

Station	Preventive and Minor Service ($/year)
Nassrieh	1,500
Kherbet Qanafar	1,200
Kfardinis	900

With good cleaning and preventive services, PV modules can reach a 25 years lifespan, which will be considered for the need of replacement. The component of the solar panel system that works the hardest is the solar inverter. By converting DC electricity to AC, it makes sure that your solar panels can produce as much electricity from the sun as possible. But after a few years of use, they are prone to malfunction like any hard-working component. For this study, we will consider the need for inverters' replacement after 7 years of operation.

6.5. Financial parameters

A project life of 25 years, and a discount rate of 10% are considered for both diesel and solar systems of each station. The discount rate represents the rate of interest used to determine the present value of future costs by discounting them. For Lebanon,

Table 10. Financial parameters

Parameter	Value	Unit
Project life	25	years
Discount rate for Lebanon	10	%

7. LCC comparison

The LCC detailed calculations are mentioned in the Appendices (Appendix IV to IX). The following table and graph show the present worth of the total costs for both, the diesel and solar systems for the three stations.

Table 11. LCC for diesel and solar system

Station	Diesel System LCC ($)	Solar System LCC ($)	% Solar/Diesel
Nassrieh	$1,492,553	$186,156	12.5%
Kherbet Qanafar	$1,451,219	$162,270	11.2%
Kfardinis	$1,374,395	$138,935	10.11%

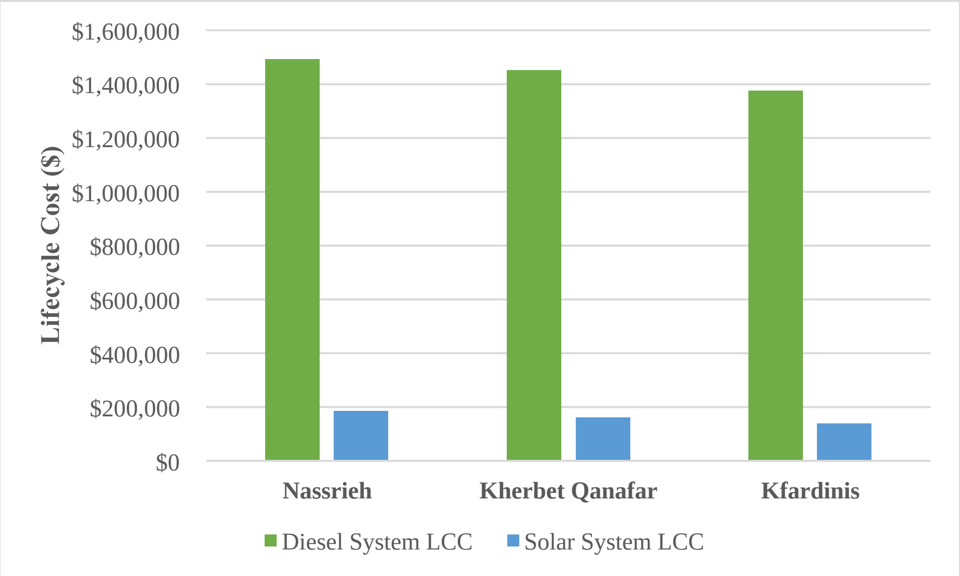

Figure 2. LCC for diesel and solar system

Looking at the total present worth for both diesel and solar systems, it is obvious that the solar system have much lower LCC than the diesel one. Compared to the diesel system, the solar system LCC represents a maximum of 12.5% of diesel LCC at the Nassrieh station. Thus, on average among the stations, the solar system exhibits a decrease in costs of around 90%.

The LCC breakdown of both diesel and solar systems are shown in the figures below. The pie charts, in figures 2, illustrate how costs are distributed for the diesel system at the three stations, and the pie charts, in figure 3, illustrates how costs are distributed for the solar system at the three stations. Looking at the diesel system, it is clear that the main costs are the operational ones. These costs form 89% of the LCC for the Nassrieh station, 91% of those for the Kherbet Qanafar station, and 95% of those for the Kfardinis station. The breakdown is normal for a system of renewable energy and demonstrates that the initial capital cost accounts for the majority of the costs. Additionally, it is clear that the capital cost of the solar system increases with system size. Nassrieh station has the largest system size and it shows the highest capital cost.

