

# Techno-Economic Optimization of Solar-Powered EV Charging Stations in Muscat, Oman using HOMER Grid

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**Abstract:** International demand for EVs is only exceeded by the need for reliable and sustainable charging infrastructure. Oman may cut carbon emissions and fossil fuel use with this adjustment, but it strains the power infrastructure and requires solar-based EV charging facilities. A Muscat, Oman, solar-powered EV charging station using HOMER Grid software is examined technically and economically. System-level factors, including solar radiation, load demand dynamics, grid access, and project features, define an autonomous solar-powered EV charging station's optimal design and location. HOMER Grid simulates and optimizes processes. The assessment covers energy production, renewable percentage, and COE for several system designs. Thus, solar-only and grid-connected hybrid systems were evaluated on NPC, ROI, and LCOE. The study indicated that solar PV-based charging and battery storage minimize grid power demand and operational costs. The optimized system covers Muscat's EV charging needs with 97.9% renewable energy and 12543731kWh of annual energy production, saving \$593,578/yr in bills and energy charges. Optimized solar-dependent systems base system COE \$0.0362/kWh to -\$0.0236/kWh suggested model, opposing grid-based charging stations. In addition to grid-connected EV charging, CO<sub>2</sub> and greenhouse emissions may be reduced. As Oman's EV infrastructure needs expand, implementing solar EV charging stations in Muscat is technically and economically viable. If properly built, solar-charged EV stations may reduce CO<sub>2</sub> emissions, increase energy security, and assist Oman in reaching its renewable energy targets.

**Keywords:** Cost of Electricity, Levelized Cost of Energy, HOMER GRID, Net Present Cost (NPC), Radiation

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## 1. Introduction

Electric vehicles (EVs) are developing fast as an alternative, better some what traditional vehicle. This rapid development in demand stresses the importance of modernizing existing power grids. EVs would play a role in the transport system of sustainability (a road towards Oman Vision 2040 and Net-Zero 2050). The government encourages electric vehicles through customs exemption, extending charging infrastructures, and including renewable energy sources. Because of their low fuel and maintenance costs, low carbon emissions, and diversification with solar and wind, EVs economically and environmentally provide the edge of energy diversification. However, limited charging points, high initial cost, and grid integration were issues that needed to be solved to

introduce EVs to a cleaner and sustainable Oman. The global usage of EVs in the year 2024, would significantly develop the Electric Vehicle (EV) Market, as sales increased by 25% from last year, 2023, to reach 17.1 million unit's sales in the year. An individual in urban residential areas has used the PV system to supply electrical loads during load shedding. Oman is thus endowed by nature with various opportunities for renewable energy resources, primarily among them solar energy. The introduction of net metering in the light of increasing adoption of PV systems would complete the government of Oman's (GOP) decision to ensure the public interest in injecting the PV system into the national grid. Renewable energy is in high demand, and the subsequent shift to electric vehicles (EVs) is being driven by growing environmental concerns and the need to reduce greenhouse gas emissions. Solar panels, wind turbines, biomass power plants, electrolyzers, fuel cells, hydrogen storage, batteries, inverters, and the grid were all part of the six scenarios thoroughly examined by HOMER Pro [1]. Given the importance of HV lines in power transmission, this study differs from most others that have focused on low voltage lines [2]. This study investigates the conceptualization of an HRES for sustainable electrification in a rural village over the long-term period. Several configurations for hybrid power systems have been modeled, using the optimization software HOMER Pro, with an emphasis on a design that also includes an electrolyzer and hydrogen tank to reduce the use of batteries [3]. The current investigation focuses on a HRES sized for off-grid remote household applications in a Greek island. It was determined that the system is reliable to fulfill the electrical and thermal demand through the entire year. This approach shows the feasibility of hybrid DC systems in remote areas, where grid extension is not feasible [4]. This study evaluates a standalone renewable energy-based charging station to meet the demand without stressing the power grid itself, focusing on four cities in Qatar. Modeling was done using HOMER software with possible configurations considering local geographical and meteorological conditions. The designs then proved to be feasible for establishing a renewable-based charging station dynamically adaptable to place through localized meteorological conditions [5]. This study analyzed whether HRES could generate power and heat for a household in the UK. The results show the feasibility of

HRES for residential energy supply and offer insights that are relevant to other countries in Europe [6]. The paper describes and evaluates EMS and optimal sizing of power sources for hybrid electric vehicles (HEVs) with fuel cells/batteries/ super capacitors concerning power distribution, energy efficiency, and component degradation. It introduces predictive EMSs, which include ANN, RL, and MPC, and hybrid EMSs that combine rule-based, predictive, real-time, and learning-based algorithms for maximum performance. The paper finds that SoC-based methods work very well for real-time energy management, particularly with large-capacity batteries, while small batteries are highly degraded. RL-based EMS enhances fuel economy and system efficiency compared to DP and rule-based EMS. Further on, ECMS, for online optimization, is more efficient than PMP and DP. Their findings indicated that RL-based EMS outperformed others in terms of minimizing energy losses and battery degradation [7]. The study was aimed at meeting the ever-increasing demand for sustainable energy in the transportation sector and that which is driven by global policies for promoting electric vehicles (EVs) to ensure a reduction in the use of fossil fuel and greenhouse gas emissions. The methodology of sizing design may be tailored for global applications in charging solutions for sustainable electric vehicles [8]. By this study, the use of renewable energy in electric vehicles (EV) charging stations for the attenuation of carbon and fossil fuel dependences was studied. The findings show the most cost-effective solution with the PV/ESS configuration because the weather office is strategic. On the other hand, the most beneficial REF scenario for both economic viability and carbon emissions is below 25%, showing a good strategy as RCA for future and eco-friendly EV charging [9]. The system performance was measured in terms of the percentage share of electricity consumption of the system components. It was ascertained that, in the configuration that electrically contributes 82% of the energy consumption, solar PV represents 62% and wind turbine power makes up 20% of the total energy generation. It was also observed that much deficit will emanate due to the construction of a grid-tied hybrid solar wind system with more than 40 kWh surplus predicted [10]. In the present research a highly efficient hybrid renewable energy system (HRES) with main sources of power being solar PV energy sources, wind mills, diesel generator, storage of battery in various forms, electrolyzer, hydrogen tanks.

In this work, to analyze the system, the configurations are optimized in HOMER software. Sensitivity analysis is also done by varying the electrical loads as well as the project life span duration and safety factors [11]. This paper explores the use of HOMER Hybrid Optimization Software for designing and analyzing hybrid power systems, which combine conventional generators with renewable sources like solar PV, wind turbines, and batteries evaluates the energy efficiency of a renewable energy system, integrating a PV system, three batteries, and a converter with an isolated AC diesel generator. On other side investigates the impact of different load profiles on the system's performance, highlighting how load variations affect the renewable energy system's response and cash flow for system components. This section also includes the integration of a wind turbine with the existing PV, battery, converter, and AC diesel generator system [12]. In this paper, stand alone hybrid renewable energy systems discussed solar and wind applications and with the data analysis provided through HOMER Pro software, that had shown it more effective and productive [13]. The study investigates the ethanol-based electrolyte of nanoporous titania photo chemically deposited on hematite photo anode electrodes for photo electro chemical splitting of water. The experimental data and the model that predicted the accuracy of the photodecomposition of water to hydrogen with the photo anode were shown through the presentation of experimental curves of different concentrations [14]. In this paper, we present a discussion on the techno-economic optimization approach for a solar-based EV charging station using the HOMER Grid program so that electric vehicle charging demands can be met well without incurring unnecessary costs and adverse environmental impacts.

