Techno-Economic Assessment of Small-Scale Grid-Connected Solar System in Coastal Cities of Lebanon

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Abstract: The goal of the present study is to examine the economic viability of 12kW grid-connected photovoltaic systems in five coastal cities in Lebanon (Beirut, Tripoli, Saida, Tyre, and Batroun). The results demonstrate that solar energy is a feasible alternative for the nation's sustainable electricity generation, especially in consideration of Lebanon's high levels of solar radiation and rising energy needs. Moreover, a variety of economic indicators, including Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, Levelized Cost of Electricity (LCOE), and Equity Payback, are computed using RETScreen software. The findings display the profitability for each PV system proposed, where all NPV values are positive and IRRs are above acceptable thresholds. Additionally, Tripoli has the lowest cost of power ($0.0974/kWh) and the lowest payback period (12.40 years), while Beirut has the highest cost and the longest equity payback period. According to the emission investigation, Tripoli avoided the most emissions and also recorded significant greenhouse gas (GHG) savings. According to these findings, solar photovoltaic systems could help Lebanon move toward renewable energy, reduce its negative environmental effects, and promote energy sustainability.

Keywords: Techno-economic, Environmental viability, Grid-connected photovoltaic system, Lebanon, Coastal cities.

1. INTRODUCTION

Energy is one of the fundamental human requirements [1]. Conventional fossil fuels have been able to meet this requirement [2]. However, the increased consumption of fossil fuels has resulted in the pollution of the environment and global warming [2-4]. As such, several scientists have sought alternative sources of energy that will produce electricity without compromising the environment [5-8].

Solar energy has grown to be a significant substitute due to its accessibility, affordability, and cleanliness [9-10]. The potential of solar energy in producing power in different countries around the world has been researched in numerous research papers. For instance, Adnan *et al*. [11] assessed the feasibility of solar energy for Pakistan with regard to fifty-eight weather stations. According to their study, in the provinces of South Punjab, Sindh, and Balochistan, a single 100 m² space can produce 45 MW to 83 MW of electricity per month. According to Shahsavari *et al*. [12], powering through solar power systems can even enhance environmental protection in Iran. Martín-Pomares *et al*. [13] found that large grid-connected photovoltaic systems are the best options for producing electricity in Qatar. Kassem *et al*. [14] examined the performance of a 30 kW grid-connected building-integrated PV system and contrasted it with a free-standing PV system. They concluded that the free-standing PV system performed better than the building-integrated system to meet the demand of the building.

Lebanon's energy situation has long been challenged by long-term poor management, political paralysis, and aging infrastructure [15]. Since the civil war ended in 1990, Électricité du Liban, the country's power company, has struggled to meet demand [16]. It is heavily reliant on imported fossil fuels and only supplies a few hours of electricity per day in many locations. During this collapse, Lebanon experienced an unexpected and rapid shift to renewable energy, particularly solar power [17, 18]. Lebanon, known as "the 600-sunday country," has an average daily solar irradiation of 5.01 kWh/m² and 3000 hours of sunlight yearly, thereby indicating considerable solar energy potential [19-21]. Recently, installed solar capacity has increased and has become a vital lifeline. Numerous studies have examined Lebanon's potential for using solar energy [22-27]. For instance, Kassem *et al*. [22]

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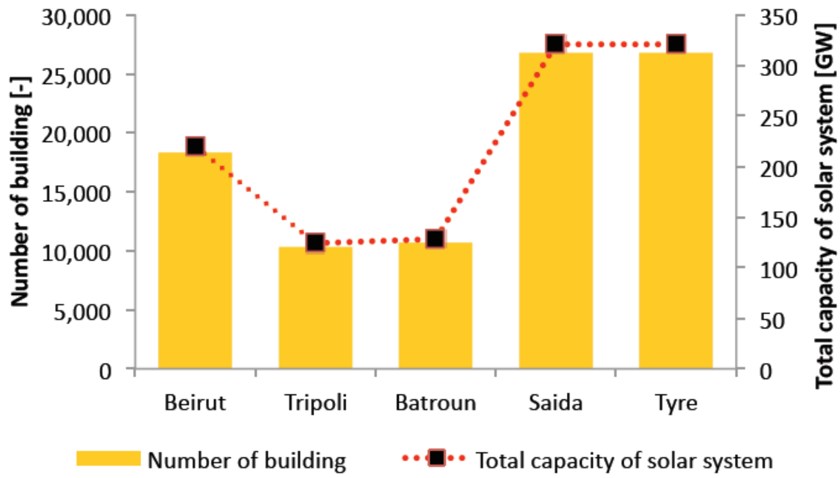

Figure 1: Number of buildings and total capacity of the proposed system in each selected city.

evaluated the viability of installing a 100 MW grid-connected wind and solar system in the Rayak region of Lebanon.

