Solar-Powered Solutions for the Water and Energy Shortage Problem: The Case Study of Nahr El Bared, Lebanon

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Received: 17 March 2023 | Revised: 2 April 2023 | Accepted: 10 April 2023

ABSTRACT

Solar power is an effective way to reduce the dependency on conventional fuels and mitigate the water and energy shortage issue. The main aim of the current paper is to assess and compare the techno-economic feasibility of rooftop grid-connected photovoltaic energy systems for generating electricity and generating drinkable water in Nahr El Bared, Lebanon. To this aim, the present paper first reviews previous scientific studies associated with the water resources and energy situation to summarize the current status in Lebanon. According to this review, Lebanon's water resources are highly polluted, domestic and industrial sewage is largely untreated, and intolerable agricultural practices further exacerbate the situation. Furthermore, population and economic growth and the continuous utilization of old power plants have led to an increase in the number of hours of power outages in the country. Accordingly, the proposed project aims to evaluate the viability of using solar energy as an alternative solution to the shortage of water and energy in the country. Secondly, the techno-economic performance of the proposed system in the selected region was evaluated based on the variations in financial parameters using RETScreen Experts software. The results demonstrate that 11770–13451kWh/yr could be generated from the solar system, which can help reduce the energy shortage and generate drinkable water. Furthermore, the investment was found to be economically viable and attractive for investors. This paper concludes that solar energy can be able to solve the energy shortage of electricity, reduce the country's electricity costs, and produce freshwater for drinking and domestic use in the country.

Keywords-Lebanon; solar energy potential; grid-connected; small-scale; RETScreen software

I. INTRODUCTION

Recently, renewable energies, including solar and wind energy, have increased their contribution in power generation worldwide. The use of renewable energy sources is imperative nowadays, due to the scarcity of fossil fuel resources in developing countries, specifically Lebanon. The generation of electricity from renewable energy sources will be an essential part of Lebanon's future development. Solar energy has been widely utilized globally to generate electricity and reduce greenhouse gas (GHG) emissions. It is a clean energy, an inexhaustible and environmentally friendly energy source. Authors in [1] found that solar power will reduce the emissions of about 69-100 million tons of CO_2, 68-99 thousand tons of NO_X, and 126-184 thousand tons of SO_2 by 2030. Authors in [2] concluded that solar energy has a significant potential to meet the world's electricity requirements in the future. Authors in [3] concluded that solar energy technologies have an essential role in reducing energy-related emissions.

Photovoltaic (PV) solar panels produce electrical power directly from the sunlight. It is a considerable power source to meet the demand for electricity in developing countries [4]. Additionally, it is utilized as an alternative source to meet the energy required for desalination plants [5]. In general, PV power systems are classified into two types (on-grid and off-grid PV systems). The on-grid PV system significantly reduces costs by eliminating the need for battery storage [6]. Also, it helps reduce the consumption of fossil fuels in the country. Additionally, the small-scale grid-connected PV system can help customers earn money using their grid-connected rooftop PV systems because they purchase much less electricity [7].

A. Water Resources in Lebanon

Generally, the main water resources of Lebanon are surface water (49%), which is mostly supplied by rivers (46%), surface storage water such as dams and lakes (3%), and groundwater (51%) [8]. In Lebanon, there are 40 rivers of which 16 are permanent [8, 9]. The total flow of the rivers is found to be in the range of 2151-3900 MCM/yr with most of the flow occurring from January to May [8, 9]. Three water basins alone represent approximately 44% of the country's area: the Litani ($2140km^2$), the Orontes ($1720km^2$), and the Hasbani ($680km^2$). On the other hand, Lebanon has many coastal rivers that originate from Mount Lebanon and flow into the Mediterranean Sea [10]. Rivers and springs are greatly affected by the annual variation in precipitation. According to the United Nations Development Program in 2014, the annual rainfall is within the range of 7.8-11.9 billion m^3 of which between 4.1 and 6.6 billion m^3 is groundwater recharge. The annual rainfall is within the range of 600-1100mm in the coastal regions and rises to more than 1400mm in higher altitudes [11]. The average rainfall and the exposed geological formations with major karstic features and fractures make the stratified environment and water permeability distinctive. Renewable water is a major source of groundwater [12]. Groundwater reserves generally consist of leakages of the rainwater that result from the melting of snow [13]. The layers that prevent or semi-prevent leakage and runoff play the main role in seizing groundwater reserves and directing them inside the stores [8]. However, groundwater makes up nearly 50% of the water supply. This has affected the management of groundwater and its quality.