The study tackles considerations relating to the feasibility of solar-powered EV charging stations for electric vehicles, with an emphasis on large and small EVs along the highways of Muscat in Oman, directed towards solving the issue of the absence of charging infrastructure for these EVs. In making use of solar PV systems, the study seeks to address power shortage, especially in areas where infrastructure weakly exists. The research predominantly concerns system sizing and optimal operational conditions, power quality considerations, and economic implications to develop

economically feasible solutions before engaging in considering the societal or technical impacts. The proposed system presents an affordable and sustainable solution for EV and electric bike charging, which conserves energy and is a step forward in renewable energy use. It, in tandem with GHG emissions and generated revenue through hybrid charging stations, also examines the economic and environmental impacts while advocating for low emissions. The sensitivity analysis assesses how results vary with sensitive parameters; therefore, a comparison is made between the environmental impact (GHG emissions) of the proposed system and one with conventional techniques. Lastly, policy components of the design model of the standalone hybrid charging are discussed.

Section 2 discusses the methodology, which describes the simulation parameters used in Homer Pro. Section 3 gives details about optimal System design configuration, which includes solar PV, battery storage, and grid interaction. Section 4 describes the results and Discussion, which analyzes economic and environmental impacts of different configurations. Section 5 includes conclusions and recommendations, which summarize findings, and suggests future research directions.

## 2. Methodology

### 2.1 Site selection and site description

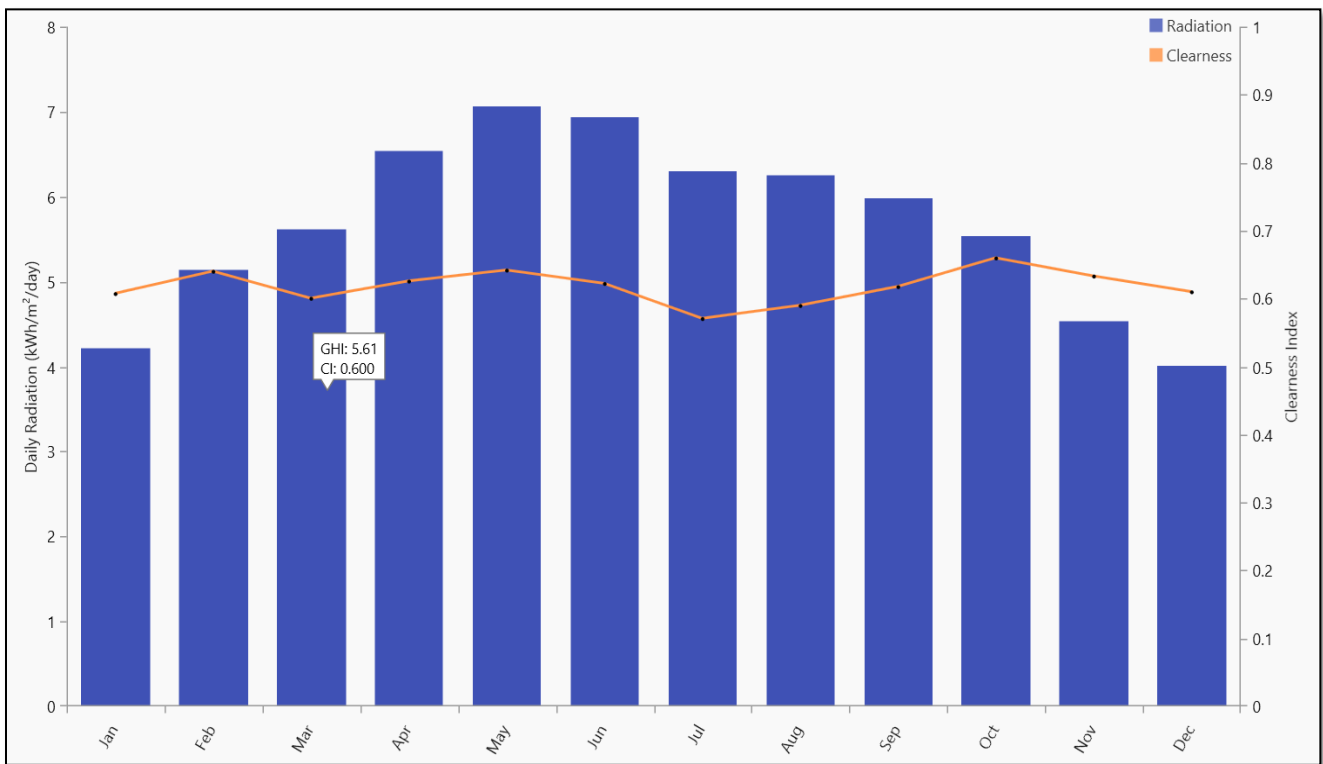
In this section, the detailed explanation of the methodology for the proposed research work deals with a case study, Muscat, Oman. The geographical location of the site is illustrated as shown in Fig. 1. There are generally two site scenarios, on-grid and off-grid. Muscat, Oman, latitude and longitude are 23°35.5 N and 58°23.0 E, respectively, with Muscat time zone (UTC/GMT + 4 hours).

### 2.2 Solar Resources

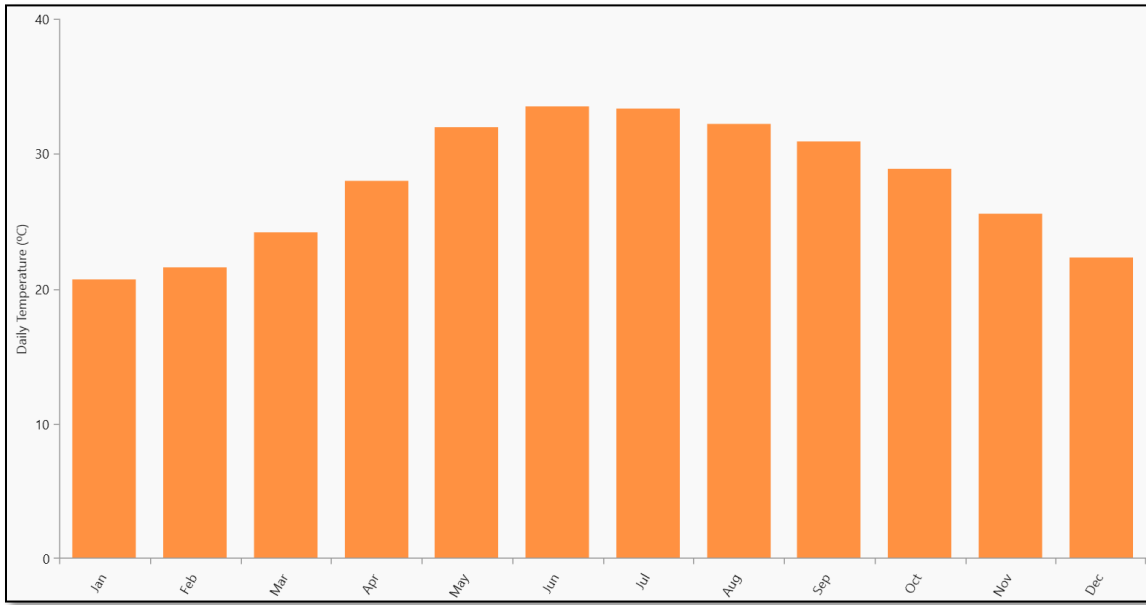
By compiling all pertinent data from the NASA site (July 1983–June 2005), HOMER Grid can gather solar resources down to the exact geographical data. Radiation data, temperature, and clarity index are the three primary characteristics of solar resources.