Therefore, to provide enough energy for residential and commercial buildings in Lebanon's coastal cities, this study suggests a 12 kW grid-connected rooftop photovoltaic plant. According to the Central Administration for Statistics 2004, the number of households in the chosen cities and the total capacity of the solar system (Eq. (1)), which is estimated based on the number of buildings in these areas, are shown in Figure **1**.

$$Total\ capacity\ of\ solar\ system = number\ of\ rooftops\ of\ building \times 12kW \quad (1)$$

In this study, the techno-economic feasibility of 12kW grid-connected photovoltaic systems in five coastal cities (Beirut, Tripoli, Saida, Tyre, and Batroun) in Lebanon is evaluated using RETScreen software. The RETScreen software is used to calculate several economic indicators, such as Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period, Levelized Cost of Electricity (LCOE), and Equity Payback.

2. MATERIALS AND METHODS

2.1. Solar Potential Classification

The solar energy potential is categorized using the yearly global solar radiation (YGSR) value. YGSR is regarded as a crucial component in evaluating the energy production of the solar system. As illustrated in Figure **2**, the solar energy categorization can be characterized based on the value of YGSR according to Kassem *et al*. [28].

2.2. Design PV System

The capacity of photovoltaic (PV) systems is determined by the number of PV modules installed.

According to Kassem *et al*. [29], the procedure for designing the PV system is illustrated in Figure **3**.

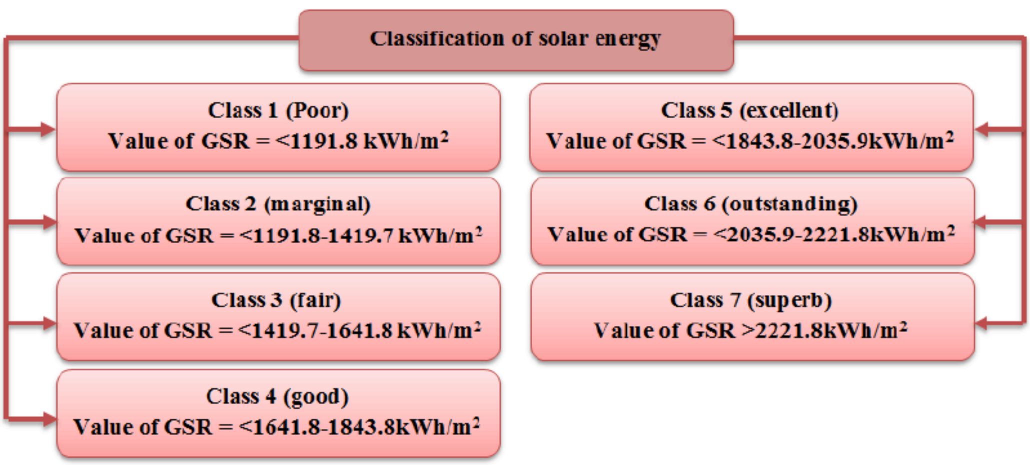

Figure 2: Solar potential classification.

