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Review

Revolutionizing Oman's energy network with an optimal mixture renewable energy source

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Abstract: The electricity demand has increased to 240% during the last decade in the Sultanate of Oman due to population growth and industrial expansion. Solar energy can act as an alternate source of energy production to meet the surge in demand for electric power. Also, the government has planned to derive 30% of the electricity from renewables by 2030. Moreover, agreements have been made to reduce greenhouse gas (GHG) emissions by decreasing 7% by 2030. The main objective of this paper is to design a grid-connected PV solar system based on the real-time data collected from the location called Nizwa, Oman using Hybrid Optimization of Multiple Electric Renewables (HOMER) software. The real-time data of average high and low temperature, solar radiation, estimated monthly average daily sunshine and peak hours of solar radiation of Nizwa has been collected from Meteorological Office Oman for January to December 2022. Nizwa recorded a temperature max of 43 ℃ during summer and 12 ℃ in January. Daily sun radiation in July averages between 5,500 and 6,000 Wh/m^2, and the average sunshine is 9 hours per day at the selected project area (Nizwa). The collected data has been analyzed and designed using HOMER software. HOMER is used to model, optimize and analyze an integrated energy system that primarily utilizes renewable and non-conventional resources for both grid connected and autonomous systems. A 9-kW grid-connected PV solar panel has been designed and implemented in the proposed system. The proposed PV solar system worked perfectly and gave the results of an estimated number of hours of operation to be 4,362 hrs/year; the cost of energy per kilowatt is $ 0.044 and the annual energy saving cost of the hybrid system is $ 173.696. For the environmental feasibility of producing 14,765 kWh/yr, carbon dioxide emissions have decreased from 7,230,440 g to 4,396.001 g, with a difference of 7,226,043.9 g of carbon dioxide.

Keywords: hybrid solar; system solar energy; photovoltaic (PV); solar radiation; HOMER

Abbreviations：VRE: Variable Renewable Energy; PPAs: Power Purchase Agreements; GCC: Gulf Cooperation Council; RE: Renewable Energy; HRES: Hybrid Renewable Energy System; PV: Photo-voltaic; HOMER: Hybrid Optimization Model for Electric Renewables; Ret Screen: Renewable Energy Technologies Screen; OPWP: Oman Power and Water Procurement Company; MIS: Mian Interconnected System; Sm^3: Standard Cubic Meter; OMR: Omani Rial; CO_2: Carbon Dioxide; GHG: Greenhouse gases; °C : Celsius Degree; GPP: Gross Domestic Products; DPS: Dofar Power System; bcm: Billion Cubic Meter; CPV: Concentrator Photovoltaic; PDO: Petroleum Development Oman; MSP: Miraah Solar Project; EOR: Enhanced Oil Recovery; AER: Authority for Electricity Regulation; Wh/m^2: Watt Hour per Square Meter; NASA: National Aeronautics and Space Administration; HES: Hybrid Energy System; $: US Dollar; CF: Capacity Factor; PR: Performance Ratio; NREL: National Renewable Energy Laboratory; TOPSIS: Technique-for-Order-Performance-by-Similarity-to-Ideal-Solution; FC: Fuel Cell; DG: Diesel Generator; G: Gas; WT: Wind Turbine; KWp: Kilowatt Power; tCO_2: Tons Carbon Dioxide; STC: Standard Test Condition; IoT: Internet of Things; NASDA: National Space Development Agency; DC: Direct Current; AC: Alternating Current; GCR: Ground Coverage Ratio

1. Introduction

With the steep growth of the world population and the prosperity of society, the consumption of fossil fuels gradually increases, aggravating plenty of global problems like energy crisis, air pollution, global warming and so on. Renewable energy with sustainable, clean and safe properties has attracted the attention of governments all over the world [1]. Hybrid renewable energy systems, such as solar PV systems, are critical for sustainability in certain areas, such as airport energy ecosystems with demand flexibility and power supply reliability [2].