According to the Ministry of Energy and Water in 2014, the number of public wells extracting groundwater is about 1325 of which 943 are operational. It has also been reported that about 46% of the wells drain unspecified aquifers, 33% drain the Sannine-Maameltain aquifer, and 9% drain the Kesrouane Jurassic aquifer [14]. The volume of water extracted from public wells is estimated at 270 MCM/yr. Moreover, the registered well number with the Ministry of Energy and Water reached 20537 in 2012. It is expected that the total number of wells is within the range of 55000-60000 distributed over the country. The volume extracted from groundwater resources through public and private wells is estimated to be about 700 MCM [14]. Moreover, water sources in Lebanon have been exposed to all kinds of pollution due to the absence of sewage networks in most of the areas, the lack of maintenance and monitoring, and not linking sewage networks to refining stations [8]. Generally, domestic sewage, solid waste, and pollution from industrial facilities, health care facilities, tourism, and quarries along with agricultural waste are considered the main sources of pollution for surface and groundwater in the country [15]. These different types of pollutants lead to water contamination such as microbiological contamination, heavy metals (copper, zinc, strontium, chromium, and nickel), or increased levels of concentration of nutrients in the surface water [8, 15]. Additionally, the coastal area is also widely affected by pollution and the discharge of untreated wastewater and solid waste [15, 16]. It has been found that the total domestic wastewater generated which is discharged into the sea through offshore flow points, is about 65%. Moreover, due to over-abstraction and anthropogenic pollution, the quality of groundwater is deteriorating [8]. Also, over-abstraction especially in the coastal regions has led to seawater intrusion, which affects the groundwater quality. Additionally, nitrate pollution is considered a major threat to groundwater resources in agricultural areas. Furthermore, by considering the karstic nature of groundwater aquifers, domestic wastewater is the main cause of bacterial pollution (mainly coliform bacteria) [17, 18].

B. The Energy Situation in Lebanon

The main electrical energy sources are fossil fuels (97%) and hydropower (3%). The total capacity of thermal plants and hydropower plants is 2368MW and 252MW, respectively. Due to the population growth and rising people living standards, the energy demand has increased. Lebanon's need for electric energy is estimated to be about 3562MW according to the Ministry of Energy and Water in 2019. Lebanon has been suffering for at least 3 decades from an escalating problem in the electricity sector. The power outage periods in all the cities of the country have increased to 6-14 hours per day. Thus, diesel generators are distributed around the country to supply the population's energy consumption demands [19-21]. With these sources, CO_2 emissions have increased over the years. Additionally, electricity generation that comes from these sources contributes about 83% of total CO_2 emissions [20, 22]. Thus, the use of renewable energy sources, such as solar energy, will reduce the GHG emissions and the dependence on fossil fuels. According to the World Bank Group (Global Solar Atlas), the specific photovoltaic power output is within the range of 3.99-5.30kWh/kWp. Moreover, Lebanon receives approximately 300h/yr of sunshine. The average sunshine hours in Lebanon range from 8h to 9h. Lebanon has high insulation on a horizontal surface ranging between $16.51MJ/m^2$ and $20.71MJ/m^2$. Therefore, it is essential to increase the access to electricity in the country with a particular focus on utilizing solar resources. Authors in [23] found that the county has a great chance of utilizing solar power in order to reduce its dependency on fossil fuels. Additionally, installing a solar system in the country is technically reliable due to the high value of average daily radiation on the horizontal surface [24]

Recently, several studies have investigated the potential of utilizing renewable energy, mainly solar, in the country [24-33]. Few studies have focused on the evaluation of the solar potential in Lebanon. For instance, authors in [29] investigated the techno-economic feasibility of small-scale grid-connected rooftop solar projects with various sun-tracking systems and PV technologies. The findings demonstrated that the proposed PV system could provide enough electricity to satisfy the demand and hence reduce the nation's current electricity shortage. Authors in [25] described the utilization of a hybrid PV-diesel system to cool a tertiary building in Beirut during the summer. The results indicated that a PV-diesel system can provide 260kW of power throughout the year. Authors in [28] developed a GIS model to locate the optimal location for a solar power plant in Lebanon. The results showed that the optimum locations (Amioun, Bterram, and Kfaraakka) with an area of 2.8km^2 can provide 50% of the North's power needs. Authors in [31] provided the footprint and solar rooftop potential maps using deep learning-based instance segmentation. They concluded that Lebanon has a total rooftop solar capacity of about 28.1TWh/year, which is about twice the electricity needed by the country in 2019. Authors in [21] assessed the feasibility of a 100MW grid-connected PV plant in the Rayak region, Lebanon. The results showed that the amount of electricity generation from PV systems (1.47GWh) could help solve the electricity crisis in the country. Based on prior scientific research findings [24-33], the results indicated that (1) the country has a huge concentrating solar power that would be able to meet the maximum energy demand, (2) solar PV systems will have significant socio-economic benefits and assist the sustainability of solar power generation in the country, and (3) the solar power systems will employ 100% renewable energy, resulting in zero carbon emissions in the future.