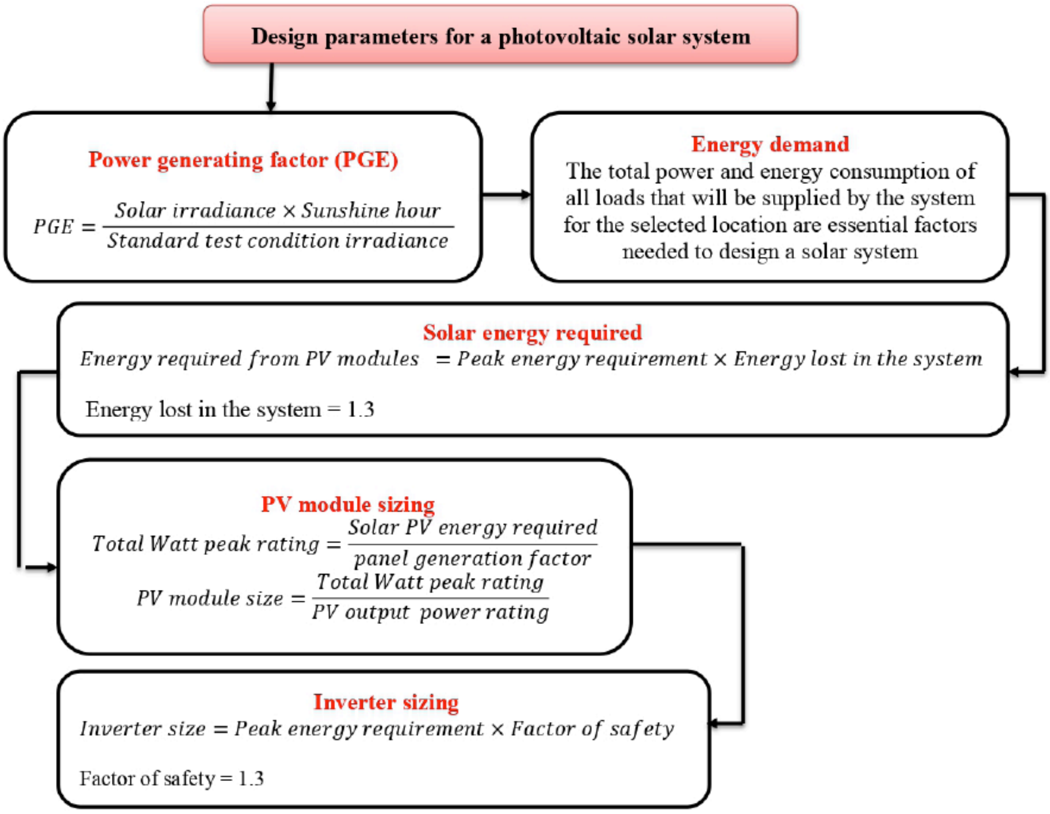

Figure 3: Procedure for Designing a Solar System.

In this study, JKM580N-72HL4-BDV, manufactured by JinKO solar, with a capacity of 580W and efficiency of 22.45%, has been chosen for the proposed 12 kW grid-connected solar system. This module is known for its efficiency and is currently available on the market. These modules require about 60 m² of space in total. Besides, four units of SAJ 5kW 2MPPT Three-Phase Grid Inverter are used for the developed solar PV system with a capacity of 5kW and an efficiency of 98%.

2.3. Economic Viability

Scientists, engineers, and researchers estimate the technical viability and economic sustainability of renewable energy systems using a variety of simulation tools [30]. In this study, a 12 kW grid-connected rooftop solar PV system's techno-economic and environmental aspects were assessed using RETScreen Expert software, which was also used to compare the system's performance in the selected cities.

RETScreen software is a valuable tool for examining and evaluating the viability of a grid-connected renewable energy system [31]. RETScreen is capable of estimating capacity factors, monthly and annual energy productions, and other important economic metrics based on the input data [32]. In order to assess the project's viability and make sure it is technically, legally, and financially sound, a feasibility analysis is also carried out.

Figure **4** displays the financial parameters for the suggested systems that were judged to be

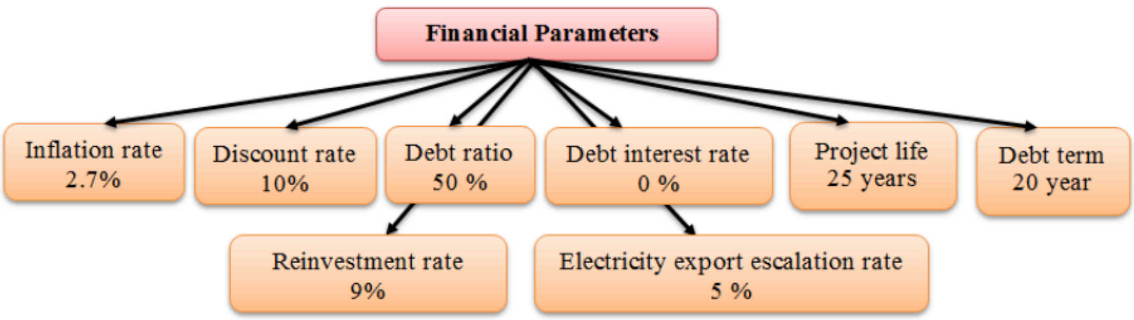

Figure 4: Financial parameters used as input parameters in the RETScreen software.