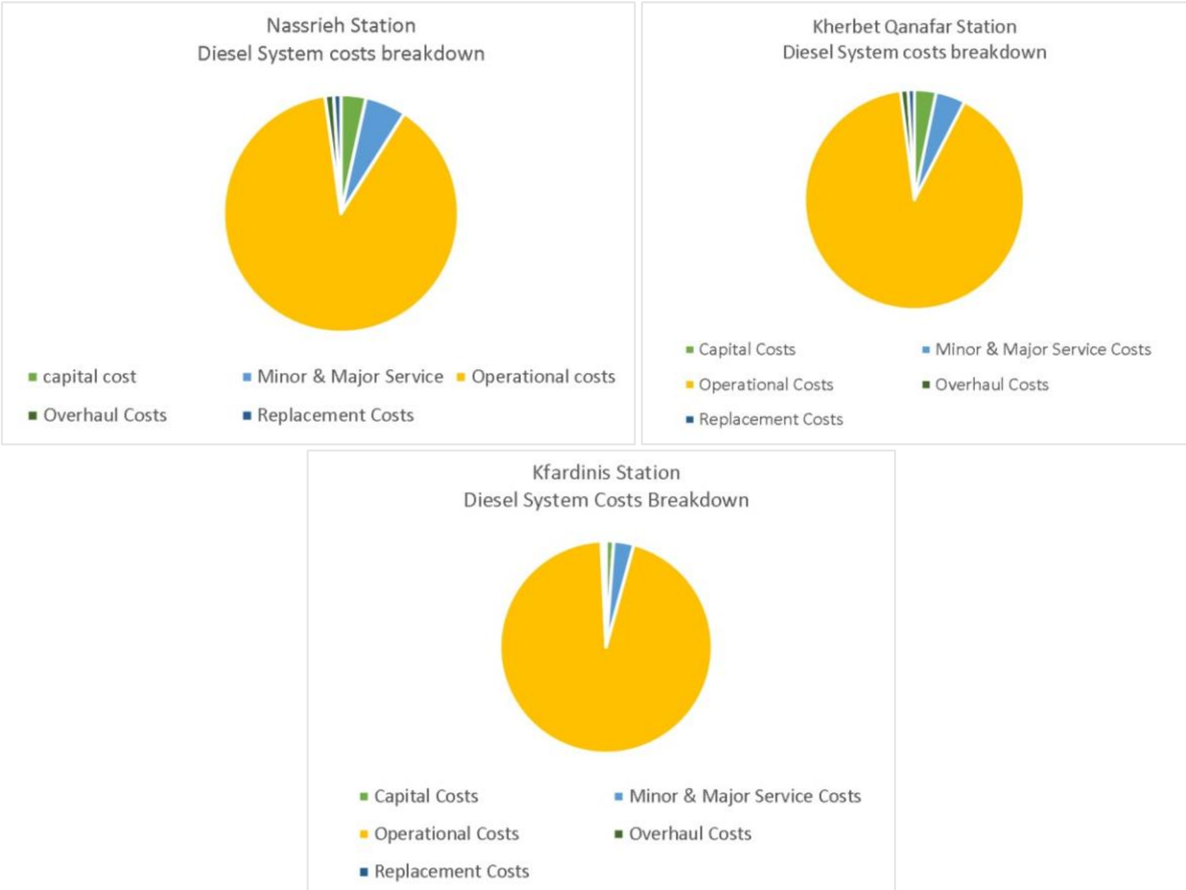

Figure 3. Cost breakdown for diesel systems

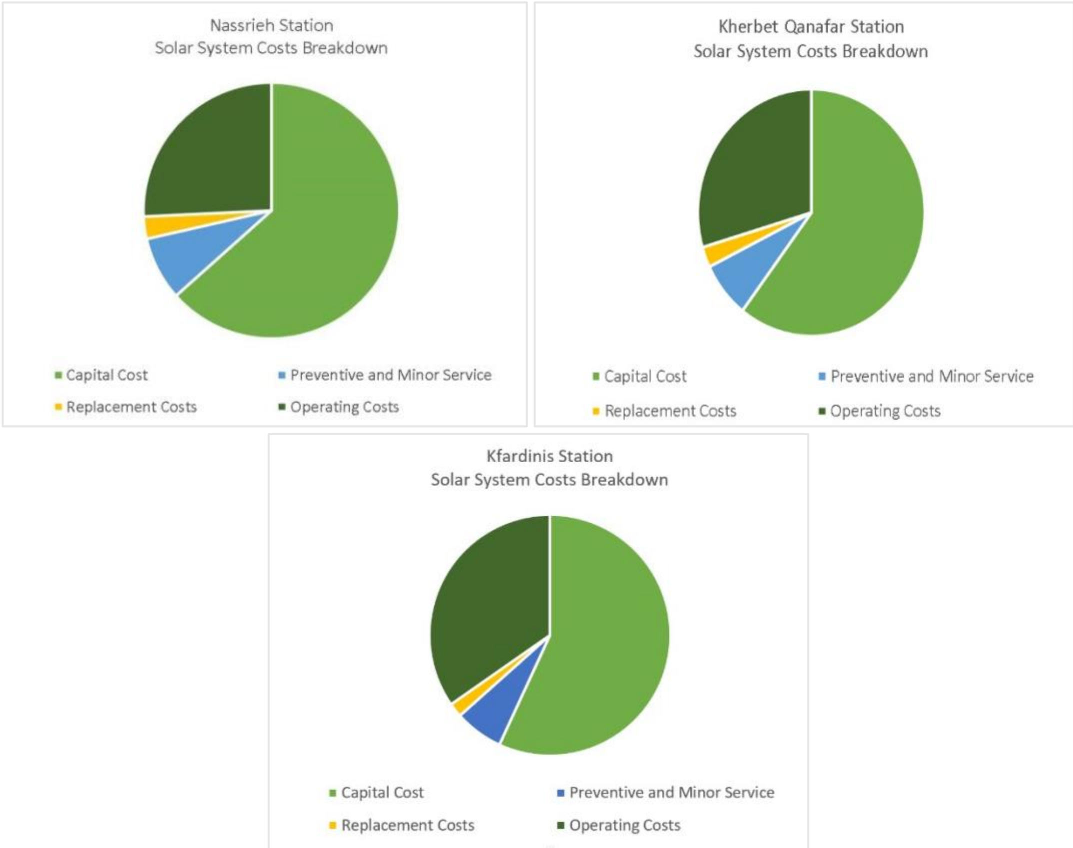

Figure 4. Cost breakdown for Solar system

8. Breakeven between solar system and diesel system

The decision between solar and diesel systems should be based on a comparison of their life cycle costs, with the option that will cost less throughout the project duration being chosen. The years to breakeven, or the point at which the cumulative LCC of PV becomes less than the cumulative LCC of diesel systems, is a measure of attractiveness.