The solar density in the Sultanate of Oman is very high. Some demand of Oman can be supplied through solar energy. Apart from the large availability of solar energy, the capacity of solar power plants in the country is very low. The solar insolation in Oman varies from 4.5 to 6.1 kWh/m^2, and the power is 1640 to 2200 kWh per year as per the renewable energy study. [https://energypedia.info/wiki/Oman_Energy_Situation]. Hence, the nation will have more solar insolation during summer in the desert areas than in the coastal areas. Thus, the country plans to extend power generation through solar energy and target to supply 30% of electricity through renewable energy by 2030.

The Gulf-Cooperation-Council (GCC) countries, which include Oman, Kuwait, Bahrain, Saudi Arabia, Qatar, UAE and Qatar, have many alternative energy sources like solar and wind. Nonetheless, it is observed that fossil fuels still dominate the primary energy consumption of the GCC, while less than 1% of total consumption is fed with renewable energy. The Gulf region has launched various renewable energy projects, initiatives and programs to meet its renewable energy targets. For example, the state had 146-GW of installed electricity capacity at the end of 2020, with renewable energy accounting for 3271-MW. Solar PV technologies remain the most dominant (71%) among other renewable energy sources. Oman's renewable energy total installed capacity is 159-MW as of 2020 [3].

Renewable energy sources provide highly reliable and environmentally beneficial solutions by reducing the GCC states' dependency on oil and gas for local energy production and consumption.

Furthermore, the world's economies and nations support RE. GCC countries, if climate change is not addressed by enacting a proactive energy policy that minimizes dependency on fossil fuels, may become uninhabitable. In addition, because those nations have a high per capita carbon emission rate, they must transition to (RE) to comply with the Paris Agreement. Governments must enact laws that stimulate the use and investment in renewable energy technology at both the business and consumer levels [4].

In line with Oman's Vision for 2040, the country aims to reduce its reliance on nonrenewable energy and encourage the growth of clean energy sources as effectively as possible. Using renewable energy will positively impact the environment by lowering carbon dioxide emissions. As the renewable energy installations increase, private sector investments will be attracted, the production cost will reduce and more dependency on renewable energy will increase the competition in the renewable energy market.

To achieve Oman's targets in the sustainable renewable sector for Oman Vision 2040, finding alternative energy sources that are sustainable and reducing our dependence on non-renewable energy sources is critical. Thus, planning solar energy projects at a particular location is essential to ascertain the financial viability of a solar PV system with a specific capacity and module technology. New technology, modern software and programs can determine and simulate model projects with accurate data output. Design-Hybrid-Renewable-Energy-System (HRES) for electrification using simulation software HOMER/ETAP/PSSE/PSCAD/DIGSILENT/RET-SECREEN/MATLAB/PV-SYST/LAB SOLAR. Many scholars worldwide have conducted feasibility studies on solar PV systems, especially in European and Middle Eastern countries. Nevertheless, the research papers on the assessment of solar PV systems give little emphasis on the tropical climate, specifically in Oman. Typically, (HOMER) or Renewable Energy Technologies Screen (Ret-Screen) simulation software or Researchers have used satellite data to analyze the technical feasibility and financial viability of a photovoltaic (PV) system.

With the increase in power demand due to the increase in population, Oman targets Vision 2040 to combine renewable energy with conventional energy systems to produce cost-effective power generation. This paper proposes the optimal mixture of renewable energy sources like solar energy and an On-Grid system as conventional energy sources, which use natural gas or diesel.

Moreover, this paper will assess the optimal mixture of renewable energy sources like solar energy and combine it with an On-Grid system as conventional energy sources, which use natural gas or diesel. The work will also discuss the economic feasibility of using the combination of renewable energy sources along with conventional energy sources. It will also include comparing GHG emission reduction when using this combination. Furthermore, it will emphasize discussing the positive impact on the cost reduction of the power generation and tariff structure by considering the project's initial investment.

This study will use simulation software and will contribute for the appropriate and optimal mixture of renewable energy sources in Nizwa City, Oman.

The proposed research aims to determine the optimal mix of renewable energy sources using a micro solar PV integrated with the grid system. Using the simulation in HOMER software, various parameters like (CO_2) level, energy production and net present cost are estimated. The results obtained are compared with conventional models to show the feasibility of the proposed system.

2. Literature review

There are various studies on the optimal mixture of solar energy sources, but there are limited studies in Oman. This part will illustrate Omani and international papers relevant to our field of research in the Continent of Asia Countries.