**Fig. 1:** Map of Muscat, Oman, showing selected EV charging station location (Latitude 23°35.5'N, Longitude 58°23.0'E)



(a)



(b)

Fig. 2: (a) Monthly solar radiation (kWh/m²/day), (b) Monthly clearness index and temperature (°C)

Fig. 2 displays the clearness index and monthly average horizontal irradiance for the specified spot. Table. 1 shows the clarity index and the mean PV radiation for each month. According to these numbers, December has the lowest sun radiation at 4.010 kWh/m², while May has the highest solar radiation at 7.060 kWh/m². Typical parameters for a photovoltaic system's design include a temperature of 27.75 degrees Celsius, a clearance index of 0.617, and an average yearly solar radiation value of 5.67 kWh/m². The sunlight reaching the earth was being analysed during the feasibility study. Atmospheric cleanliness, tantamount to the operation of the charging station, is also studied. Comparisons between sunny days and cloudy days can be made using parameters like the clearness index and solar irradiance values, as portrayed in Fig. 2. According to the data shown in Fig. 3 (b), the electric vehicle charging station's peak load is 405.71 kW, and its average daily load demand is 2426.45 kWh. The station was chosen for its location in Muscat, Oman.

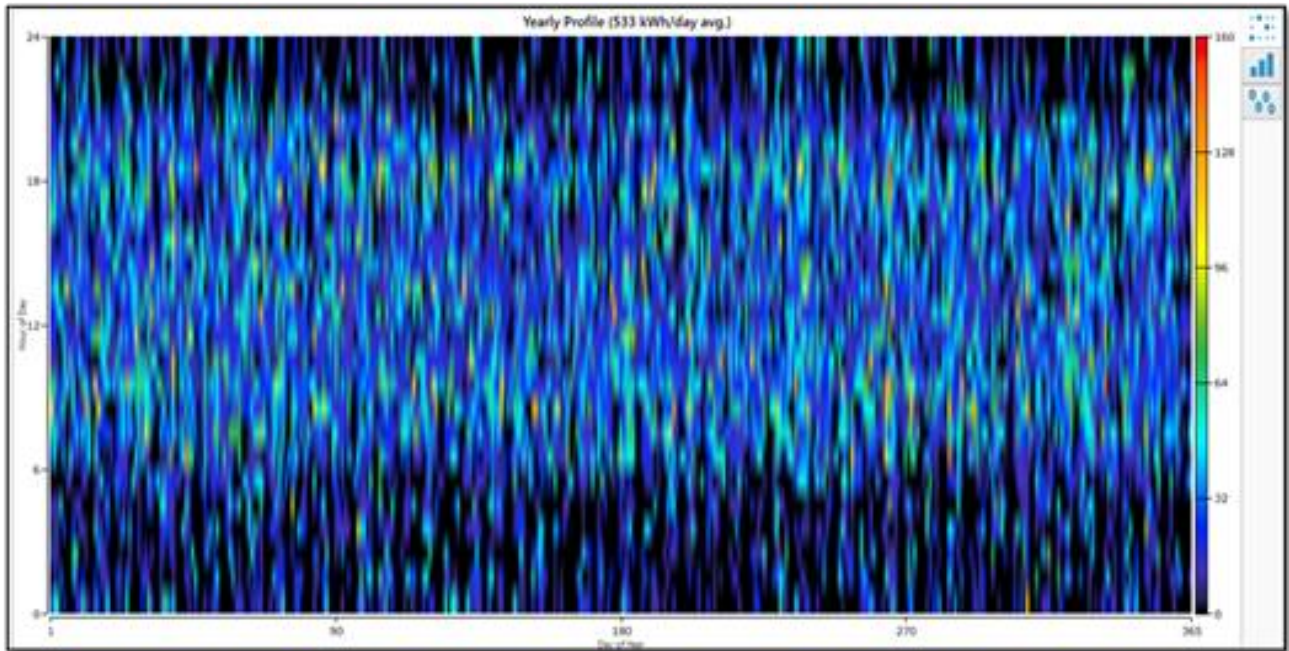
### 2.3 Flow Chart

All the resource data of the present site are fed into the system. The main loads and EV load profile, as shown in Fig. 3 (a). The NPC, COE, CC, and emissions of the system are then investigated. The main steps

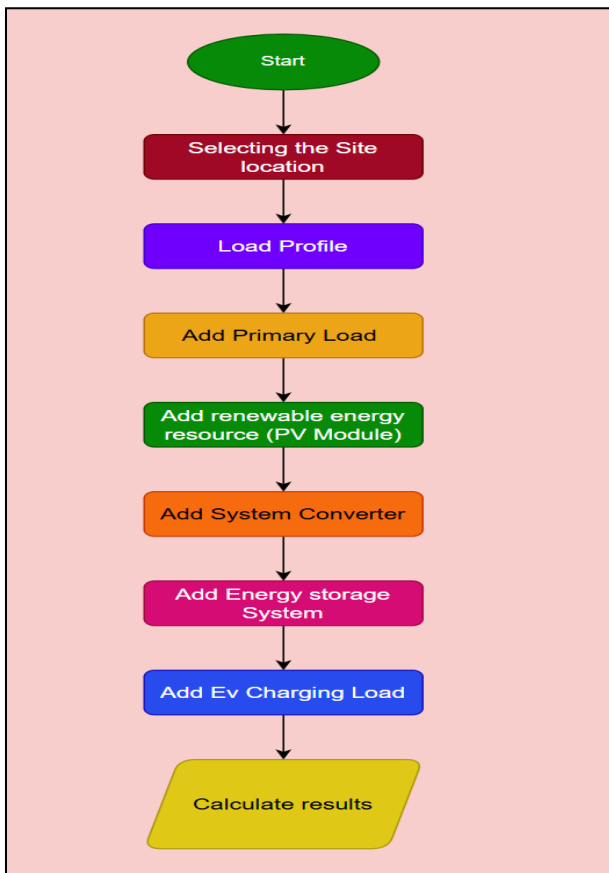
involved in the proposed approach are depicted in Fig. 3 (b). This work proposes resource and load interfacing. Next, the PV capacity and battery storage are calculated. Finally, after the interface and optimization of the load, the outcome of the optimum charging infrastructure is assessed.