C. Solar Desalination Unit

One major global problem is the increasing demand for drinking water. Seawater/brackish water desalination units are considered an alternative way to solve the problem of freshwater supply. In general, desalination is the process of purifying water and removing excess salinity and minerals from it through several processes [34, 35]. Desalination processes are categorized into two main categories: thermal processes and membrane processes. According to [36], the most widely utilized and reliable technology process is Reverse Osmosis (RO), which has also been utilized as an alternative source of clean water production [35, 36]. Generally, the desalination processes require a significant amount of energy. Therefore, renewable energy, particularly solar energy, is a viable alternative as a clean energy source to operate desalination plants and reduce fossil fuel dependency and the cost of clean water production.

Many researchers have investigated the potential of renewable energy in terms of wind and solar energy. For instance, authors in [37] utilized wind energy potential as an energy source for an RO desalination plant in Spain. Authors in [38] evaluated the feasibility of solar energy projects to supply the required power for seawater desalination in Algeria. Moreover, several studies investigated the feasibility of grid-connected solar plants as an energy source for desalination plants [35, 38-41]. Authors in [35] investigated the economic viability of small-scale grid-connected PV systems with various sun-tracking systems as clean energy for brackish water desalination units in Northern Cyprus. The grid-connected PV system was used as a power source for a 2500m^3/d saltwater RO desalination plant [38]. Authors in [39] analyzed grid-connected PV/Wind projects as power sources for RO and multiple-effect distillation plants. Authors in [40] proposed a new strategy for grid-connected seawater reverse osmosis focused on energy cost reduction. Authors in [41] evaluated the potential of solar energy and designed a solar-powered seawater RO desalination plant for Gaza Strip.

D. Research Objectives

Lebanon is facing an energy deficiency and some of its regions are still not electrified, particularly in rural areas. The energy supply and demand are very large. Besides, the poor economy does not allow importing fossil fuels on a large scale. Consequently, the potential of renewable energy resources can be utilized to electrify off-grid areas, specifically rural areas, or on-grid in urban locations for reducing the consumption of fossil fuels and environmental pollution. Lebanon is known to have a good potential for solar energy and the potential of solar energy for solving the electricity and water crisis in the country has been evaluated in a few studies. Thus, there is no doubt that a comprehensive economic and environmental study must be conducted to obtain results that can serve as a roadmap for investing in solar energy in the country. Besides, it has been indicated that grid-connected solar power systems are an alternative solution for the electricity crisis, one that reduces carbon emissions and mitigates power shortage. Consequently, it can be concluded that the small-scale solar systems in the country can not only bridge the energy gap but also reduce the environmental pollution impact.

The current research is a first attempt to examine the viability of small-scale solar energy systems in Lebanon from a strategic viewpoint to address the country's electricity shortage and generate freshwater for household consumption. This paper presents a methodology to accurately evaluate the techno-economic and environmental sustainability of rooftop PV systems in Nahr El Bared, Lebanon. A typical household was selected for this region to create a load profile according to the monthly electricity bills and reduce the groundwater salinity using RO desalination. The techno-economic feasibilities for the rooftop solar systems at the selected location were developed for various policy scenarios using the RETScreen Experts software.