Figures 8, 9 and 10 show the cumulative costs of both the diesel and solar systems for the three studied stations. The breakeven occurs within the first year in all the stations. The solar system starts with having a higher cost (capital cost), however, it becomes more feasible with less than a year of operation.

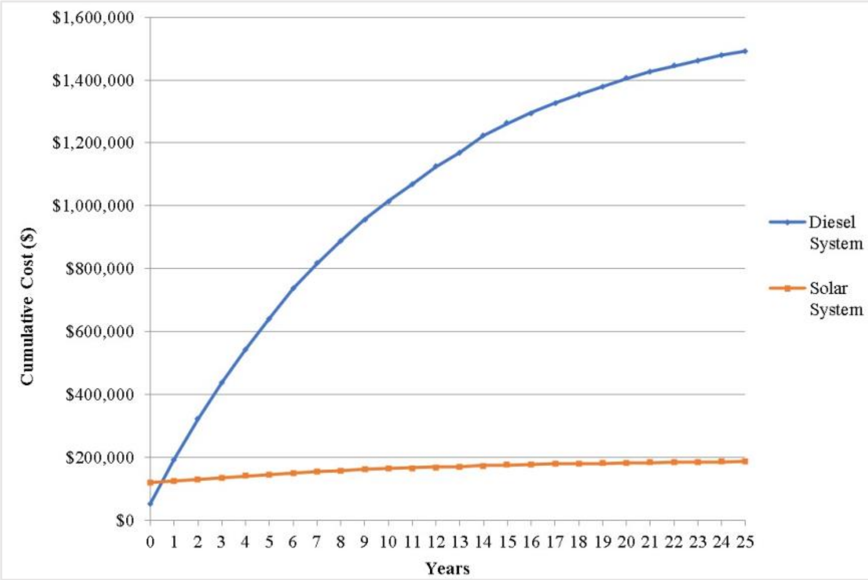

Figure 5. Cumulative Cost of Diesel system vs. Cumulative Cost of Solar System as a Function of Years (Nassrieh Station)

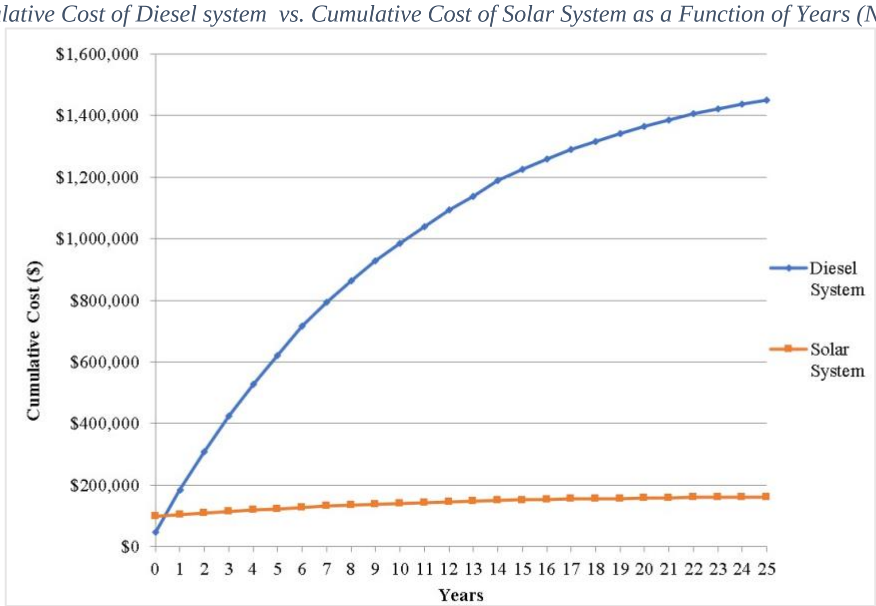

Figure 6. Cumulative Cost of Diesel system vs. Cumulative Cost of Solar System as a Function of Years (Kherbet Qanafar Station)