A summary of studies for several configurations on the HOMER software is illustrated below in Table 1, which includes or involves details: name of authors, project site, publication year and software used.

Table 1. Published studies on Hybrid Energy Systems (HES) using HOMER Software.

Author/Ref. [No.]	Project site /Publish year	Configuration	Results/Visibility Economically/Environmentally
Abdullah Al Badi [5]	Oman ALMazyouna 2022	DG, PV & Storage Batts	There is a 28% reduction in harmful gases when using the fixed hybrid system, as compared to the natural gas and diesel system. (NPC) is $ 84.8 M and (COE) is $ 0.161/kWh for Hybrid system while they were higher for diesel generation system (NPC) is $ 99.4 M and (COE) is $ 0.188/kWh.
Sabah Abdul-Wahaba [6]	Oman (Marmul, Fahud, Sohar & Qairoon Hairiti) 2019	Off grid (Ingeteam) 1164 kVA with Generic PV & DG	Proposed system was able to lower the COE to $ 0.0763, $ 0.0855, $ 0.0862, and $ 0.0869 per kilowatt hour across all 4 suggested potential locations. Avoiding 9,728,892.115 and 13,148,128.5 kg/year of pollutants if using a PV system instead of natural G/DG, respectively, where COE is USD$ 0.085/kWh. Marmul was the best location found for using PV followed by Fahud, Sohar and Qairoon Hairiti due to their low costs of electricity (0.0763, 0.0855, 0.0862 and 0.0869 USD$/kWh, respectively).
Yahya Z. Alharthi [7]	Saudi Arabia 2019	PV, WT & Grid	High ROI which is around 8.5% and less payback period.
Yahya Z. Alharthi [8]	Saudi Arabia Sharurah, H. ALbatin & Riyadh 2018	PV, Wind T. & Grid	The System led to the minimum (LCOE) of $ 0.03655. Yanbu City has the best renewable energy output power. The systems' performance showed reasonable power production and lower CO_2 emissions at Albatin and Sharurah.
Fazlur Rashid [9]	Bangladesh Bhola Kukri Island 2021	Hybrid PV, WT, DG & biomass	LCOE is much lower for PV/WT/DG/biomass (0.142 $/kWh) than PV/DG (0.199 $/kWh), PV/WT (0.239 $/kWh), PV/DG/WT (0.167 $/kWh), PV/DG (0.343 $/kWh) and WT/DG (0.175 $/kWh).
Sunita Kumari [10]	India Rural areas 2020	Hybrid (PV, WT, & DG)	DG & batt has a less total cost. PV, WT and DG with battery are a little higher than case 1. COE, from the proposed system, is higher than the cost of grid electricity but due to the necessity of environmental protection and far-seeing the current living standard of rural communities such HS will play a perfect role for the country.

Continued on next page

Author/Ref. [No.]	Project site /Publish year	Configuration	Results/Visibility Economically/Environmentally
Jagriti Kumari [11]	India Tamil Nadu A rural Village 2017	Hybrid WT, PV, Biomass, H, Hydro & DG	The PV, DG and battery system is the most cost-effective, with a total NPC of US$ 271,637 and a COE of US$ 0.23/kWh. The reduction in CO_2 emissions is estimated at 242 tons of CO_2/year and US$ 3140/year collected from the Carbon Credit.
Hajer [12]	Tunisia Kerkennah 2020	Hybrid (PV, WT & Grid)	The proposed system is economically and environmentally beneficial, with an (NPC) of $ 66,180, 0,137 $/kWh (COE) and nearly fifty percent RE penetration.
Fahad Ali [13]	Pakstan District Dera Ismail Khan 2020	Off-Grid/Grid-Integrated PV, DG & Batt	(LCOE) in grid-integrated systems (0.072 $/kWh and 0.078 $/kWh) is more economical than the off-grid systems (0.145 $/kWh and 0.167 $/kWh). Most importantly, this hybrid energy system can provide a 24/7 continuous electricity to the site.
Mohammad Amin [14]	Iran North-west of Iran 2019	PV, WT, Biogas generator and with Battery Storage Bank	The most cost-effective situation is stand-alone systems that use a biogas generator in conjunction with PV. Fuel cells would boost COE by 33–37% while also improving system dependability. The best setups are a 15-kW biogas generator with 100-kW PV or 90-kW PV with 2 WT units, with energy costs of 0.164 and 0.168 $/kWh, respectively. In grid-connected mode, the best possibilities for delivering electricity in the specified rural region are a 60 kW on-grid PV system with 0.096 $/kWh COE and a 60 kW PV and 2 WT units with 0.102 $/kWh. The COE of grid-connected systems is 40–50% lower than that of stand-alone systems and using costly backup components like fuel cells is not cost effective. If fuel cells are to be used as a hybrid system backup, the most cost-effective configuration would be in a PV/biogas/FC.
Barun K. Das [15]	Australia Broome 2021	PV, WT, Battery, Thermal load Controller & Gas Boiler	The hybrid PV/WT/Batt choice has a lower COE (0.255 $/kWh) for delivering the thermal load using the thermal load controller and the gas boiler than without using extra energy (0.274 $/kWh). The optimized PV/WT/Batt-based hybrid system may provide potential cost savings and environmental advantages over the DG-based system. The proposed system is highly reliable while meeting the electric and thermal demands (99.92%).

