Performance investigation of grid-connected photovoltaic systems for family household: A case study in Amman, Jordan

Y Kassem¹,², H Çamur¹, A A Othman¹, L Alshrouf¹, M Yasin¹ and Y Abu-Aysheh¹

¹Mechanical Engineering Department, Engineering Faculty, Near East University, Nicosia (via Mersin 10, Turkey), Cyprus
²Civil Engineering Department, Civil, and Environmental Engineering Faculty, Near East University, Nicosia (via Mersin 10, Turkey), Cyprus

Abstract. The main objective of the paper is to investigate the feasibility of small-scale grid-connected PV systems with various PV technologies (mono-crystalline silicon and poly-crystalline silicon) and sun-tracking modes including fixed tilt and 2-axis systems for rooftop households in Amman, Jordan. A case study is applied to Al Jama’a and Abu Nusir, Amman, Jordan. Typical households were chosen for this region to establish a load profile according to monthly electrical bills. The results show that the annual electrical energy from fixed small-scale PV panels tilted at an optimal angle was ranged from 3499.04kWh to 8811.62kWh, while the annual electrical energy from the PV tracking system was within the range of 4788.05-12128.30kWh. This amount of energy output would contribute significantly to reduce fossil fuel consumption and CO2 emissions in the country. Moreover, it is found that the highest energy consumption can be covered by PV systems is recorded in winter. Also, the average energy production cost is ranged from 0.0444-0.0530$/kWh for all proposed systems based on the financial assumptions used in this study. It is concluded that the small-scale grid-connected rooftop PV systems are found to be economically justifiable.

1. Introduction

All-Energy has been an indispensable need for humanity. This need was met with conventional fossil fuels until the recent past. However, the use of fossil fuels has polluted the environment and led to climate change due to greenhouse gas emissions [1]. The environmental problems resulting from the increasing consumption of fossil fuels have led and encourage scientific researchers to search for alternative sources of energy that would be able to generate energy and protect the environment [2]. Many scientific researchers found that renewable energy like solar and wind plays a significant role in reducing greenhouse gas emissions (GHG) [3]. Ynhmuj ybg Recently, solar power has been considered as one of the main potential, economically viable, and environmentally friendly energy sources among renewable energy sources. Many studies have investigated the potential of solar energy for generating power in various countries around the world [4, 5].

In Jordan, the growth of populations, raising the standards of living, and rapidly growing industry sector have led to increasing the demand for fossil fuel consumption. Therefore, the utilizing of renewable energies such as solar energy as power sources can be an alternative solution for reducing the degree of dependence on imported fuel and reduce CO2 emissions. Several scientific studies have
investigated the potential of solar and wind energy in different regions in Jordan [6, 7]. According to previous scientific studies from 2001 to 2020, it can be concluded that Jordan has a huge solar energy potential compared to wind energy, and no scientific studies proposed 2kW and 5kW grid-connected solar power systems to meet the electricity demand of households in the Amman region in Jordan.

Therefore, the study aims to investigate the techno-economic and environmental sustainability of rooftop PV systems in two different locations in Amman. To achieve this, the NASA database has been utilized. Different sun-tracking systems including fixed tilt and 2-axis systems are investigated in this study. Moreover, numerous economic indices have been taken into consideration as a measure of performance indicator for the proposed projects. To this aim, RETScreen Experts software is used in the present study.

2. Material and methods

2.1. Study Area and Data

Amman is the capital city of Jordan. The area of it is estimated to be 1680 km². It is located at the latitude of 31°57'18.79” N, the longitude of 35°56'42.11” E. In general, the climate in Jordan is characterized by warm and dry summers and moderate wet winters. The annual average temperature is within the range of 12-15°C and the highest temperature value, which ranged from 40°C to 46°C, is occurred in desert areas. Therefore, Jordan combines the climate of the Mediterranean basin with the desert climate. Based on previous scientific studies, the NASA database showed good agreement with the measurement data of global solar irradiation based on previous scientific studies. Therefore, the monthly NASA database is utilized to investigate the potential of solar energy in the selected region.