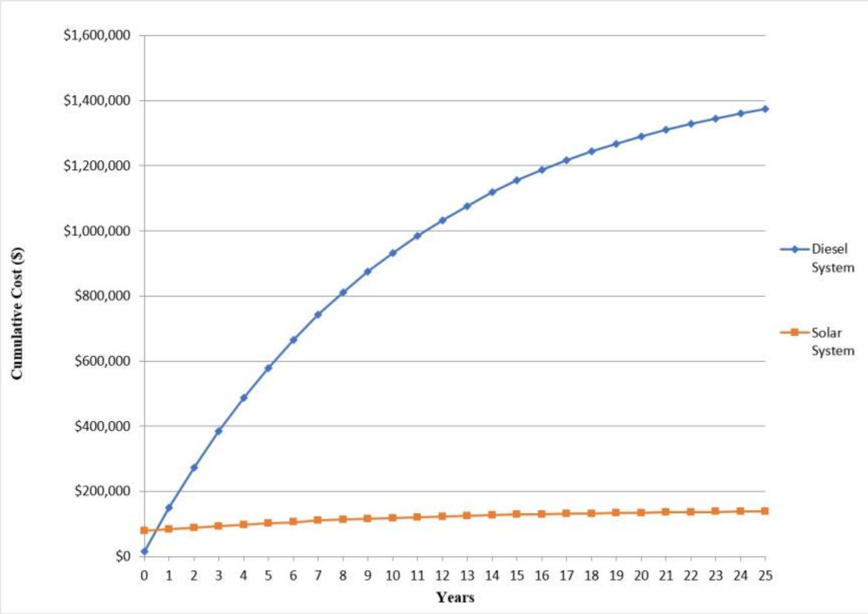

Figure 7. Cumulative Cost of Diesel system vs. Cumulative Cost of Solar System as a Function of Years (Kfardinis Station)

Notes:

*The typical lifespan of a solar system is around 25 years, and with the required annual preventive and minor service costs and replacement costs of accessories every 7 years within the 25 year span (as indicated in Appendices VII, VIII , and IX), the solar system is expected to last without changing it.

*Regarding the performance of already installed solar water pumping systems by other municipalities, the 75 Hp solar water pumping system of the Bqosta Municipality in South Lebanon proved to be efficient in supplying water to residents at low elevations, but inadequate to supply water at higher elevations whether in the wet or dry season. So, for this particular case, the Municipality was obliged to purchase a generator to assist the solar system in pumping.

9. Environmental Impact

According to the findings, diesel-powered pumping systems are more environmentally hazardous than solar-powered pumps (Armanuos, et al., 2016). This is for diesel pumps are powered by onsite diesel generators to provide electricity to the pumps, making them the most contaminating technology, which is highly reliant on oil availability and pricing (UNDP, 2015). Around 97% of global warming potential is linked to the fuel lifecycle: diesel consumption alone accounts for 65% of global warming, fuel manufacture accounts for 25%, transportation accounts for 5%, and generator manufacturing accounts for 5% (Naseem & Imran, 2007). The contribution of diesel fuel pump environmental impacts to midpoint environmental impacts is

70% for natural resources, 18% for human health, 10% for climate change, and 2% for ecosystem quality (Armanuos, et al., 2016).

Unlike diesel pumps, solar pumps are the most practical non-fossil water pumping devices (UNDP, 2015). Solar pumping systems, on the other hand, contribute 3% to climate change, 2% to human health and natural resource impacts, and 0.5% to ecosystem quality (Armanuos, et al., 2016). Solar energy's main advantage is that it creates virtually no emissions, resulting in clear environmental benefits in terms of greenhouse gas reduction (Naseem & Imran, 2007). In 2016, Green Essence Lebanon estimated that its solar water pumping projects avoided about 1,000 tons of CO_2, the equivalent of growing 26,000 trees (The Switchers Community, 2017).

Furthermore, solar water pumps do not contribute to noise pollution as they do not produce noise, unlike diesel pumps (UNDP, 2015).