Table. 1: Annual solar energy radiation data

Month	Cleanness Index	Daily radiation (Kwh/m²/day)	Temperature
Jan	0.607	4.21	20.68
Feb	0.639	5.13	21.59
Mar	0.6	5.61	24.15
Apr	0.625	6.53	27.99
May	0.641	7.06	31.98
Jun	0.621	6.94	33.52
July	0.57	6.3	33.36
Aug	0.589	6.25	32.2
Sep	0.617	5.98	30.89
Oct	0.659	5.53	28.91
Nov	0.632	4.53	25.52
Dec	0.609	4.01	22.31
Average	0.617	5.67	27.7583



3 (a)



(b)

**Fig. 3:** (a) Load profile of EV charging station, (b) Design flow chart

### 2.4 Initial Assessment

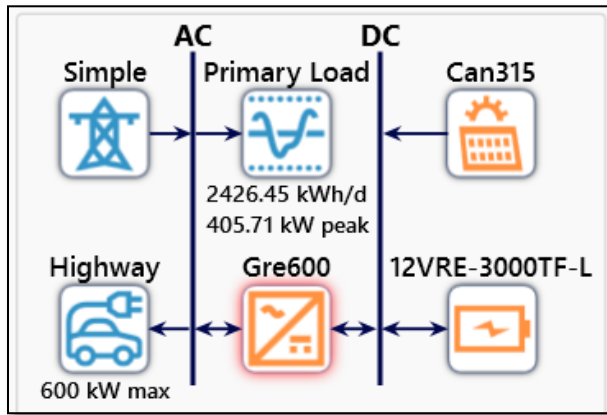
Initially, the evaluation of a power system is always against the performance metrics of proper operation, efficiency and cost scenarios. A battery storage area supplements the charging station, and this storage system is linked to a solar PV system to reduce the energy costs for on-load charging stations. All capital costs (CC), replacement costs (RC), net present cost (NPC), cost of electricity (COE), operation and maintenance costs (OMC), and salvage value (SV) of the project were determined using the HOMER Grid. All these costs would also help in assessing the economic feasibility of the proposed model.

## 3. System design and Optimization

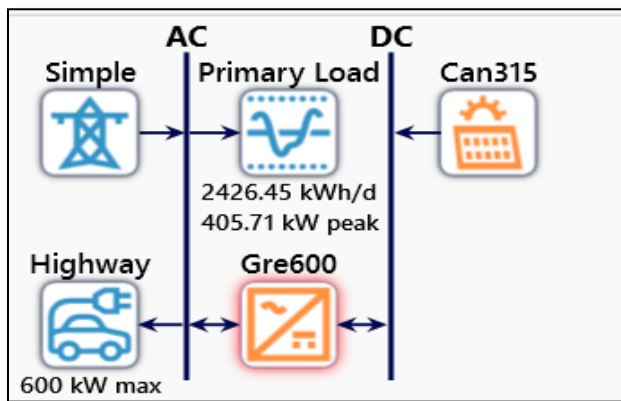
### 3.1 System Architecture

The proposed system consists of three components: a Canadian Solar 315CS6U-315P-AG PV module, PV of 600 KW size/rating, and Discover 12VRE-3000TF-L bus voltage of 24V with 2 strings, 600 kW capacity Green Power Technologies PV500WD system converter also. Table. 2 shows the components cost analysis between the storage system and the system architecture. Fig. 4 (a) show the model of the suggested system. The model's PV system and battery storage are linked by the DC bus. The converter is also linked to the AC system since it changes the voltage of AC signals to DC signals

and back again. See Fig. 4 (b) for references. Without a battery backup, the system model indicates that the PV system is linked to DC and the grid supply throughout the night, when the load is powered by the grid. Table 2 lists the system components that the model suggests.



(a)



(b)

Fig. 4: (a) System model with battery backup, (b) Without battery backup

Table 2: Cost analysis of system components

	Canadian Solar 315CS6U-315P (PV Module) 1KW	Discover 12VRE-3000TF-L (battery storage) 1kwh	Green power Technologies PV500WD (converter) 600KW
Rated capacity			
Capital Cost (\$)	300	410	72,000
Replacement Cost (\$)	150	410	50400
O&M (\$/Year)	3.6	0	3000
Lifetime	25	18	15

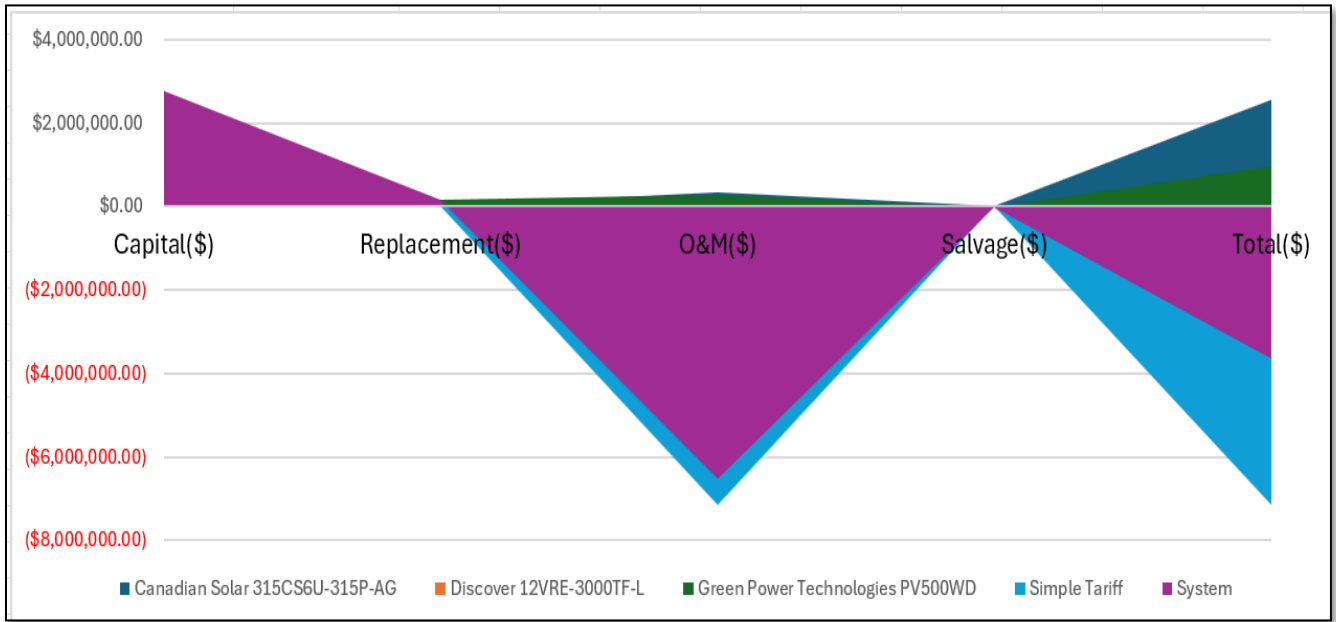
### 3.2 Optimization results

The outcomes of the techno-economic analysis and optimisation of a grid-connected solar PV system with backup, utilising the HOMER grid, for an electric vehicle charging station in Muscat, are detailed in this part. The optimisation findings are presented in the first portion, followed by the results of the techno-economic analysis and a brief presentation of its potential to reduce emissions. The proposed model with PV and Grid with battery backup as in Fig. 5, along with the start up cost and operation and maintenance (O&M) costs.