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Author/Ref. [No.]	Project site /Publish year	Configuration	Results/Visibility Economically/Environmentally
Sabhan Kanata [16]	Indonesia Sebesi Island 2021	Case-1: 3 DGs). Case-2: 3DGs, PV & WT. Case-3: 3DGs, PV, WT & Batt.	(NPC) and (COE) case-3 has the lowest, namely \$ 912,180 and 0.281 \$/kWh, respectively. These two parameters were able to reduce respectively 29.29% and 29.22% of the base case. Meanwhile, from the environmental part, a very superior performance is shown in case-3 reducing gas emissions by 68% in this case can. Case 3 is very feasible economically and environmentally.
Dewan Mahnaaz [17]	Bangladesh Mohammad Pur Dhaka 2021	Case 1: (PV-Grid). Case 2:(PV - Battery -Grid)	Case-1 was the best case for residential building as the electricity sold was more than electricity purchased and as no battery was connected, the operating cost was lower. NPC and COE were lower than case 2. Case-1 meets the annual electrical load of the specific area with minimal losses and cheap of operation cost.
Mei Shan Ngan [18]	Malaysia Johor Bahru 2012	Hybrid (PV/WT & DG).	DG configuration is the cheapest system among the studied systems, for (NPC) of RM 8,484,458 based on the diesel price of RM 1.75/L. (COE) is RM 1.353/kWh. The CO_2 emission was 351,844 kg/year. The hybrid PV/DG released about 303,229–323,504 kg/year of CO_2 gas for different PV capacities. The percentage of reduction of CO_2 emission ranges from 8 to 14%. It means that at least 28–49 tons of CO_2 gas can be avoided to be released into the atmosphere every year.
Ali Al-Karaghou [19]	Iraq South Iraq 2010	Hybrid (PV & DG)	The initial cost, NPC of DG and COE are \$ 4,500, \$ 352,303 & \$ 1.332/kWh, respectively and for Hybrid system are \$ 50,700, \$ 60,375 & \$ 0.238/kWh. COE from the PV and generator systems alone were US\$ 0.444/kWh and US\$ 1.367/kWh, respectively. PV system instead of a DG can prevent the release of 14,927 kg/year of CO_2, 36.8 of CO, 329 of NOx, 4.08 of HC, 30 of SO2 and 278 of suspended particles.
Zeinab Abdullah [20]	Sudan 2012	(PV & WT)	PV and WT generator reduce the operating costs.