The following are the annual carbon dioxide emission levels in kg/year for the diesel generator of each station, where 1 liter of diesel is equivalent to 2.6 kg of CO_2 on average (Jakhrani, et al., 2012):

Table 12. Annual carbon dioxide emission levels in kg/year for the diesel system

Station	**CO_2 emissions per year (kg/year)**
Nassrieh	355,306
Kherbet Qanafar	271,489
Kfardinis	235,732

Conclusion

The main findings of this study are:

- Even though solar systems have high capital costs, they are more feasible than the diesel systems on the long-term.
- Switching to a renewable energy (solar energy) helps in eliminating the greenhouse gas emissions, making solar an environmentally-benign solution.
- Sustainable water pumping, which will enhance water supply and WASH services for Lebanese host communities and Syrian refugees in the Bekaa Governorate.

Appendices

Appendix I: Solar system BOQ – Nassrieh Station

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Nassrieh Station

		Bill Of Quantity				
Works		**Material description**	**Unit**	**Unit Price**	**QTY**	**Total Price**
ELECTRICAL WORK						
1	Supply and Install solar power system	**PV modules and mounting kit**				
		545 W Monocrystalline Solar Module	No	188	394	74,072
		Special PV mounting Structure	Ls	60	394	23,640
		Panel Boards				
		4-Way Connector	No	14	197	2,758
		40 A Circuit Breaker	No	20	18	360
		Inverters				
		30 kW DC-to-AC Inverter	No	880	6	5,280
		Cables				
		Black G-Tech RG59 Coaxial Cable	Lm	58	1	58
		Red G-Tech RG59 Coaxial Cable	Lm	58	1	58
		Installation				
		Transportation and installation of all the equipment and materials	Ls	11,803	1	11,803
Total Price:						**$118,029**

Appendix II: Solar system BOQ – Kherbet Kanafar Station

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Kherbet Qanafar Station

		Bill Of Quantity				
	Works	Material description	Unit	Unit Price	QTY	Total Price
		ELECTRICAL WORK				
1	Supply and Install solar power system	**PV modules and mounting kit**				
		545 W Monocrystalline Solar Module	No	188	327	61,476
		Special PV mounting Structure	Ls	60	327	19,620
		Panel Boards				
		4-Way Connector	No	14	164	2,296
		40 A Circuit Breaker	No	20	15	300
		Inverters				
		30 kW DC-to-AC Inverter	No	880	5	4,400
		Cables				
		Black G-Tech RG59 Coaxial Cable	Lm	58	1	58
		Red G-Tech RG59 Coaxial Cable	Lm	58	1	58
		Installation				
		Transportation and installation of all the equipment and materials	Ls	9,801	1	9,801
		Total Price:				**$98,009**

Appendix III Solar system BOQ– Kfardinis Station

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Kfardinis Station

			Bill Of Quantity				
Works			**Material description**	**Unit**	**Unit Price**	**QTY**	**Total Price**
ELECTRICAL WORK							
1	Supply and Install solar power system		**PV modules and mounting kit**				
			545 W Monocrystalline Solar Module	No	188	262	49,256
			Special PV mounting Structure	Ls	60	262	15,720
			Panel Boards				
			4-Way Connector	No	14	131	1,834
			40 A Circuit Breaker	No	20	12	240
			Inverters				
			30 kW DC-to-AC Inverter	No	880	4	3,520
			Cables				
			Black G-Tech RG59 Coaxial Cable	Lm	58	1	58
			Red G-Tech RG59 Coaxial Cable	Lm	58	1	58
			Installation				
			Transportation and installation of all the equipment and materials	Ls	7,854	1	7,854
Total Price:							**$78,540**

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Appendix IV Diesel system LCC Nassrieh Station