The optimal results with a grid-connected PV Module were achieved at the plant location H9QM+649 in Muscat, Oman. To determine which system configuration has the lowest cost of energy (CoE) and the highest renewable energy fraction, the HOMER grid compares the costs and capacities of each option. While running the simulation, it determines whether the hybridized energy systems are feasible in the long run. A few configurations are produced from this hourly simulation, with the base case system shown in light grey. To find the optimum system design that suits the EV charging system configuration out of all the possible combinations of meeting load demand, three separate scenarios were considered from the various energy systems that were built. Fig. 5 (b) elaborates on the optimised components in detail (light grey represents the reference scenario).

### 3.3 Energy Generation and Consumption

Fig. 6 also presents a summary of the optimised system's annual and monthly performance. Solar photovoltaic (PV) generation contributes 98% of annual energy generation (12,543,731 kWh/yr) and 1.99% grid purchases amount (25,4899 kWh/yr), achieving optimised model's renewable energy fraction share of 97.9%. Grid sales stayed at 108,41,139 kWh/year, while electricity consumption was 885,654 kWh as shown in Fig. 7, as given in Table 4, (70%) and electric vehicle chargers served 194649 kWh/year. The monthly electric production from PV and grid is illustrated in Fig. 7 and depicts the energy production and Canadian module PV output of the suggested components.

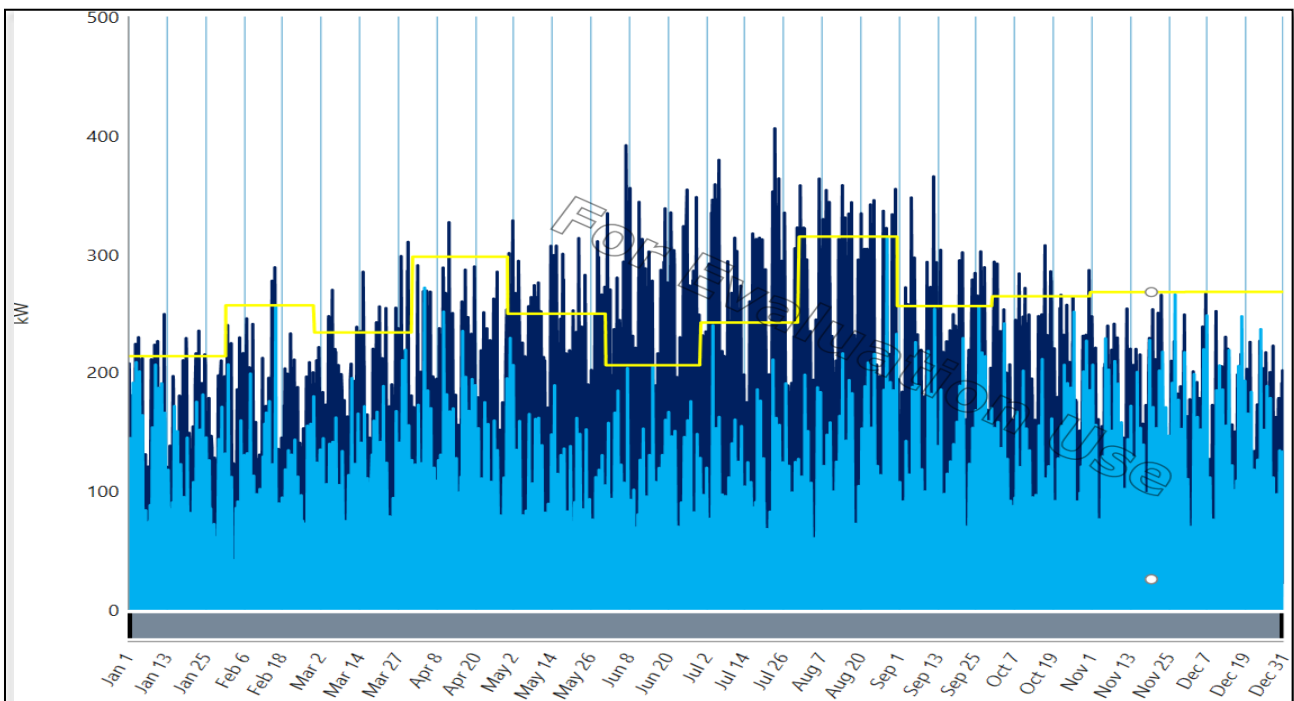


(a)

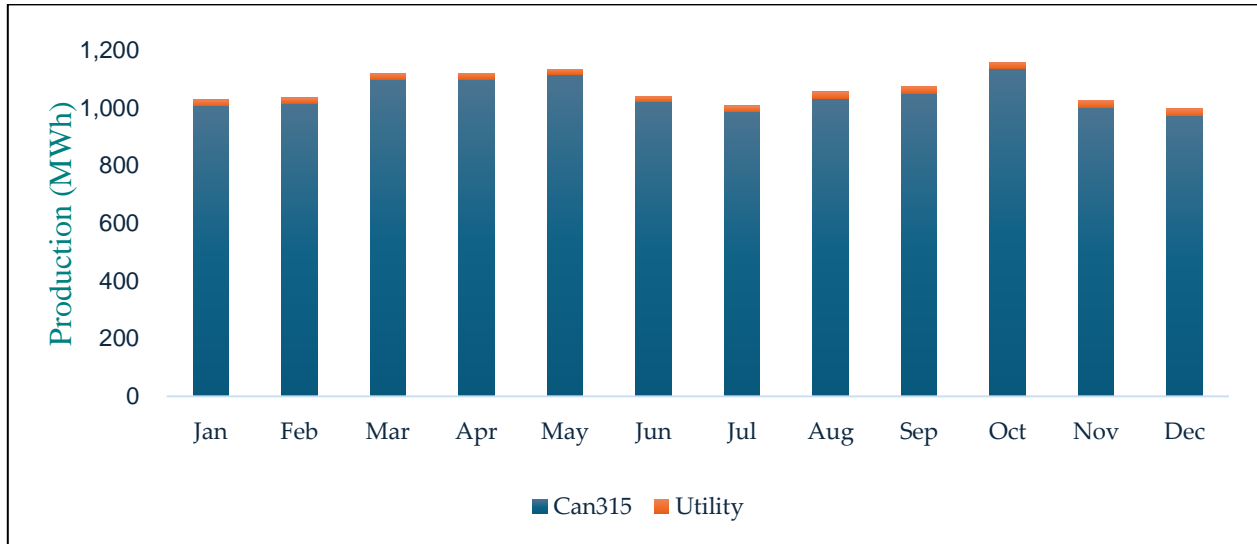
Architecture				Cost				System			Project Economics			
Can315 (kW)	12VRE-3000TF-L (#)	Simple	Gre600 (kW)	NPC (\$)	LCOE (\$/kWh)	Operating cost (\$/yr)	CAPEX (\$)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)	Utility Bill Savings (\$/yr)	Net Present Utility Bill Savings (\$)	Demand Charge (\$/yr)
7.395		1	4.527	-\$3.64M	-\$0.0236	-\$495,131	\$2.76M	97.8	0	19	5.1	\$593,578	\$7.67M	\$59.14
7.395	10	1	4.526	-\$3.63M	-\$0.0236	-\$494,961	\$2.77M	97.9	0	19	5.1	\$593,515	\$7.67M	\$60.88
		1		\$504,939	\$0.0362	\$39,059	\$0.00	0	0			\$0	\$0	\$0