II. MATERIALS AND METHODS

A. Study Area

Nahr El-Bared is located in the northern part of Lebanon with a population of about 30000. The mean maximum and minimum elevations are 27m and 12m above sea level, respectively. Nahr El-Bared camp is separated into two camps: the old camp (78m^2 average apartment area and 360000m^2 total built residential area) and the new camp (150m^2 average household area and 300000m^2 total constructed household area). Nahr El-Bared is facing a water crisis due to the shortage of electricity and seawater intrusion. According to the institute for Palestinian studies, about 60% of drinking water is salty in most regions in the selected area. Moreover, the large number of private wells, which are located along the coastline, is a major cause of seawater intrusion according to the Institute for Palestinian studies. Recently, the level of salinity has increased to 90% of the public and private wells extracting groundwater, which forced the residents to buy freshwater from internal refineries' water trucks to fill the water storage tanks. This has given rise to serious problems due to the cost of water from these sources (the price of 1m^3 varies from 2 USD to 4 USD, which depends on the locations in the region) and the shortage of electricity. Moreover, power outages in the selected location are considered one of the most difficult situations by the residents, as the hours of feeding from the electricity company do not exceed 3 to 4 per day

B. On-grid Photovoltaic System

Grid-connected PV systems consist of PV panels that supply the required power during the day and are connected to the local electrical grid to generate power at night. Moreover, the excess power from the PV system is fed back to the grid when the power generated is more than the load required [42]. In general, the grid-connected PV system consists of solar panels, inverters, a power-conditioning unit, and grid-connection equipment. To get more power from the PV arrays, the PV panels should have high cell efficiency and a high operating temperature. Generally, the inverter is one of the most important components of a grid-connected system because it converts direct current (DC) to alternating current (AC). In addition, electricity meters are utilized to read the flow of electricity to and from the grid.

Recently, on-grid PV systems have attracted substantial attention due to the advantages of their compatibility with the electricity grid. In this system, the output power of the PV system is connected directly to the grid and the household. The electric energy produced by the PV system can cover the energy demand of the household. When the produced energy by the PV system is high, the remaining energy can be fed into the grid through an electric meter. This system comprises PV panels, which absorb sunlight and produce direct current, an inverter, a distribution controller, and load as shown in Figure 1. Generally, it is necessary to estimate the optimal sizing of grid-connected PV systems as the first step to meet the energy demand of the household.

According to [43], the amount of output energy by the PV system (E_{PV}) should be greater than the amount of electricity taken from the grid (E_{grid}) as shown in (1). In this case, the energy demand of the household can be shared between the PV system and the electric grid. The generated energy from the PV system is utilized to cover the household/building instantaneous electricity load and the surplus energy is injected into the grid.

$$E_{PV} > E_{grid} \tag{1}$$

The maximum power (P_{max}) of the developed on-grid solar PV system can be estimated as a function of global solar radiation (G_{sr}) in kWh/m^2/d, solar radiation at standard test conditions (P_i) in kW/m^2, PV derating factor (f_{PV}), daily power consumption (E_{AC}) of the household in kWh/d, and the inverter yield (η_{inv}), as in (2) [44]:

$$P_{max} = \frac{E_{AC}\,P_i}{G_{sr} f_{PV} \eta_{inv}} \tag{2}$$

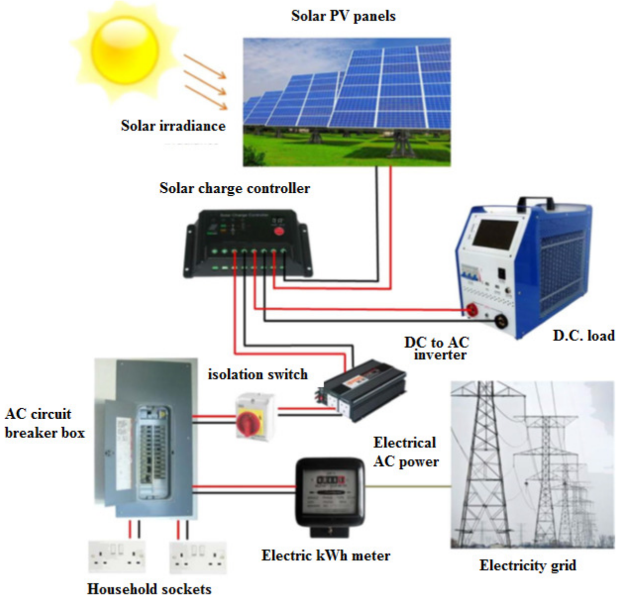

Fig. 1. Components of an on-grid PV system.