Year (n)	Capital Cost	Generator Working Time (hrs/year)	Cumulative Hours for Overhaul	Cumulative hrs for Replacement	Minor & Major Service ($/year)	Diesel Consumption (l/year)	Cost of Diesel ($/year)	Overhaul Costs ($/year)	Replacement Costs ($/year)	Labor Costs ($/year)	Pr Factor	Total Costs in Present Worth ($/year)
0	$51,500	2,190	2,190	2,190	$8,423	91,980	$127,852			$4,800	1.000	$192,575.28
1		2,190	4,380	4,380	$8,423	91,980	$127,852	$0	$0	$4,800	0.909	$128,250.25
2		2,190	6,570	6,570	$8,423	91,980	$127,852	$0	$0	$4,800	0.826	$116,591.14
3		2,190	8,760	8,760	$8,423	91,980	$127,852	$0	$0	$4,800	0.751	$105,991.94
4		2,190	10,950	10,950	$8,423	91,980	$127,852	$0	$0	$4,800	0.683	$96,356.31
5		2,190	140	13,140	$8,423	91,980	$127,852	$15,450	$0	$4,800	0.621	$97,189.88
6		2,190	2,330	15,330	$8,423	91,980	$127,852	$0	$0	$4,800	0.564	$79,633.32
7		2,190	4,520	17,520	$8,423	91,980	$127,852	$0	$0	$4,800	0.513	$72,393.92
8		2,190	6,710	19,710	$8,423	91,980	$127,852	$0	$0	$4,800	0.467	$65,812.66
9		2,190	8,900	21,900	$8,423	91,980	$127,852	$0	$0	$4,800	0.424	$59,829.69
10		2,190	11,090	24,090	$8,423	91,980	$127,852	$0	$0	$4,800	0.386	$54,390.63
11		2,190	280	26,280	$8,423	91,980	$127,852	$15,450	$0	$4,800	0.350	$54,861.15
12		2,190	2,470	28,470	$8,423	91,980	$127,852	$0	$0	$4,800	0.319	$44,950.93
13		2,190	660	660	$8,423	91,980	$127,852	$0	$51,500	$4,800	0.290	$55,782.20
14		2,190	2,850	2,850	$8,423	91,980	$127,852	$0	$0	$4,800	0.263	$37,149.53
15		2,190	5,040	5,040	$8,423	91,980	$127,852	$0	$0	$4,800	0.239	$33,772.30
16		2,190	7,230	7,230	$8,423	91,980	$127,852	$0	$0	$4,800	0.218	$30,702.09
17		2,190	9,420	9,420	$8,423	91,980	$127,852	$0	$0	$4,800	0.198	$27,910.99
18		2,190	11,610	11,610	$8,423	91,980	$127,852	$0	$0	$4,800	0.180	$25,373.63
19		2,190	800	13,800	$8,423	91,980	$127,852	$15,450	$0	$4,800	0.164	$25,593.13
20		2,190	2,990	15,990	$8,423	91,980	$127,852	$0	$0	$4,800	0.149	$20,969.94
21		2,190	5,180	18,180	$8,423	91,980	$127,852	$0	$0	$4,800	0.135	$19,063.58
22		2,190	7,370	20,370	$8,423	91,980	$127,852	$0	$0	$4,800	0.123	$17,330.53

23		2,190	9,560	22,560	$8,423	91,980	$127,852	$0	$0	$4,800	0.112	$15,755.03
24		2,190	11,750	24,750	$8,423	91,980	$127,852	$0	$0	$4,800	0.102	$14,322.75

Total Diesel Costs ($)	**$1,492,553**

Appendix V Diesel system LCC – Kherbet Kanafar Station

Year (n)	Capital Cost	Generator Working Time (hrs/year)	Cumulative Hours for Overhaul	Cumulative Hours for Replacement	Minor & Major Service ($/year)	Diesel Consumption (l/year)	Cost of Diesel ($/year)	Overhaul Costs ($/year)	Replacement Costs ($/year)	Labor Costs ($/year)	Pr Factor	Total Costs in Present Worth ($/year)
0	$46,500	2,190	2,190	2,190	$6,317	91,104	$126,635			$4,800	1.000	$184,251.87
1		2,190	4,380	4,380	$6,317	91,104	$126,635	$0	$0	$4,800	0.909	$125,228.97
2		2,190	6,570	6,570	$6,317	91,104	$126,635	$0	$0	$4,800	0.826	$113,844.52
3		2,190	8,760	8,760	$6,317	91,104	$126,635	$0	$0	$4,800	0.751	$103,495.02
4		2,190	10,950	10,950	$6,317	91,104	$126,635	$0	$0	$4,800	0.683	$94,086.38
5		2,190	140	13,140	$6,317	91,104	$126,635	$13,950	$0	$4,800	0.621	$94,194.92
6		2,190	2,330	15,330	$6,317	91,104	$126,635	$0	$0	$4,800	0.564	$77,757.34
7		2,190	4,520	17,520	$6,317	91,104	$126,635	$0	$0	$4,800	0.513	$70,688.49
8		2,190	6,710	19,710	$6,317	91,104	$126,635	$0	$0	$4,800	0.467	$64,262.26
9		2,190	8,900	21,900	$6,317	91,104	$126,635	$0	$0	$4,800	0.424	$58,420.24
10		2,190	11,090	24,090	$6,317	91,104	$126,635	$0	$0	$4,800	0.386	$53,109.31
11		2,190	280	26,280	$6,317	91,104	$126,635	$13,950	$0	$4,800	0.350	$53,170.58
12		2,190	2,470	28,470	$6,317	91,104	$126,635	$0	$0	$4,800	0.319	$43,891.99
13		2,190	660	660	$6,317	91,104	$126,635	$0	$46,500	$4,800	0.290	$53,371.20
14		2,190	2,850	2,850	$6,317	91,104	$126,635	$0	$0	$4,800	0.263	$36,274.37
15		2,190	5,040	5,040	$6,317	91,104	$126,635	$0	$0	$4,800	0.239	$32,976.70
16		2,190	7,230	7,230	$6,317	91,104	$126,635	$0	$0	$4,800	0.218	$29,978.82
17		2,190	9,420	9,420	$6,317	91,104	$126,635	$0	$0	$4,800	0.198	$27,253.47