(b)

Fig. 5: (a) Components cost analysis without battery backup, (b) Optimization results of the proposed system



(a)



(b)

Fig. 6: Monthly electricity consumption and production of solar PV and grid

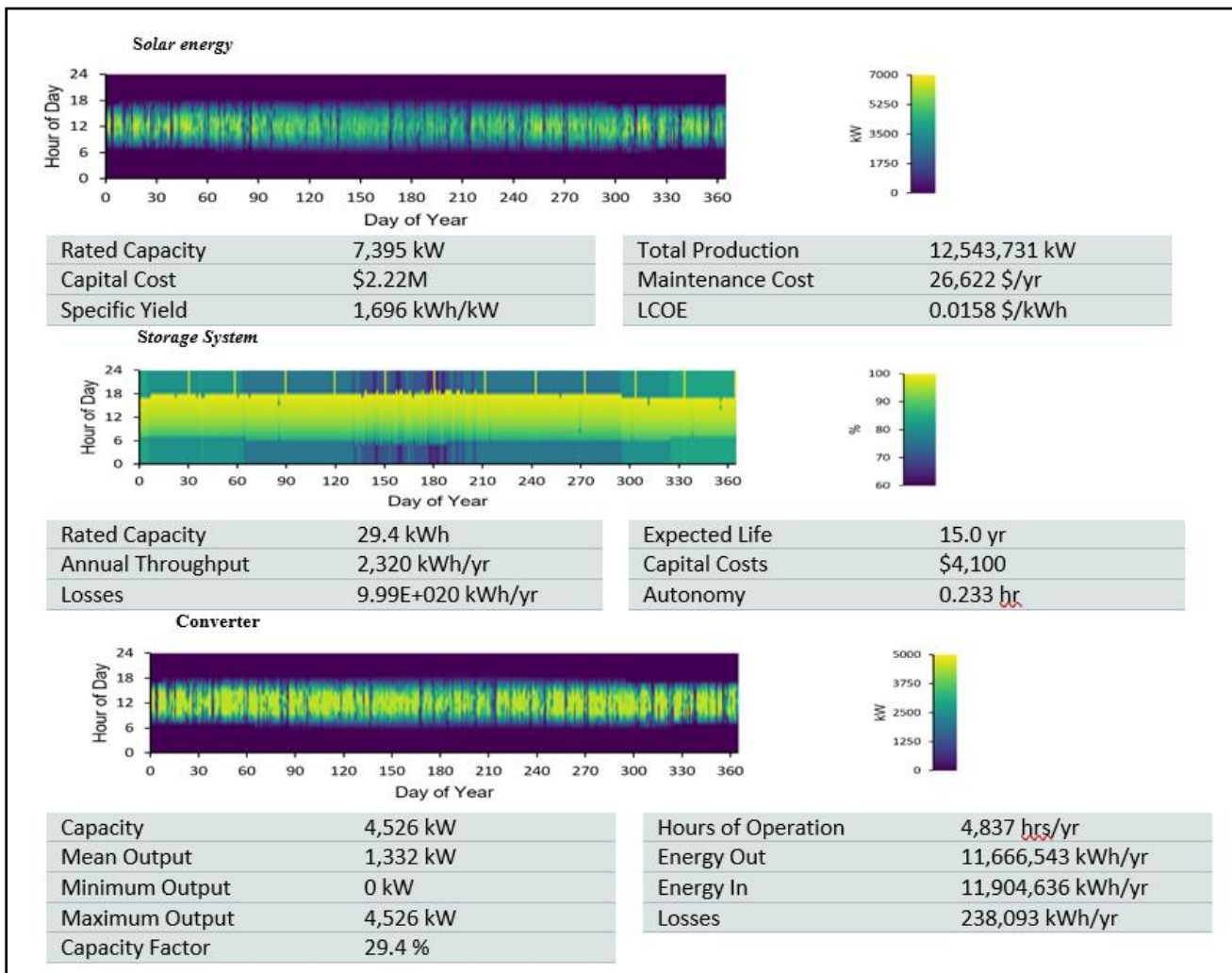


Fig. 7: Energy produced by system components for proposed design

### 3.4 EV Charging

The system carries out 7,256 charging sessions in a year as shown in the Fig. 8. The annual savings in energy are 10,950 kWh, while each session uses 26.8 kWh of energy. Charging sessions are at a count of 19.9 per day. Charging results are extensively discussed in Table. 3.

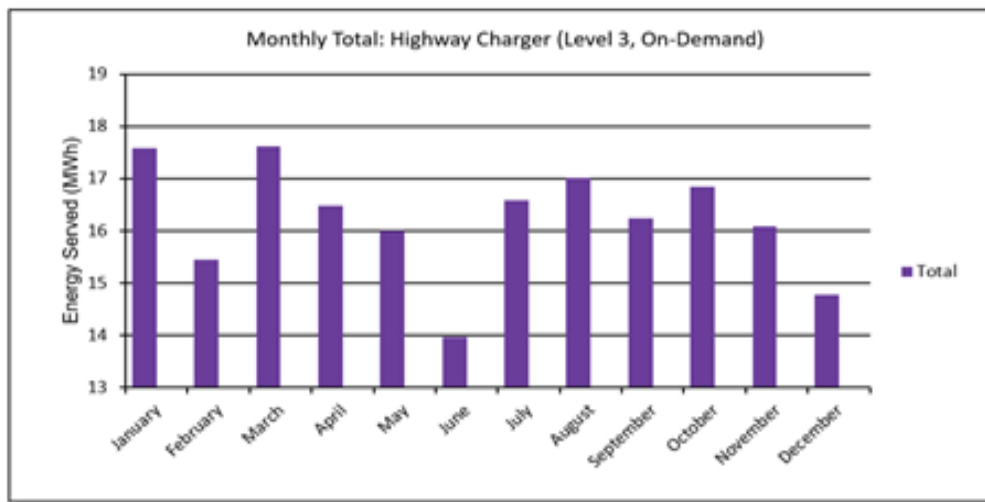
With a peak load of 158 kW EV load served on the highways as shown in Fig. 8, this EV depot has an annual energy consumption of 194, 649 kWh. Due to all chargers being in use before they arrived, an average of 0.1 potential customers per day could not charge. These charging characteristics apply to the electric vehicles serviced by this location, charging data for large and small EVs are given in Table. 4.