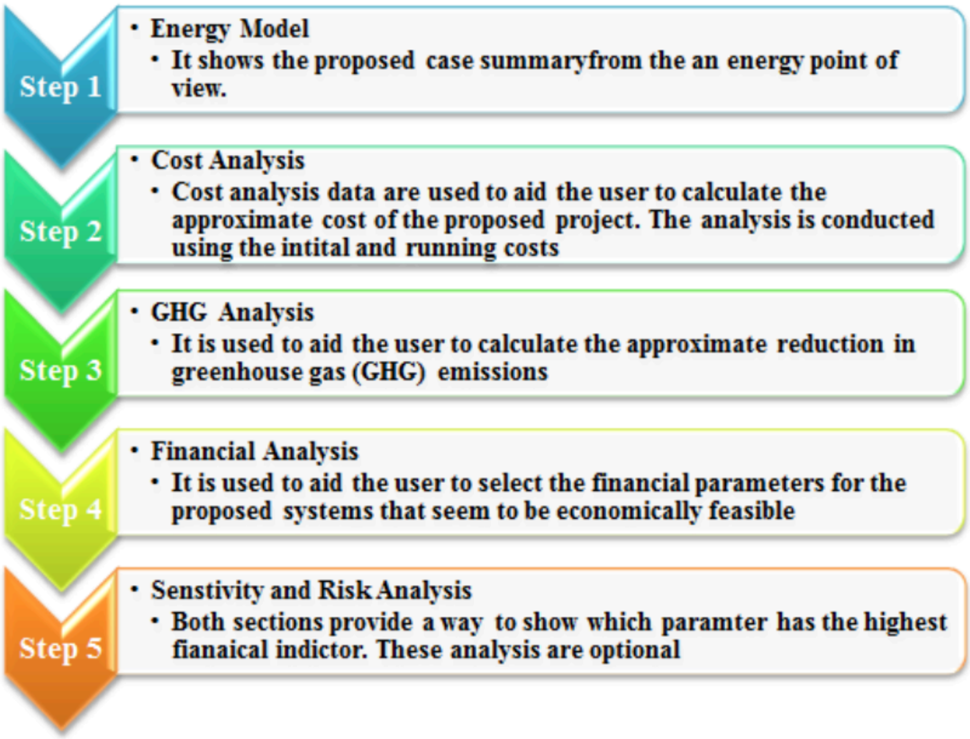

Figure 5: Steps of evaluating the developed renewable energy system using RETScreen software.

economically viable. The methodology used by the RETScreen Expert software is shown in Figure **5**.

3. RESULTS AND DISCUSSION

3.1. Solar Energy Potential Assessment

As mentioned previously, global solar radiation data were collected from the NASA power dataset for the period of 1982-2023. The monthly variation of global solar radiation (GSR) and air temperature (AT) is shown in Figure **6**. The two indicators (GSR and AT) show a similar seasonal pattern, rising gradually starting in January, reaching their peak in the summer (June to August), and then falling in the run-up to December. With hot, dry summers and mild, rainy winters, this pattern is typical of the Mediterranean climate. For all cities, GSR peaks in June at 244 kWh/m² in Tyre and 258 kWh/m² in Batroun. January sees the lowest values, which range from 50 to 54 kWh/m². Besides, all locations experience their highest air temperatures in August, when they average about 28$°C$, and their lowest in January, when they average about 13 to 15$°C$. Batroun and Beirut have slightly better solar energy potential than the other cities, as evidenced by their slightly higher summertime GSR. GSR continuously stays above 200 kWh/m^2, indicating that May through September is the best time of year to harvest solar energy.

Moreover, Figure **7** shows the solar resource classification for each of the selected regions based on the YGSR. It is shown that all of the chosen areas are categorized as good or excellent and have abundant solar resources. Additionally, it is discovered that Batroun's solar resources fall into the excellent (class 5) category. As a result, this city's high YGSR value indicates that it is one of the best places to install solar panels in the future.

3.2. Technical Viability

The purpose of this study is to investigate the potential for solar energy capture by building roofs through examining a fixed-tilt rooftop solar PV system in various cities. The five coastal cities of Lebanon have slightly different optimum slope and azimuth angles for optimizing solar energy capture. Due to slight variations in geography and solar path, the slope angle, which establishes the tilt of the solar panels, varies between 28° and 30°. At 30°, Batroun possesses the highest suitable slope, followed by Beirut, Tripoli, and Tyre at 29°, and Sidon at 28°. There is also a small fluctuation in the azimuth angle, which indicates the panel's orientation with respect to the southeast. Beirut and Tripoli have an azimuth angle of -2°, which is also slightly east of south, while Batroun has an angle of -3°, which indicates a slight eastward orientation. Tyre displays a slight west orientation at 3°, while Sidon is most effectively oriented directly south at an azimuth angle of 0°. According to these values, solar panels should be positioned in all cities with a tilt of about 30° and a general southerly orientation, with slight variations to the east or west depending on the location. In the coastal region of Lebanon, solar photovoltaic systems operate more efficiently and