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18		2,190	11,610	11,610	$6,317	91,104	$126,635	$0	$0	$4,800	0.180	$24,775.88
19		2,190	800	13,800	$6,317	91,104	$126,635	$13,950	$0	$4,800	0.164	$24,804.47
20		2,190	2,990	15,990	$6,317	91,104	$126,635	$0	$0	$4,800	0.149	$20,475.94
21		2,190	5,180	18,180	$6,317	91,104	$126,635	$0	$0	$4,800	0.135	$18,614.49
22		2,190	7,370	20,370	$6,317	91,104	$126,635	$0	$0	$4,800	0.123	$16,922.26
23		2,190	9,560	22,560	$6,317	91,104	$126,635	$0	$0	$4,800	0.112	$15,383.87
24		2,190	11,750	24,750	$6,317	91,104	$126,635	$0	$0	$4,800	0.102	$13,985.34

Total Diesel Costs ($)	**$1,451,219**

Appendix VI Diesel system LCC Kfardinis Station

Year (n)	Capital Cost	Generator Working Time (hrs/year)	Cumulative Hours for Overhaul	Cumulative Hours for Replacement	Minor & Major Service ($/year)	Diesel Consumption (l/year)	Cost of Diesel ($/year)	Overhaul Costs ($/year)	Replacement Costs ($/year)	Pr Factor	Labor Costs ($/year)	Total Costs in Present Worth ($/year)
0	$16,000	2,190	2,190	2,190	$4,212	90,666	$126,026			1.000	$4,800	$151,037.28
1		2,190	4,380	4,380	$4,212	90,666	$126,026	$0	$0	0.909	$4,800	$122,761.16
2		2,190	6,570	6,570	$4,212	90,666	$126,026	$0	$0	0.826	$4,800	$111,601.06
3		2,190	8,760	8,760	$4,212	90,666	$126,026	$0	$0	0.751	$4,800	$101,455.51
4		2,190	10,950	10,950	$4,212	90,666	$126,026	$0	$0	0.683	$4,800	$92,232.28
5		2,190	140	13,140	$4,212	90,666	$126,026	$4,800	$0	0.621	$4,800	$86,827.95
6		2,190	2,330	15,330	$4,212	90,666	$126,026	$0	$0	0.564	$4,800	$76,225.02
7		2,190	4,520	17,520	$4,212	90,666	$126,026	$0	$0	0.513	$4,800	$69,295.48
8		2,190	6,710	19,710	$4,212	90,666	$126,026	$0	$0	0.467	$4,800	$62,995.89
9		2,190	8,900	21,900	$4,212	90,666	$126,026	$0	$0	0.424	$4,800	$57,268.99
10		2,190	11,090	24,090	$4,212	90,666	$126,026	$0	$0	0.386	$4,800	$52,062.72

11		2,190	280	26,280	$4,212	90,666	$126,026	$4,800	$0	0.350	$4,800	$49,012.11
12		2,190	2,470	28,470	$4,212	90,666	$126,026	$0	$0	0.319	$4,800	$43,027.04
13		2,190	660	660	$4,212	90,666	$126,026	$0	$16,000	0.290	$4,800	$43,750.12
14		2,190	2,850	2,850	$4,212	90,666	$126,026	$0	$0	0.263	$4,800	$35,559.54
15		2,190	5,040	5,040	$4,212	90,666	$126,026	$0	$0	0.239	$4,800	$32,326.85
16		2,190	7,230	7,230	$4,212	90,666	$126,026	$0	$0	0.218	$4,800	$29,388.05
17		2,190	9,420	9,420	$4,212	90,666	$126,026	$0	$0	0.198	$4,800	$26,716.41
18		2,190	11,610	11,610	$4,212	90,666	$126,026	$0	$0	0.180	$4,800	$24,287.64
19		2,190	800	13,800	$4,212	90,666	$126,026	$4,800	$0	0.164	$4,800	$22,864.51
20		2,190	2,990	15,990	$4,212	90,666	$126,026	$0	$0	0.149	$4,800	$20,072.43
21		2,190	5,180	18,180	$4,212	90,666	$126,026	$0	$0	0.135	$4,800	$18,247.66
22		2,190	7,370	20,370	$4,212	90,666	$126,026	$0	$0	0.123	$4,800	$16,588.79
23		2,190	9,560	22,560	$4,212	90,666	$126,026	$0	$0	0.112	$4,800	$15,080.71
24		2,190	11,750	24,750	$4,212	90,666	$126,026	$0	$0	0.102	$4,800	$13,709.74