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Author/Ref. [No.]	Project site /Publish year	Configuration	Results/Visibility Economically/Environmentally
Hoarcă Cristian [21]	Romania Ramnica Valcea 2017	C.1: PV & Batt. C.2: WT & Batt. C.3: PV, WT& Batt.	In case 1, 2 & 3, COE generated is 2.98 RON/kWh, 7.97 RON, 1.75 $/kWh & 2.9 RON, 0.64 $/kWh. The initial capital of the systems is RON 58,780, $ 12,972.71, RON 341,240, $ 75,311.47 & RON 58,460, $ 12,902.08. NPC is RON 78,722, $ 6,338.92, RON 475,725.9, $ 104,992.44 and RON 76,863, $ 16,963.62. (OC) is RON 1,543, $ 340.53, RON 10,403, $ 2,295.93 & RON 1,424, 314.27 $/year.
Kenneth E. Okedu [6]	Nigeria 2014	WT, PV, DG & Batt.	Case 1: Only WT, LCOE is $ 0.390/kWh. NPC of $ 238.066, OC of $ 9,384/yr. Case 2: WT & DG, LCOE is $ 0.649/kWh. NPC are higher than costs in case 1.
Deepak Kumar Lal [22]	India District of Orissa State 2011	Hybrid (PV, WT & DG)	The simulation done for different cost of diesel fuel ($ 0.8/L, $ 0.9/L, $ 1.0/L, $ 1.2/L, the optimum solution of the proposed model the COE is found to be ($ 0.207 /kWh), PV-WT-DG which is slightly higher than the COE from conventional sources at present.
Vishnu Makwana [23]	India An Educational Institute 2019	Grid & PV	In a year, 36.64% of energy in KWH is saved. In terms of units saved, around 53,918 KWH are saved. So, it comes to 4,493 KWH per month. The net savings in Rupees are 895,384.5.
Norat Mal Swarnkar [24]	India Rajasthan 2017	C.1: 4 kW PV, 1kW WT. C.2: 41 kW PV & (3) 3 kW WT C.3: 70 kW PV & (3) 10 kW WT	In cases 1, 2 and 3, the COE is 13.39, 12.57 and 13.26 INR/kWh, respectively. COE varies according to project viability. The payback duration for all scenarios is 10-12 years, and the IRR varies from 5% to 7.5%. The yearly decrease in greenhouse emissions for Cases 1, 2 and 3 is 6,280, 63,905 and 121,528 kg CO_2, respectively. The lifetime emission reductions are about 157, 1,597 and 3,038 t CO_2. All three (HES) setups are financially viable and result in considerable reductions in emissions from grid energy supply.
Sonali Goel [25]	India Telecom tower load 2014	PV, WT & Diesel Hybrid System	In COE, the PV-WT-DG system was found to be more expensive ($ 0.839 /kWh) than the WT-DG system with a lower load of 22.7 kWh/d. In contrast, at higher loads of 55 and 83 kWh/d, this model has the lowest (COE) of all systems. This system's (COE) ranges from $ 0.839 to $ 0.506/kWh, with yearly diesel consumption varying from 97 to 6,752 Liters and load ranging from 22.7 to 83 kWh/d. As load increases from 22.7 to 83 kWh/d, excess electric energy production decreases from 45.2% to 1.10%. (COE) reduces as load grows, whereas NPC and OC increase. greater (OC) at greater loads might be attributed to increased fuel consumption at higher loads.

According to the above literature, implementing a hybrid system will reduce (CO_2) by up to 28% more than conventional systems. Similarly, to focus on achieving the Paris Agreement's long-term target of remaining well below 2%, aggressive mitigation steps are necessary beyond 2030 [26]. It also provides low Net Present Cost (NPC) and Cost of Energy (COE) compared to the existing system.

By conducting a brief literature survey, it is identified that most of the conventional systems have a higher percentage of (CO_2) emission. Also, the cost of energy production is significantly high. In this paper, it is proposed that by using an Optimal mixer of renewable energy source in the Omani network using a grid-connected photovoltaic system, the emission level of (CO_2) and cost of energy production can be reduced.

3. Renewable energy in Oman

3.1. Peak demand in Oman

Generally, the scenario of peak demand in Oman is changing. MIS has increased from 5,565 MW in 2015 to 6,473 MW in 2021 at an average annual growth rate of about 3% for MIS (As well as an increase by 4% in 2021 against 2020). DPS also shows that it increased at an average annual growth rate of around 1%, which increased from 495 MW in 2015 to 534 MW in 2021 and increased by 1% in 2021 compared to 2020 [27]. In Musandam, peak demand decreased by 6% in 2021 compared to 2020. So, total peak demand has increased from 6,837 MW in 2020 to 7,081 MW in 2021 [12].