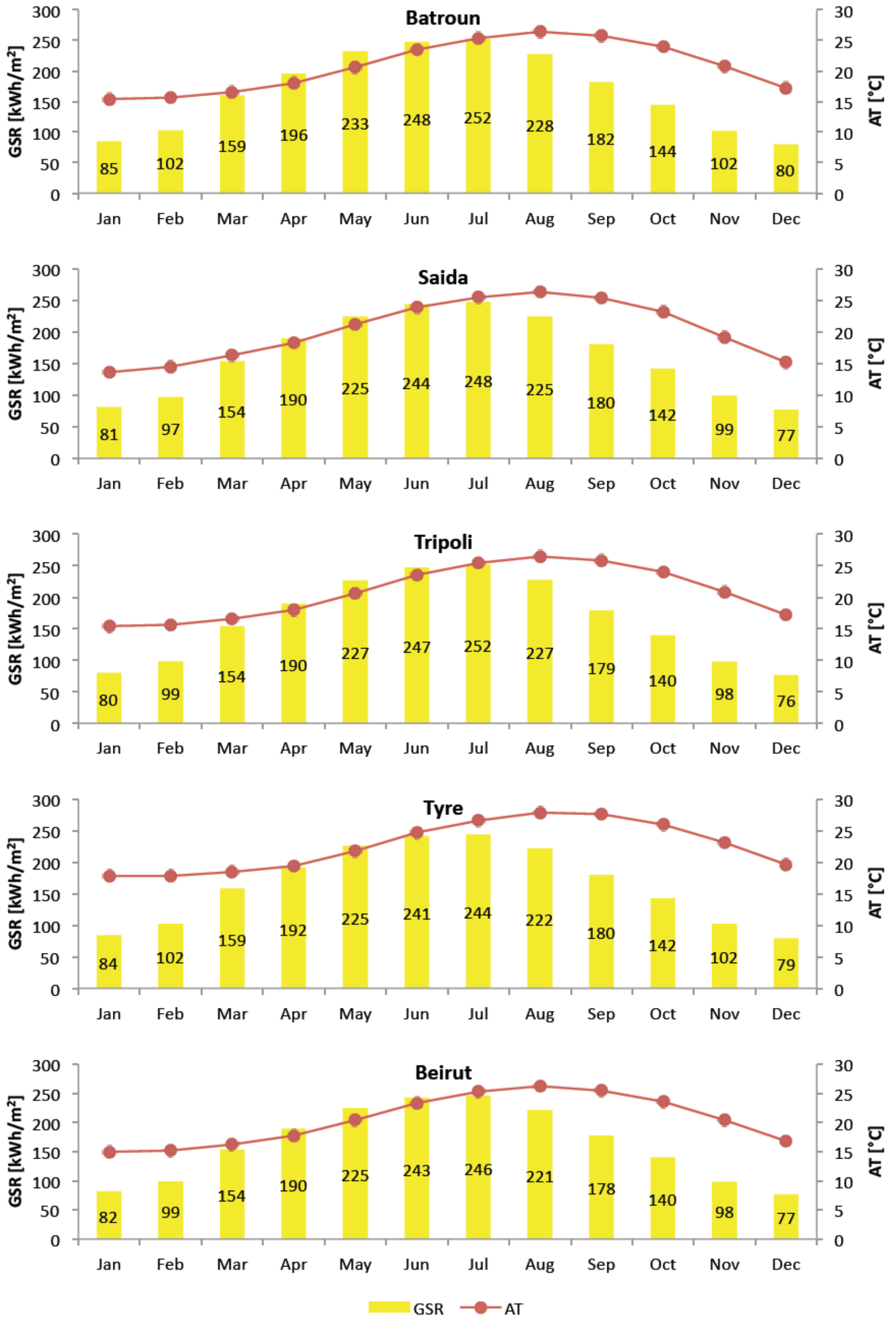

Figure 6: Monthly variation of GSR and AT for all selected cities.

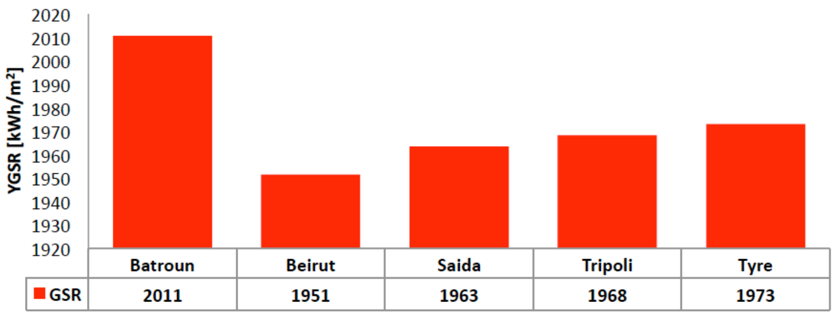

Figure 7: YGSR categorization.

produce more energy annually when these ideal angles are used.