**Table. 3:** EV annual energy served on highways (Charging metrics)

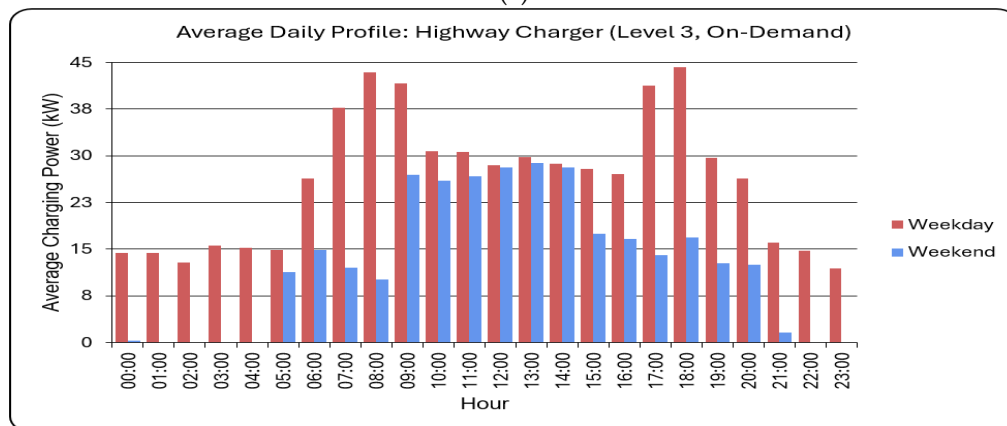
Charging metrics	Energy Served
Annual Energy Served	195 MWh
Peak Load	158 kW
Energy per Session	26.8 kWh
Charging Sessions per Day	19.9
Charging Sessions per Year	7,256
Average Missed Sessions per Day	0.121
Utilization Factor	6.90 %

**Table. 4:** Charging data for large and small EVs

Name	Percentage of EV Served	Maximum Charging Power per EV	Average Charging Duration
Large EVs	30.0 %	150 kW	20.0 min
Small EVs	3.0 %	3.0 kW	3.0 min



(a)



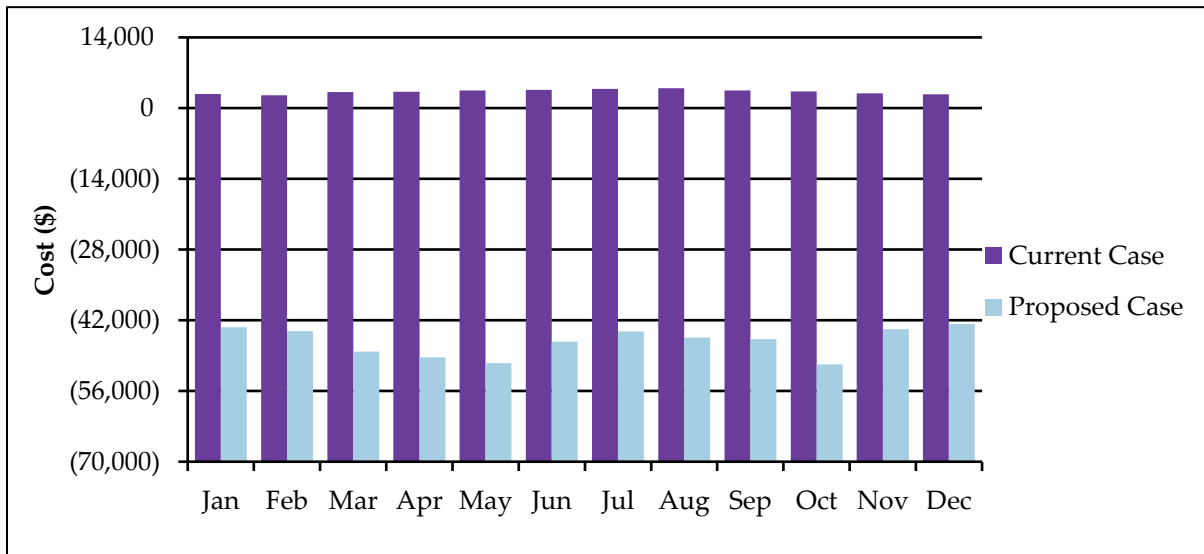
(b)

**Fig. 8:** EV annual energy served by EV load on highways (a) Highway charger monthly total, (b) Highway charger average daily profile

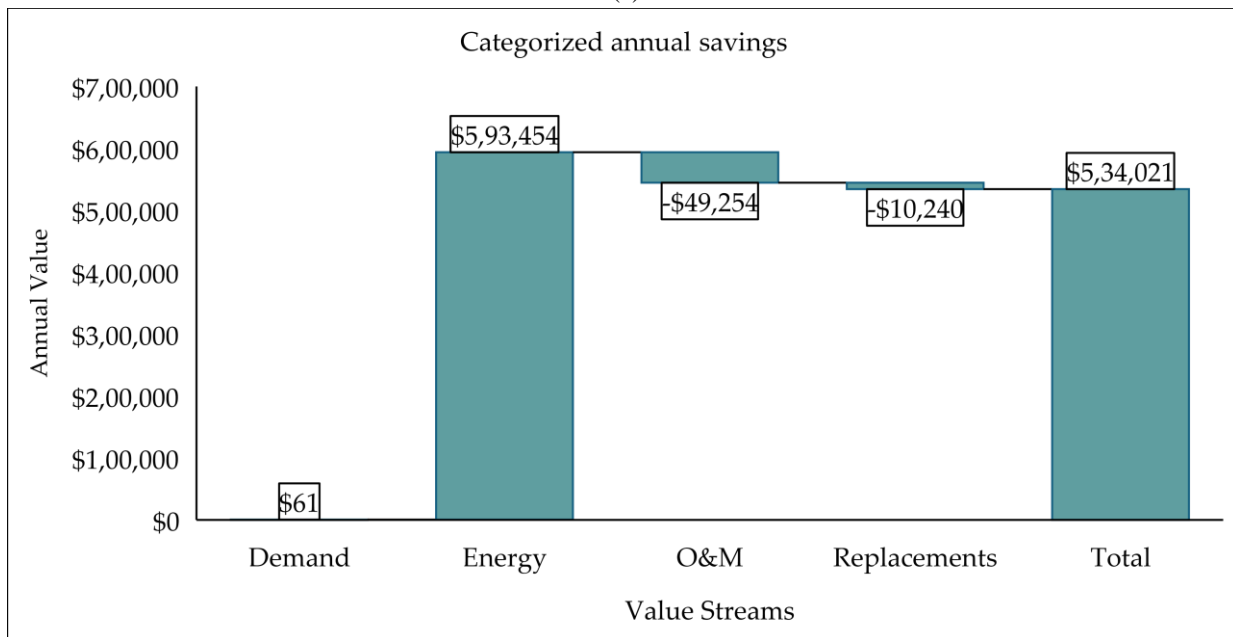
**4. Economic Evaluation Results**

The techno-economic examination of a renewable energy system's economic performance. When calculating the financial benefits of the proposed system, it is essential to include all operational expenses incurred up to this point, as well as the original investment and replacement costs. This analysis takes into account all costs that arise throughout the system's lifetime. In the HOMER grid model, the optimal system was determined using the TNPC. Afterwards, the