C. Energy Required for an RO Desalination Plant

The power needed for a RO plant should be calculated to assess its energetic requirements and integrate it with the renewable energy system. The power needed to desalinate the water (i.e. push water through membranes mechanically) as well as the electricity needed to pump the feed water to the plant and the treated water into the water system are all taken into account when calculating the overall power requirement of an RO plant. The major source of water for the desalination plant is the saline groundwater from the coastal aquifer. According to [45, 46], the energy needs for an RO desalination plant can be calculated using by:

$$P_D = \frac{SEC \cdot q}{CF_D} \tag{3}$$

where P_D is the power requirement of the RO in kW, CF_D is the capacity factor of the plant, q is the flow rate for the feed water in m^3/h, and SEC is the specific energy consumption of desalination in kWh/m^3.

D. RETScreen Expert Software

RETScreen Expert is a clean energy management tool developed by the Canadian government. It is a decision support tool utilized to determine the potential of energy, costs, savings, GHG emission reduction, and economic viability [47, 48]. RETScreen is commonly employed to explore the feasibility of grid-connected wind and PV power systems. For instance, authors in [48] used RETScreen to evaluate the techno-economic feasibility of a grid-connected PV system in Nigeria. Authors in [49] utilized it to investigate the potential of PV systems for electricity generation in various locations in Libya. Authors in [50] evaluated the cost-benefit of a 100MW solar PV installation in Pakistan using RETScreen.

III. RESULTS AND DISCUSSION

The mean monthly energy demand for the selected household is illustrated in Figure 2. The energy demand data were collected during 2012-2021. It is found that the energy demand is within the range of 210-309kWh with an average value of 250kWh. The highest and lowest value of energy demand is recorded in December and July, respectively.

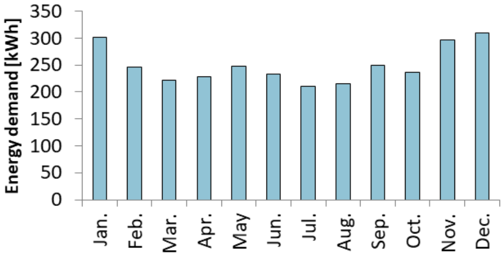

Fig. 2. Monthly mean energy demand for the selected household during 2012-2021.

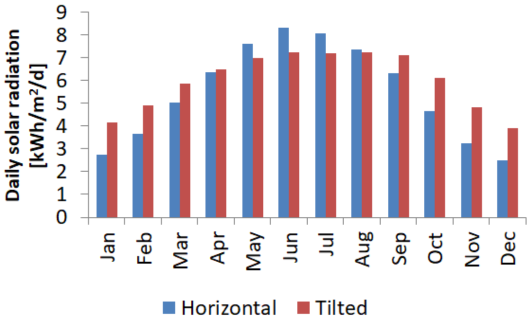

Fig. 3. Monthly average daily global radiation on a horizontal surface and a 34° tilted plane.

According to [51], the influence of the tilt angle on the solar electricity generation can be considered a minor effect when compared to the natural variation. The tilted and azimuth angles were chosen based on the highest value of solar irradiance and electricity exported to the grid. The monthly average daily global radiation on a horizontal surface and global radiation on a horizontal surface and a 34° tilted plane are illustrated in Figure 3 for the selected location. June and December are the periods with the highest and lowest solar radiation. The minimum and maximum tilted solar radiation were found to be 3.9kW/m^2/d and 7.2 5.57kW/m^2/d. The power requirement of the brackish water RO is calculated to estimate its energetic needs in order to estimate the capacity of the PV system. In this research, the total power demand of the RO plant is calculated using by (3). The desalination capacity factor and specific energy consumption of desalination are assumed based on [48, 52, 53]. Table I lists the parameters needed for the calculation of the power requirements of the RO.

TABLE I. PARAMETERS FOR ESTIMATING THE POWER REQUIREMENT OF THE RO

Parameters	Value
Desalination capacity factor [%]	95
Specific energy consumption of desalination [kWh/m^3]	1.5
Flow rate of the feed water [m^3/h]	0.5 and 1
Power requirement [kW]	1 and 2

Moreover, using (2), the maximum power of the PV system is found to be 6kW based on the minimum value of solar radiation. Thus, the total capacity of the PV system is estimated to be 7kW and 8kW, which depends on the power requirement of the RO desalination unit (Table I). The required area for the proposed systems is estimated to be within the range of 33-37m^2. In this study, the solar module JKM545M-72HL4-TV with a capacity of 545W and efficiency of 21.13%, manufactured by Jinko Solar, is used. Output AC power, DC-AC conversion efficiency, and capital cost of the inverter are the main factors to select a suitable inverter. OST 6000TL-D1 and OST 3000TL-S1 Solar Inverter with a capacity of 6kW and 3kW were selected.