2.2. Family electricity consumption and PV system sizing

This section aims to evaluate the techno-economic performance of small-scale grid-connected PV systems with various sun-tracking systems and PV technologies for a family household. Designing the electrical load is an essential part of this section. The energy demand in the family house is required for different usage. The energy demand (\(E_{load}\)) in kW/d of the considering household can be estimated using the given equation [8].

\[
E_{load} = \sum_{j=1}^{N_{category}} P_j n_j T_j
\]  

(1)

where \(P_j\) is the rated power of the j-th kind of household appliance (kW), \(T_j n_j\) is the number of the j-th kind of household appliance, \(T_j\) is the used hours per day of the j-th kind of household appliance (h/day) and \(N_{category}\) is the category number of household appliances.

Table 1 lists the electrical devices used in the considered family houses (small house and villa), located in different locations in Amman, Jordan (the small house is located in Al Jama’a, Amman, and the villa is located in Abu Nusir, Amman). The monthly electrical energy consumptions of the considered household are shown in Figure 1 for chosen house and villa between 2011 and 2020 and 2014-2020, respectively.

2.3. Design of the PV power system

For the proposed small-scale grid-connected PV system, mono-Si-CS6X-300M and poly-Si - CS6X-310P were selected which are manufactured by Canadian Solar. It was chosen in this study as it is one of the efficient available PV modules in the market. The specification of the selected modules is available in Ref. [8]. Moreover, one inverter is used to convert the DC into AC and feed it directly to the grid for the proposed PV systems (Table 2).

2.4. Economic analysis

Many software such as like RETScreen and HOMER software is used to estimate the economic indicators for financial analysis. Several researchers had utilized RETScreen software to investigate the feasibility of a grid-connected PV system [9]. In the present study, six economic indicators of financial analysis including Net present value (NPV), Levelized cost of energy (LCOE), Internal rate of return (IRR), Simple payback (SP), Equity payback (EP), and Annual life cycle savings (ALCS) are estimated
using RETScreen. Also, the energy production and the capacity factor (CF) for the proposed systems are determined using RETScreen.

### Table 1. Electrical equipment consumption

| Designation            | Power [w] | Number of devices | Designation   | Power [w] | Number of devices |
|------------------------|-----------|-------------------|---------------|-----------|-------------------|
| House Villa            |           |                   | Air conditioning | 2900      | 1 3               |
| Refrigerator           | 1500      | 1 3               | Refrigerator   | 1500      | 1 3               |
| Television             | 250       | 1 3               | Television    | 250       | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |
| Refrigerator           | 1500      | 1 3               | Refrigerator   | 1500      | 1 3               |
| Television             | 250       | 1 3               | Television    | 250       | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |
| Washing machine        | 2250      | 1 3               | Washing machine | 2250      | 1 3               |
| Electric cooker        | 1800      | 1 2               | Electric cooker | 1800      | 1 2               |
| Vacuum cleaner         | 1440      | 1 3               | Vacuum cleaner | 1440      | 1 3               |
| Toast                  | 1500      | 1 3               | Toast         | 1500      | 1 3               |

![Small house](image1.png)

**Small house**

![Villa](image2.png)

**Villa**

**Figure 1.** Load demand of the small house and villa collected from Jordan Electric Power Company
Table 2. Specification of selected inverter

| Item                     | Specification |
|--------------------------|--------------|
| Model name               | NXI 120      |
|                          | NXI 360      |
| Manufacturer             | Luminous     |
|                          | Luminous     |
| System rating [kW]       | 2            |
|                          | 6            |
| Maximum solar panel connection [kW] | 2            |
|                          | 6            |
| Efficiency [%]           | 96.8         |
|                          | 96.8         |
| Weight [kg]              | 9.8          |
|                          | 9.8          |
| Cost [USD]               | 350          |
|                          | 550          |

3. Results and Discussion

3.1. Monthly solar radiation

It is well known that the performance of PV modules is influenced by several climate parameters including meteorological factors of the specific location. Thus, solar irradiance is one of the essential parameters among them. Table 3 lists the monthly global solar radiation (GSR) and average air temperature (AT) for the selected locations (Abu Nusir and Al Jama’a) in Amman, Jordan. It is observed that the value of GSR is within the range of 86.60-252.92 kWh/m² for both selected locations. It is found that the highest GSR is recorded in July with a value of 252.68 kWh/m² and 252.92 kWh/m² for Abu Nusir and Al Jama’a, respectively, while the minimum one is obtained in December (i.e. 87.92 kWh/m² for Abu Nusir and 86.60 kWh/m² for Al Jama’a). Moreover, it is found that the annual GSR is 2035.64 kWh/m² and 2024.83 kWh/m² for Abu Nusir and Al Jama’a, respectively. Based on the value of solar radiation at the selected location, it is found that the solar resource of the selected locations is categorized as excellent (class 5) according to Kassem et al [8]. Therefore, this region is a suitable region for installing a PV system in the future due to the high value of GSR. Furthermore, the highest value of AT is recorded in July (i.e. 24.43°C and 23.97°C for Abu Nusir and Al Jama’a, respectively) next highest in August i.e., 24.41°C for Abu Nusir and 23.91°C for Al Jama’a.