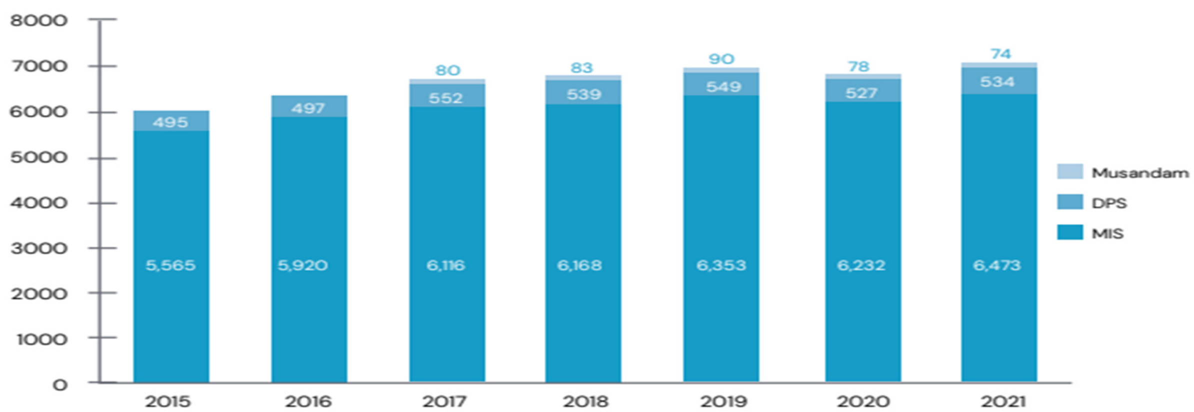


Figure 1. Peak demand in Oman from 2015 to 2021 (MIS, DPS and Musandam). [Source-Annual Report 2021, Oman Power and Water Procurement Co. (SAOC)]

3.2. Renewable energy in Oman with including solar energy

The Sultanate has adopted regulations that encourage the extensive utilization of renewable energy sources. Production of electricity from renewable energy sources in Oman this year has reached 650 MW, a remarkable milestone since a modest beginning on a smaller scale in 2019 and will further be increased to 3,350 MW by 2027 [https://solarquarter.com/2022/08/26/oman-to-generate-3350-mw-capacity-of-renewable-energy-by-2027]. According to the latest five-year capability report of Oman Electricity Transmission Company or OETC, it expects to have up to 2.25 gigawatts of renewable energy connected to its transmission grid before 2026 [https://solarquarter.com/2023/05/09/oman-electricity-transmission-company-to-boost-renewable-energy-capacity-with-2-25gw-by-2026/].

On a smaller scale in 2013, the Authority for Public Services Regulation (formerly the Authority for Electricity Regulation) published the first strategy to promote the development of renewable energy technology in rural areas. The objective of the new plan was to integrate renewable energy sources into the existing diesel-based energy networks that supply electricity to remote areas. In response to this requirement, the 303-kW solar system known as Mazyonah Energies 2022 was constructed in an isolated area. Consequently, other rural area projects, such as a 500-kW wind-powered pilot project on Masirah's rural island, were constructed [3].

In Oman, there are numerous present and potential solar energy projects. The Miraah Solar Project (MSP), which is being sponsored jointly by (PDO) and Glass-Point Solar, is the most extensive solar power installation currently being built. With the use of Enhanced Oil Recovery (EOR) technology, this solar project is expected to create more than a thousand megawatts (MW) of power. The (MSP) will annually contribute to national efforts to reduce emissions of greenhouse gases by offsetting around 300,000 tons of carbon dioxide. To supplement the 7 MW EOR solar plant in southern Oman, the (MSP) project was initiated. The (EOR) Solar project has generated a significant amount of steam, which has made the use of (EOR) technology in oil production feasible. Oman's southernmost province of Amin is home to a 100-MW solar facility funded partly by (PDO). The award phase of a 25-year solar power project with the goal of supplying energy to assist meet the company's internal power demand and possibly reducing annual CO_2 emissions by 137,000. Building on the Ibri Solar PV Project in the northeastern part of Oman has commenced, thanks to the efforts of the Ministry of Housing (OMH) and the Power and Water Procurement Company (OPWP). This $ 500 million, 500 MW plant was operated in 2021, providing power to around 33,000 homes. As part of PDO's efforts to achieve long-term sustainability in energy generation, an estimated 18,500 PV car park installation was built in Mina Al Fahal. A total of one thousand (1,000) homes and numerous (PDO) business buildings have been supplied with power from this 5.92-MW capacity project since 2017. It amounts to nine (9) million kWh. As a result, annual CO_2 emissions were reduced by 6,662 tons. The authority for Electricity Regulation (AER) is now talking with key players to launch the Sahim Rooftop Solar Project as part of the government's rural electrification development strategy. The scheme is expected to deliver rooftop solar energy through PV technology to 3,000 houses.