A. *Technical Viability*

The performance of PV systems in terms of PV output and capacity factor depends on the orientation angles. Thus, the Electricity Exported to the Grid (EEG) and Capacity Factor (CF) were estimated at a tilted angle of 34° and azimuth angle of 0° for the selected location. It should be noted that fixed-tilt mounting systems are simpler, cheaper, and require less maintenance compared to tracking systems. The mean monthly value of EEG for all the considered PV systems is shown in Figure 4. It is observed that the EEG is within the range of 676.55-1161.75kWh and 773.20-1327.71kWh for PV systems with a capacity of 7kW and 8kW, respectively. The lowest and highest values of EEG are recorded in December and July, respectively.

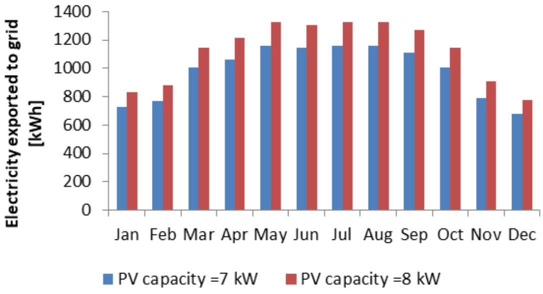

Fig. 4. Monthly average value of EEG on a 34° tilted plane for the proposed PV systems.

Moreover, the monthly average electricity produced by the PV system and the electrical energy purchased from the grid is illustrated in Figure 5. It is found that the PV systems cover the household load and RO brackish groundwater desalination unit. The installation of the PV systems can solve the electricity crisis and produce freshwater for drinking and domestic use.

The annual value of EEG of the proposed system is 11769.99kWh and 13451.42kWh for a system with capacity of 7kW and 8kW, respectively. The CF of the proposed systems is 19.19%. This result can be supported by previous studies. For instance, authors in [48] found that the CF value of their proposed PV plants varied from 20.40% to 21.70%. Authors in [54] found that the CF values of 10MW grid-connected PV systems are within the range of 20.08-25.07%. Authors in [55] found that the proposed PV projects in Oman have a CF ranging from 16% to 23%. According to [56], the value of CF for grid-connected PV systems with various sun-tracking techniques fell between 17.54 and 27.42%. As a result, the current study's value for each site is compatible with the acceptable values. Consequently, it is technically feasible to construct a rooftop PV system that is connected to the local power grid.

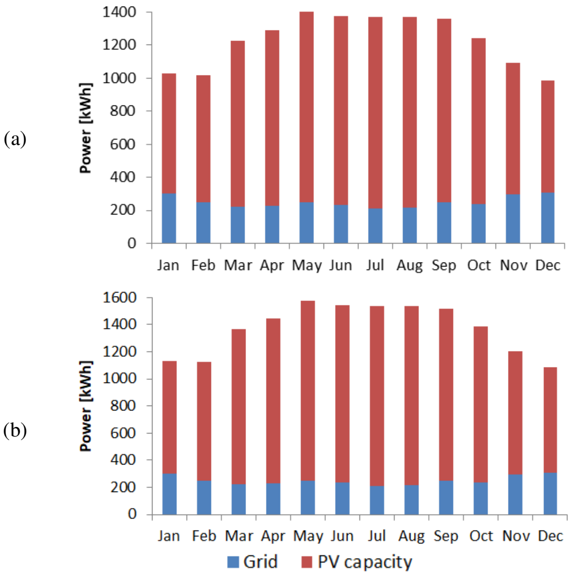

Fig. 5. Monthly average electric production of (a) 7kW and (b) 8kV PV systems.