The amount of solar radiation and the number of sunny, clear days have a significant impact on PV energy production. These factors also affect the system's capacity factor and the amount of energy that is supplied to the grid annually. Based on the optimum angles for solar panels, Figure **8** shows the monthly variability of the average energy supplied to the grid for a few chosen cities. It is found that there are significant seasonal and spatial variations in the monthly electricity exported to the grid from photovoltaic (PV) systems in the selected five coastal cities. Due to increased solar radiation availability, electricity export values in all cities peak in late spring and summer (May to July) and fall in winter (January and December). Beirut continuously exhibits the lowest monthly exports for the majority of the year, with its lowest in January (1.0535 MWh), while Tripoli records the highest monthly export in July (2.4127 MWh). Annually (Figure **9**), Beirut records the lowest total electricity export at 19.684 MWh, while Tripoli records the highest at 23.765 MWh, closely followed by Batroun at 23.560 MWh.

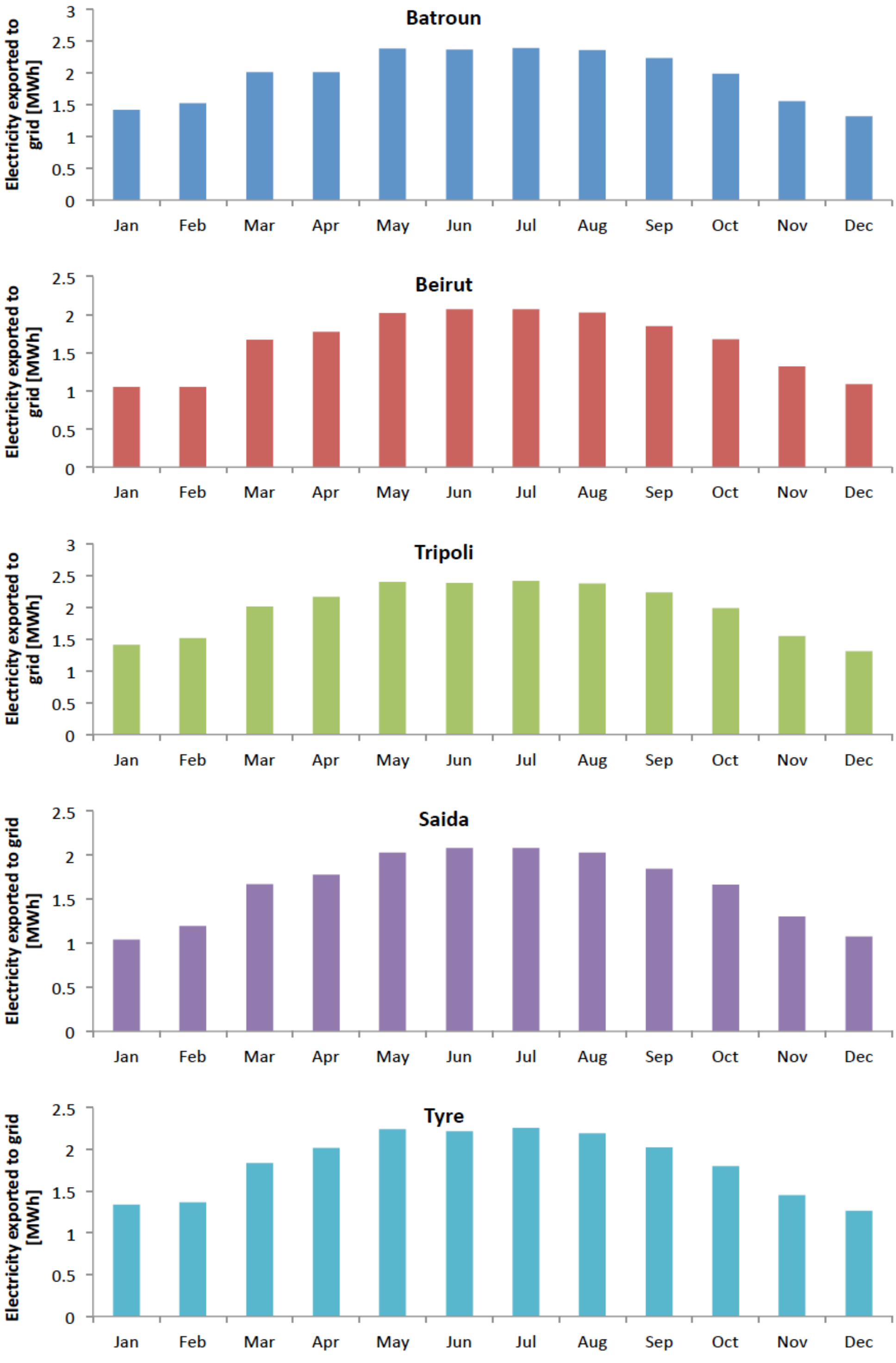

Figure 8: Monthly variation of electricity exported to the grid for all selected cities.