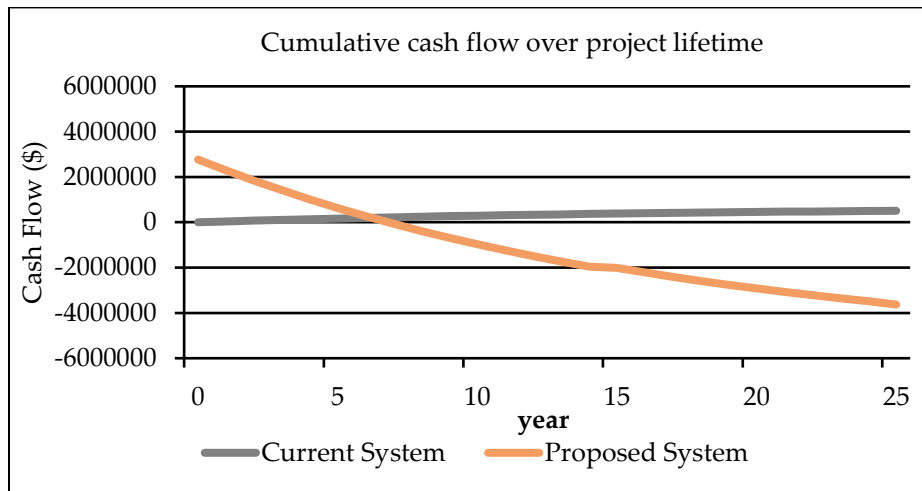
optimisation exercise ranked all scenarios against various setups using the TNPC to determine the least expensive one. Optimal system selection for renewable energy promotion was based on levelized CoE and renewable energy proportion in certain instances. Comparison of annual savings for base and proposed models as mentioned in Table. 5, savings on monthly utility bills are shown in Fig. 9, broken down by month throughout the year. Levelized cost of energy is - \$0.0236/kWh, and the system's total net present cost is - \$3.64M.



(a)



(b)



(c)

**Fig. 9:** (a) Cost analysis, (b) Annual savings, (c) Cumulative cash flow for proposed system

To reduce the levelized CoE from \$0.0362/kWh to - \$0.0236, the optimal solution recommends installing 600 kW of PV systems in Oman. Electricity generated during blackouts by solar PV systems and sold to the conventional grid is thus utilized to offset emissions. Carbon dioxide, sulfur dioxide, and nitrogen oxides are the normal emissions from the power grid, and they are present here as well. Table 6 presents a cost-benefit analysis of the reference and optimized systems, while Table 7 details all relevant indicators for estimating potential emissions reductions. The comparative study shows that grid-connected solar PV with battery facilitations outperforms in terms of levelized cost of energy, renewable energy fraction, and environmental impact.

**Table 5:** Comparison of annual savings (Base vs proposed model)

	Consumption Charge	Demand charge	Fixed Rate	Total
Base Case	\$38,891	\$167.56	\$0.780	\$39,059
Proposed Case	-\$554,563	\$106.68	\$0.780	-\$554,455
Annual Savings	\$593,454	\$60.88	\$0.00	\$593,515

**Table 6:** Comparison of levelized COE of reference and costs for reference system and proposed system

Description	Reference System	Proposed System
Net Present Cost	\$504,939	-\$3.64M
CAPEX	\$0.00	\$2.77M
OPEX	\$39059	\$494961
LCoE (per kWh)	\$0.0362/kWh	-\$0.0236/kWh

**Table 7 (a):** Economic metrics

Description	Value
Internal Rate of Return	19.3%
Return on Investment	15.3%
Simple Payback	5.08 Yr
Annualized Utility Bill Savings	\$593578
Net Present Value	\$4.14M
Annualized Savings	\$534,021

**Table 7 (b):** Emissions reduction

Emission	Reduction (kg/year)
Carbon Dioxide	-6690504 kg/year
Sulphur dioxide	-29006 kg/year
Nitrogen Oxides	-14186 kg/year

## 5. Conclusion

In this research paper a solar PV-based EV charging station is techno economically analyzed and optimized using HOMER Grid software, in Muscat Oman. Solar energy would cater for the increasing need for EV charging which would reduce costs, on the one hand, and step up unclean environmental characteristics when integrated with storage and grid interaction. The ideal setup was able to deliver high Renewable Share to reduce the electricity costs and greenhouse gas emission in comparison to traditional grid charging. This indicates that a solar EV charging station would be a very feasible option for both cost and environmentally friendliness in providing energy for Muscat. The proposed battery backup system has a renewable fraction of 97.9%. The simple payback period of the system with storage is 5.08 years with 19.3% IRR.

Annual utility bill savings of the proposed \$ 593578 with backup storage of 4 hours. Annual total purchase and sale of energy with backup 254,899kWh and 10,841,139 kWh, respectively. By the suggested system, annually 7,256 charging sessions are conducted which would provide an annualized energy savings of 10,950 kWh with a session energy consumption of 26.8 kWh. A daily average of 19.9 charging sessions is done. The depot consumes 194,649kWh in a year as it has a peak load of 158kW, serving EVs along highways.

### 5.1 Future recommendations

It is possible to improve the smooth functioning and recover value-based operations of the photovoltaic-based electrical vehicle charging stations in Muscat, Oman, by exploring hybrid systems and ways through which it can integrate other grant sources to renewable energy, such as wind or hydrogen energy, thereby framing energy availability and system resilience. In this regard, more research is necessary on the integration of AI-based management systems to switch between charging and operational time, increase operational efficiency, and reduce costs. Moreover, small research studies should be carried out to see which government policies, subsidies, or incentives lead to better economic viability of photovoltaic EV charging stations. It may be possible to be a more easily decided with these investigative measures; however, it is difficult about the scalability of these systems and a better understanding of their impact on grid stability if such a system were exponentially adopted. Lastly, new research should consider user behavior and charging patterns to more accurately predict demand, design, and viability of electric vehicle charging modes powered by solar cells, thereby enriching their understanding.

### Conflict of Interest

The authors declared “No conflict of interest”

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