B. *Economic Sustainability*

To determine if the project is viable and sustainable economically, an economic study is vital. Thus, the techno-economic feasibility for rooftop PV systems at the selected location was evaluated for different values of electricity export rate (0.03-0.12USD/kWh in the step of 0.03USD/kWh) and discount rate (0% and 5.4%) to explore the possible variations in the results. The values of the used financial input parameters, namely inflation rate (2.9%), reinvestment rate (9%), project life (25 years), debt ratio (70%), debt interest rate (0%), and debt payment period (20 years), were assumed based on previous studies. Based on these input parameters, NPV, ALCS, SP, EP, LCOE, and the Internal Rate of Return (IRR) were estimated BY RETScreen. Table II summarizes the cost of the proposed system. Moreover, the cost of the final desalinated water is listed in Table III. It should be noted that the PV module and inverter were selected from a list of efficient PV modules and inverters which are currently available in the market. The cost of the small-scale RO brackish groundwater desalination unit (0.5m^3/h and 1m^3/h) can be found in the literature. The initial investment cost of the proposed system is 6507 USD and 10482 USD for a PV system with a capacity of 7kW and 8kW, respectively.

The NPV was determined for each location and each value of the Electricity Export Rate (EER) is tabulated in Table III. It is found that the value of NPV for each value of EER is positive, which indicated that the project is potentially feasible [57, 58]. Besides, it is noticed that there is a strong correlation between NPV and EER. Moreover, IRR is estimated to evaluate the economic viability of the project [48, 57]. The IRR provides the true return of interest generated by the equity over the life of the project [47]. The results showed that increasing the rate of exporting electricity led to an increase in the value of IRR. In addition, it is observed that the value of IRR gotten for the three locations is higher than the required rate of return of the project. ALCS is calculated by using NPV, discount rate, and project lifetime. It is found that ALCS is within the range of 274.0-2571.1 USD/year for PV systems with a capacity of 7kW and 93.4-2773.5 USD/year for PV systems with a capacity of 8kW, as shown in Table III.

TABLE II. COSTS OF THE PV PROJECT AND THE RO DESALINATION UNIT

Parameter	Unit	Value
PV module cost	USD/W	0.3
Lifetime of the PV module	Year	25
Cost of a 6kW inverter	USD	450
Cost of a 3kW inverter	USD	250
Miscellaneous/contingency fund	% of the total initial cost	3
Installation and spare parts	% of the total initial cost	8.6
Feasibility study, development, and engineering cost	% of the total initial cost	0.6
Lifetime of inverter	Year	10
Inverter replacement periodic cost	-	Every 10 years
Investment cost of a 7KW PV system	USD	3366
Investment cost of a 8KW PV system	USD	5273
Investment cost of brackish groundwater desalination unit (0.5m^3/h)	USD	3141
Investment cost of brackish groundwater desalination unit (1m^3/h)	USD	6282

Furthermore, the economic viability of a project is estimated by determining the payback period, which indicates the time required to recover the initial investments, with net positive income [47, 48]. Table III lists the payback period including EP and SP for all selected locations. It is found that the EP is within the range of 1.50-15.8 years. The developed PV project with 7kW technology has the lowest value of EP. The proposed project with 8kW has the longest SP (7.2-28.6) compared to the other project (4.6-18.4 years). The results reveal that the increase in EER will lead to a decrease in EP and SP. The results demonstrate that the SP value exceeds the lifetime of the project (25 years) when EER is equal to 0.03 USD/kWh, especially for the project of 8kW. This indicates that installing PV projects at the selected locations is not economically viable when EER is equal to 0.03 USD/kWh. Additionally, the value of B-C, which is utilized to determine the cash flow generated viability, is higher than 1 as shown in Table III. These findings indicate the feasibility of the projects [59].

C. Climate Co-Benefit Assessment

In addition to economic feasibility, an estimate of the environmental benefits in terms of reducing GHG emission of the proposed system would be attractive. The climate co-benefits in terms of GHG emission reduction were calculated using RETScreen and are listed in Table IV in multiple equivalent formats. The results indicate that a large amount of CO_2 emissions can be avoided by implementing the developed PV project in each location. It should be noted that the total amount of CO_2 emission reduction for each location is determined based on the electricity generated annually [56]. The annual GHG emission reduction is 8.32 tCO_2 for the 7kW PV system and 9.51 tCO_2 for the 8kW PV system, as shown in Table IV.