3.2. Electricity generation and capacity factor

The optimum angles including slope angle and azimuth angle for the fixed-tilt system are estimated using Photovoltaic Geographical Information System (PVGIS) simulation tool. Therefore, the slope and azimuth angles for Abu Nusir and Al Jama’a are estimated to be 28° and 4° and 28° and 6°, respectively. Table 4 shows the annual electricity generation (EG) and capacity factor (CF) for the proposed systems. For the 2kW grid-connected PV system, it is found that the total annual value of EG is within the range of 3499.04-3592.96 kWh and 4788.05-4947.66 kWh for fixed-tilt and Two-axis system, respectively. For the 5kW grid-connected PV system, it is found that the total annual value of EG is varied from 8581.28-12128.30 kWh for fixed-tilt and Two-axis system. The maximum value of EG is recorded in July for all proposed systems. It can be concluded that the amount of output power could be increased by 50% when the Two-axis sun trucking system is used. Besides, it is noticed that the poly-Si system is produced more EG compared to the mono-Si system. However, the capacity factor of poly-Si systems is lower than CF of mono-Si systems, i.e. CF value is within the range of 19.02-26.44% for mono-Si systems and CF value is varied from 18.90% to 26.27% for poly-Si systems. These observations can be supported by other scientific researchers who analyzed the feasibility of a grid-connected PV system [8-10]. Therefore, it can be concluded that the value gotten from the present study for the selected location is compatible with the acceptable values. Consequently, it is technically sustainable to build a grid-connected rooftop PV system in the selected locations.
### Table 3. Monthly variation of GSR and AT for the selected locations

| Month | Abu Nusir | | | Al Jama’a | | |
|-------|-----------|---|---|-----------|---|---|
|       | GSR [kWh/m²] | AT [°C] | GSR [kWh/m²] | AT [°C] | |
| Jan.  | 90.06      | 5.35 | 88.13      | 4.61 | |
| Feb.  | 103.29     | 7.30 | 101.26     | 6.56 | |
| Mar.  | 156.00     | 11.41| 153.51     | 10.76| |
| Apr.  | 191.21     | 15.85| 189.59     | 15.28| |
| May   | 228.53     | 19.95| 228.51     | 19.44| |
| Jun.  | 248.31     | 22.82| 248.47     | 22.34| |
| Jul.  | 252.68     | 24.43| 252.92     | 23.97| |
| Aug.  | 231.56     | 24.41| 231.79     | 23.97| |
| Sep.  | 189.02     | 21.97| 188.10     | 21.37| |
| Oct.  | 150.62     | 18.15| 150.51     | 17.50| |
| Nov.  | 106.43     | 11.87| 105.45     | 11.07| |
| Dec.  | 87.92      | 6.54 | 86.60      | 5.73 | |