Total Diesel Costs ($)	**$1,374,395**

Appendix VII: Solar system LCC   Nassrieh Station

Year (n)	Capital Cost ($)	Preventive and Minor Service ($/year)	Replacement Costs ($/year)	Labor Costs ($/year)	Pr Factor	Total Costs in Present Worth ($/year)
0	$118,029	$1,500		$4,800	1.000	$124,329
1		$1,500		$4,800	0.909	$5,727.27
2		$1,500		$4,800	0.826	$5,206.61
3		$1,500		$4,800	0.751	$4,733.28
4		$1,500		$4,800	0.683	$4,302.98
5		$1,500		$4,800	0.621	$3,911.80
6		$1,500	$5,280	$4,800	0.564	$6,536.61
7		$1,500		$4,800	0.513	$3,232.90
8		$1,500		$4,800	0.467	$2,939.00
9		$1,500		$4,800	0.424	$2,671.81
10		$1,500		$4,800	0.386	$2,428.92
11		$1,500		$4,800	0.350	$2,208.11
12		$1,500		$4,800	0.319	$2,007.37
13		$1,500	$5,280	$4,800	0.290	$3,354.31
14		$1,500		$4,800	0.263	$1,658.99
15		$1,500		$4,800	0.239	$1,508.17
16		$1,500		$4,800	0.218	$1,371.06
17		$1,500		$4,800	0.198	$1,246.42
18		$1,500		$4,800	0.180	$1,133.11
19		$1,500		$4,800	0.164	$1,030.10
20		$1,500		$4,800	0.149	$936.45
21		$1,500	$5,280	$4,800	0.135	$1,564.81
22		$1,500		$4,800	0.123	$773.93

23		$1,500		$4,800	0.112	$703.57
24		$1,500		$4,800	0.102	$639.61

Total Solar Costs ($)	**$186,156**

Appendix VIII: Solar system LCC Kherbet Qanafar Station

Year (n)	Capital Cost ($)	Preventive and Minor Service ($/year)	Replacement Costs ($/year)	Labor Costs ($/year)	Pr Factor	Total Costs in Present Worth ($/year)
0	$98,009	$1,200		$4,800	1.000	$104,009
1		$1,200		$4,800	0.909	$5,454.55
2		$1,200		$4,800	0.826	$4,958.68
3		$1,200		$4,800	0.751	$4,507.89
4		$1,200		$4,800	0.683	$4,098.08
5		$1,200		$4,800	0.621	$3,725.53
6		$1,200	$4,400	$4,800	0.564	$5,870.53
7		$1,200		$4,800	0.513	$3,078.95
8		$1,200		$4,800	0.467	$2,799.04
9		$1,200		$4,800	0.424	$2,544.59
10		$1,200		$4,800	0.386	$2,313.26
11		$1,200		$4,800	0.350	$2,102.96
12		$1,200		$4,800	0.319	$1,911.78
13		$1,200	$4,400	$4,800	0.290	$3,012.51
14		$1,200		$4,800	0.263	$1,579.99
15		$1,200		$4,800	0.239	$1,436.35

16		$1,200		$4,800	0.218	$1,305.77
17		$1,200		$4,800	0.198	$1,187.07
18		$1,200		$4,800	0.180	$1,079.15
19		$1,200		$4,800	0.164	$981.05
20		$1,200		$4,800	0.149	$891.86
21		$1,200	$4,400	$4,800	0.135	$1,405.36
22		$1,200		$4,800	0.123	$737.08
23		$1,200		$4,800	0.112	$670.07
24		$1,200		$4,800	0.102	$609.15

Total Solar Costs ($)	**$162,270**

Appendix IX: Solar system LCC – Kfardinis Station

Year (n)	Capital Cost ($)	Preventive and Minor Service ($/year)	Replacement Costs ($/year)	Labor Costs ($/year)	Pr Factor	Total Costs in Present Worth ($/year)
0	$78,540	$900		$4,800	1.000	$84,240
1		$900		$4,800	0.909	$5,182
2		$900		$4,800	0.826	$4,711
3		$900		$4,800	0.751	$4,282
4		$900		$4,800	0.683	$3,893
5		$900		$4,800	0.621	$3,539
6		$900	$2,640	$4,800	0.564	$5,204
7		$900		$4,800	0.513	$2,925
8		$900		$4,800	0.467	$2,659

9		$900		$4,800	0.424	$2,417
10		$900		$4,800	0.386	$2,198
11		$900		$4,800	0.350	$1,998
12		$900		$4,800	0.319	$1,816
13		$900	$2,640	$4,800	0.290	$2,671
14		$900		$4,800	0.263	$1,501
15		$900		$4,800	0.239	$1,365
16		$900		$4,800	0.218	$1,240
17		$900		$4,800	0.198	$1,128
18		$900		$4,800	0.180	$1,025
19		$900		$4,800	0.164	$932
20		$900		$4,800	0.149	$847
21		$900	$2,640	$4,800	0.135	$1,246
22		$900		$4,800	0.123	$700
23		$900		$4,800	0.112	$637
24		$900		$4,800	0.102	$579

Total Solar Costs ($)	**$138,935**

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