TABLE III. ECONOMIC PERFORMANCE OF DEVELOPED PV PROJECTS FOR THE SELECTED LOCATION

PV capacity	**Parameters**	**Case#1**	**Case#2**	**Case#3**	**Case#4**	**Case#5**	**Case#6**	**Case#7**	**Case#8**
7 kW	Electricity export rate [USD/kWh]	0.03	0.06	0.09	0.12	0.03	0.06	0.09	0.12
	Discount rate [%]	5.4	5.4	5.4	5.4	0.0	0.0	0.0	0.0
	Pre-tax IRR-equity	14.7	33.0	51.5	70.2	14.7	33.0	51.5	70.2
	Pre-tax IRR-assets	4.4	12.5	18.8	24.7	4.4	12.5	18.8	24.7
	Simple payback [Year]	18.4	9.2	6.1	4.6	18.4	9.2	6.1	4.6
	Equity payback [Year]	8.7	3.5	2.1	1.5	8.7	3.5	2.1	1.5
	Net Present Value (NPV) [USD]	3712.1	12117.0	20521.9	28926.8	11193.0	28888.1	46583.1	64278.2
	Annual life cycle savings [USD/year]	274.0	894.5	1515.0	2135.5	447.7	1155.5	1863.3	2571.1
	Benefit-cost (B-C) ratio	2.9	7.2	11.5	15.8	6.7	15.8	24.9	34.0
	Debt service coverage	1.6	3.3	4.9	6.5	1.6	3.3	4.9	6.5
	Energy production cost [USD/kWh]	0.0294	0.0294	0.0294	0.0294	0.0221	0.0221	0.0221	0.0221
8 kW	Electricity export rate [USD/kWh]	0.03	0.06	0.09	0.12	0.03	0.06	0.09	0.12
	Discount rate [%]	5.4	5.4	5.4	5.4	0.0	0.0	0.0	0.0
	Pre-tax IRR-equity	7.4	20.1	31.8	43.6	7.4	20.1	31.8	43.6
	Pre-tax IRR-assets	2.9	8.0	10.3	11.9	2.9	8.0	10.3	11.9
	Simple payback [Year]	28.6	14.3	9.5	7.2	28.6	14.3	9.5	7.2
	Equity payback [Year]	15.8	6.2	3.6	2.5	15.8	6.2	3.6	2.5
	Net Present Value (NPV) [USD]	1265.7	10871.4	20477.0	30082.6	8667.9	28890.8	49113.7	69336.6
	Annual life cycle savings [USD/year]	93.4	802.6	1511.7	2220.8	346.7	1155.6	1964.5	2773.5
	Benefit-cost (B-C) ratio	1.4	4.1	6.9	9.7	3.5	9.3	15.2	21.0
	Debt service coverage	1.0	2.1	3.1	4.2	1.0	2.1	3.1	4.2
	Energy production cost [USD/kWh]	0.0458	0.0458	0.0458	0.0458	0.0344	0.0344	0.0344	0.0344

TABLE IV. GHG EMISSION REDUCTION (TCO2)

Annual GHG emission reduction [tCO_2] equivalent to	**PV capacity**	
	7 kW	**8 kW**
Gross annual GHG emission reduction	8.32	9.51
Care and light trucks not used	1.52	1.74
Liters of gasoline not consumed	3575.18	4085.92
Barrels of crude oil not consumed	19.35	22.11
People reducing energy use by 20%	8.32	9.51
Acres of forest absorbing carbon	1.89	2.16
Hectares of forest absorbing carbon	0.77	0.87
Tons of waste recycled	2.87	3.28

IV. CONCLUSIONS AND FUTURE WORK

Population growth and energy demand have prompted governments and researchers to find alternative energy sources. Solar-powered energy has received the most attention among the alternative energy sources due to its environmentally friendly nature. In this paper, the use of solar energy as an alternative source for generating electricity and drinking water was investigated. Accordingly, this paper first reviewed the literature on water resources and the energy situation in the country to offer persuasive suggestions for policymakers to consider solar energy as an energy source in the future. The result showed that the use of solar energy can help the country reduce its dependence on fossil fuels and generate electricity at a low cost as well as produce freshwater using small units of RO brackish groundwater desalination. A household was selected to determine the energy demands according to the monthly electricity bills in addition to the energy required for RO desalination to assess the PV system's capacity. Then, the techno-economic feasibility of rooftop grid-connected PV systems was investigated. The results demonstrated that rooftop grid-connected PV systems are technically, economically, and environmentally feasible for the selected region. Hence, solar energy can be an alternative energy source to solve the water and energy shortage in the country.

Future work is needed to address the profit from the use of the photovoltaic system, which largely depends on the tariffs for the region and the possibility of connecting a given power to the grid about the quality of electricity, voltage values, and the stability of the distribution system.

ACKNOWLEDGMENT

The authors would like to thank the Faculty of Engineering, especially the Mechanical Engineering Department, at Near East University for their support and encouragement.

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