### Table 4. Value of EG, CF, and Economic performance for all proposed systems

| Location     | Variable | Fixed-tilt axis | Two-axis |
|--------------|----------|-----------------|----------|
|              |          | Mono-Si         | Poly-Si  | Mono-Si   | Poly-Si   |
| Abu Nusir    | EG [kWh] | 8581.28         | 8811.62  | 11811.26  | 12128.3  |
|              | CF [%]   | 19.21           | 19.09    | 26.44     | 26.27    |
|              | SP [year]| 6.13            | 5.95     | 5.89      | 5.72     |
|              | EP [year]| 2.35            | 2.23     | 2.2       | 2.09     |
|              | NPV [$]  | 7456.06         | 7800.2   | 10515.96  | 10983.5  |
|              | ALCS [$/year]| 639.81        | 669.34   | 902.38    | 942.5    |
|              | LCOE [$/kWh]| 0.0457        | 0.0444   | 0.0476    | 0.0462   |
|              | Performance [%]| 81.73        | 81.17    | 92.81     | 92.17    |
| Al Jama’a    | EG [kWh] | 3499.04         | 3592.96  | 4788.05   | 4947.66  |
|              | CF [%]   | 19.02           | 18.90    | 26.13     | 26.03    |
|              | SP [year]| 6.58            | 6.23     | 8.23      | 7.96     |
|              | EP [year]| 2.66            | 2.42     | 4.16      | 3.88     |
|              | NPV [$]  | 2898.41         | 3089.07  | 3252.61   | 3479.78  |
|              | ALCS [$/year]| 248.71        | 265.07   | 279.11    | 298.6    |
|              | LCOE [$/kWh]| 0.0511        | 0.0484   | 0.053     | 0.0502   |
|              | Performance [%]| 85.05        | 84.47    | 88.99     | 88.94    |

### 3.3. Performance of the Proposed PV Systems

The performance of the aforementioned sun-tracking systems is evaluated by the estimation of the economic and environmental factors for each system. In this study, the financial parameters (project life (25 years), inflation rate (0.76%), discount rate (7%), debt ratio (78.02%), debt interest rate (5%), debt term (15 years), and electricity export escalation rate (2%)) are considered as input variables for estimated economic indicators, which are assumed based on other previous scientific studies. In the present study, the system cost is around $2239-$5261 for 2kW and 4kW fixed-tilt PV system and $3939-$6961 for 2kW and 4kW Two-axis PV system, which is estimated based on recent market data in the country and is consistent with cost prices available in the literature. The main results regarding the economic performance of the 2kW and 5kW grid-connected rooftop PV system for all developed PV systems are summarized in Table 4. It is noticed that the value of LCOE is slightly increased by 4% when the Two-axis system is used. This increment of LCOE is primarily due to the high-cost Two-axis system. It is noticed that the developed systems are provided a very good insight into the economic viability of the project for all regions. Additionally, the obtained results demonstrated that the development of the
The proposed 5kW PV power system is economically acceptable due to the obtained favorable economic results.

4. Conclusions
In this study, the feasibility of small-scale PV system in different locations in Jordan is investigated. It is found that the annual energy output showed that the 2kW and 5kW grid-connected PV systems in the selected locations were within the range of 3499.03-4947.66kWh and 8581.28-12128.30kWh when fixed tilt and Two-tracking systems have been used, respectively. Also, it is observed that found that the highest energy consumption can be covered by PV systems is recorded in the spring and summer seasons. Moreover, the results indicate that the energy production cost of the proposed systems is competitive with the electricity company tariff. Additionally, the difference between the energy production cost (EPC) from a fixed-tilt system and EPC from a Two-axis tracking system is lower than 4%. It can be concluded that a grid-connected PV system with Two-axis sun-tracking was found to be economically justifiable. Furthermore, it is found that a 5kW grid-connected PV system is a more economical option than 2kW because of higher values of NPV, BCR, ALCS, and IRR as well as lower values of EB, SB, and LCOE values.

References
[1] Riahi K, Vuuren D P, Kriegler E, Edmonds J, O’Neill, B C, Fujimori, S, . . . Tavoni M 2017 Global Environmental Change 42 153-168
[2] Vijayavenkataraman S, Iniyan S and Goic R 2012 Renewable and Sustainable Energy Reviews 16 878-897
[3] Schnitzer H, Brunner C and Gwehenberger G 2007 Journal of Cleaner Production 15 1271-1286
[4] Kassem Y, Gökçekuş H and Çamur H 2018 Global J. Environ. Sci. Manage. 4 465-482
[5] Kassem Y, Çamur H and Aateg R A 2020 Energies 13 3708
[6] Aagreh Y and Al-Ghzawi A 201 Applied Energy 103 25-31
[7] Al-Najideen M I and Airwashdeh S S 2017 Resource-Efficient Technologies 3 440-445
[8] Vishnupriyan J and Manoharan P S 2018 Journal of cleaner production 185 309-321
[9] Mohammadi K, Naderi M and Saghafigar M 2018 Energy 156 17-31
[10] Rehman S, Ahmed M A, Mohamed M H and Al-Sulaiman F A 2017 Renewable and Sustainable Energy Reviews 80 319-329