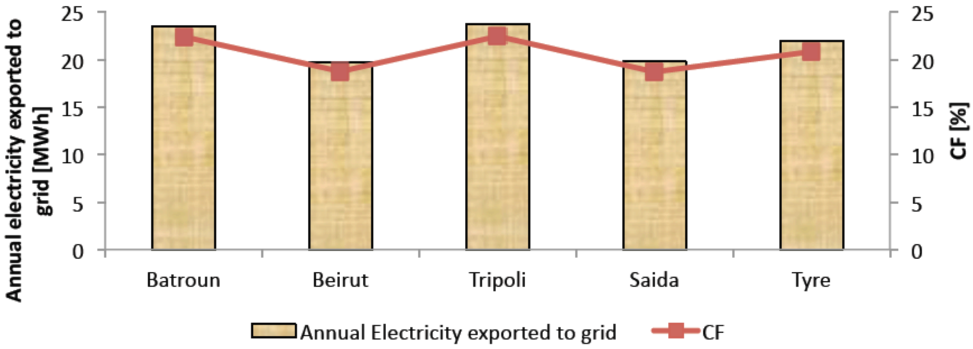

Figure 9: Annual value of electricity exported to the grid and capacity factor for all selected cities.

The variations can be seen in the capacity factor (CF) values as shown in Figure **9**. Tripoli has the highest CF at 22.5%, which shows that it uses the installed solar capacity more efficiently than Batroun (22.4%) and Tyre (20.8%). At 18.7% and 18.8%, respectively, Saida and Beirut have lower CFs. Differences in solar irradiance, ideal panel orientation, and regional climate conditions can all be blamed for variations in electricity export and CF. These observations are useful for maximizing the deployment of PV along Lebanon's coast.

3.3. Economic Sustainability and Emission Reduction Assessment

During the evaluation of the viability and long-term viability of solar PV projects, economic analysis is essential. Assessing a PV power plant's economic feasibility is crucial for directing investors and politicians. The RETScreen software, which utilizes significant financial parameters such as the discount rate, inflation rate, debt ratio, reinvestment rate, and debt interest rate as input variables, was used to perform financial assessments for this study. As shown in Figure **10**, the software computes a number of significant financial metrics based on these inputs, such as the Internal Rate of Return (IRR), Modified IRR, Simple Payback Period, Equity Payback Period, Net Present Value (NPV), Annual Life Cycle Savings, Debt Service Coverage, Benefit-Cost (B-C) Ratio, GHG Reduction Cost, and the Levelized Cost of Electricity.

The main measures of economic viability for PV projects are NPV, IRR, and payback period, per references [33]. The financial attractiveness of the suggested systems was confirmed by the analysis, which showed positive NPV values for every city. Moreover, the project's profitability is reinforced by the IRR values surpassing the acceptable threshold [33, 34]. Out of the five cities, Sidon has the longest payback period (14.90 years), followed by Beirut (14.86 years), and Tripoli has the shortest (12.40 years). Tripoli has the shortest equity payback period (6.84 years), while Beirut has the longest (8.32 years). At \$0.0974/kWh, Tripoli has the cheapest electricity prices, followed by Batroun (\$0.0976/kWh), while Beirut has the highest price at \$0.1167/kWh.

The RETScreen Emission Analysis Worksheet was used to determine the reduction of greenhouse gas (GHG) emissions attributable to PV installations [34]. It is estimated that each city is going to reduce GHG by 16.80 tCO_2/year, with Tripoli experiencing the largest reduction and highest cost savings of \$87,210/tCO_2. Sidon has the lowest level of emissions reduction, followed by Batroun. These findings support the economic and environmental benefits of installing PV systems in coastal cities in Lebanon.

3. CONCLUSIONS

The economic and environmental analysis demonstrated the viability of solar photovoltaic schemes in Lebanon's five coastal cities and their significant value in achieving the sustainability goal. The research indicates that Tripoli can be regarded as a model city for the implementation of sustainable solar power due to its maximum payback period, lowest levelized power cost, and maximum reduction in greenhouse gas (GHG) emissions. Furthermore, Beirut and Sidon have slightly longer payback periods and higher electricity costs, but they still provide good returns and environmental advantages. These PV systems enable Lebanon to create a sustainable transition to renewable electricity by promoting energy security, reducing dependency on fossil fuels, and lowering carbon emissions. The significant GHG reductions in every city demonstrate the benefits of solar energy for the environment and climate mitigation, and they are consistent with international climate action objectives. In general, the installation of PV systems in coastal communities in Lebanon is an intentional initiative toward a more robust and sustainable energy future that will support both national and international

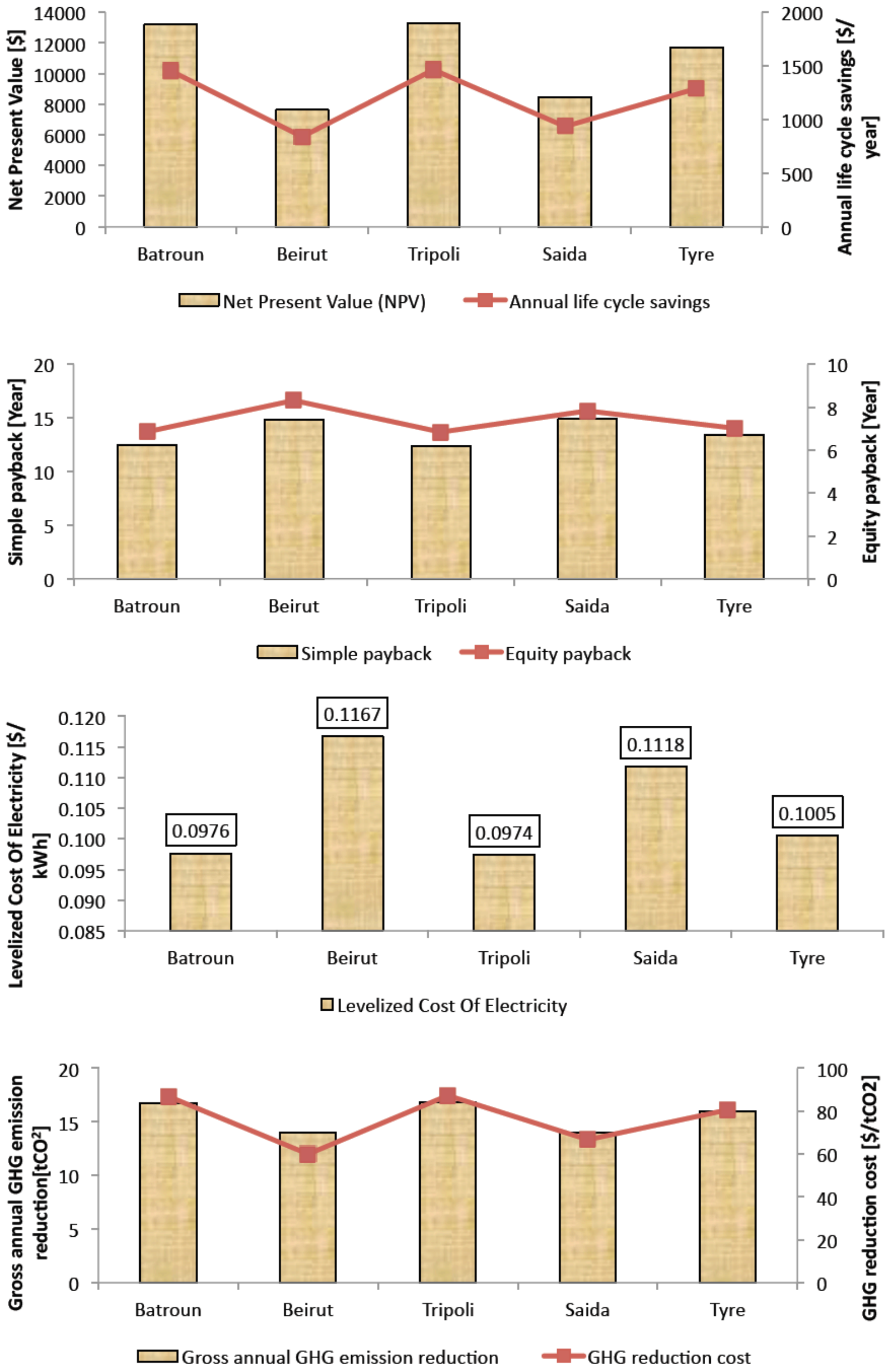

Figure 10: Economic performance of developed solar systems.

sustainability goals and improve the environment and economy.

CONFLICTS OF INTEREST

The author declared no conflicts of interest.

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