Additionally, several other rooftop PV-installed powering projects in Oman's cities and provinces are in the planning stages. Rural locations include Al-Wusta (2,000 kW) in Dhofar province, Hiji (100–1,500 kW), Sohar (303 kW), Masirah Island (500 kW), Al Mazyonah (299 kW) and Al Mathfa (28 kW). Investing in these modest projects is predicated on the excellent outcome of the piloted on-grid PV solar concentrating system deployed in select Muscat homes [28].

According to Patrick's paper, Oman has planned investments in renewable energy for the past two decades, and it was during this time that the first wind-powered water turbines were installed in Muscat to assist in water distribution to residential properties. As part of the nation's national development priorities, several expansive renewable energy initiatives are planned to help establish future energy security and ensure socioeconomic development [28]. In a recent article published in 2022, the following names of active renewable energy projects in Oman give possible business prospects for experienced renewable energy firms.

4. Study area

Nizwa is one of the largest states in the Dakhiliyah governorate in Oman. Nizwa is roughly 140 kilometers (87 miles) (1.5 hours) from Muscat, Oman's capital. Around 72,000 individuals are expected to live there. Nizwa has electricity demand for Annam around 191.5-MW in 2021 and increased the demand by 7% in 2022 that is 206.8 MW based on data given by Oman electricity transmission company. Nizwa's location is between 22° 56′ 0″ N, 57° 32′ 0″ E. Nizwa recorded the temperature max 43 °C during summer months and 12 °C in January. Unfortunately, Nizwa city has not implemented any project for renewable energy sources till now, and there is no study paper on those sources in Nizwa City.

Figure 2. Location of Nizwa city in Oman.
[https://en.wikipedia.org/wiki/File:Oman_adm_location_map.svg]

4.1. Geography and climate in Nizwa in Oman

Nizwa is surrounded by mountains on all sides. According to the Koppen climate categorization, Nizwa has an arid climate. Temperatures in January may drop to a pleasant 12 degrees Celsius, and the weather is generally a little cool from November through March. Extreme heat and dryness characterize the summers, approaching 43.5 °C in June, and the average high temperature a year is 35 degrees Celsius.

OPWP became involved with the Solar Project data, specifically with the two weather monitoring sites in Adam & Manah (Nizwa). The figures below represent the data trend for (DNI) and (GHI) during the period [6].

Month	Mean Daily Minimum Temperature (°C)	Mean Daily Maximum Temperature (°C)	Mean Total Rainfall (mm)
Jan	12.3	26.2	0.7
Feb	14.0	29.6	5.7
Mar	17.1	32.5	9.4
Apr	21.9	37.8	15.2
May	26.0	42.0	1.9
Jun	28.4	43.5	10.9
Jul	28.0	42.7	6.6
Aug	26.9	41.6	8.0
Sep	25.0	39.7	3.5
Oct	20.9	36.6	5.9
Nov	17.8	31.6	1.7
Dec	14.1	27.8	3.8

Figure 3. Climate data for Nizwa (average temperature and rainfall). [http://worldweather.wmo.int/en/city.html?cityId=1412]

4.2. Solar radiation in Nizwa-Oman

Oman's favorable geographic position between latitudes 168 and 268 N and longitudes 518 and 598 E makes it suitable for using PV and wind turbines to address the growing need for power [5]. The solar energy density in Oman is among the highest worldwide. Daily sun radiation in July averages between 5,500 and 6,000 Wh/m^2 and 2,500–3,000 Wh/m^2 in January throughout the nation [29].

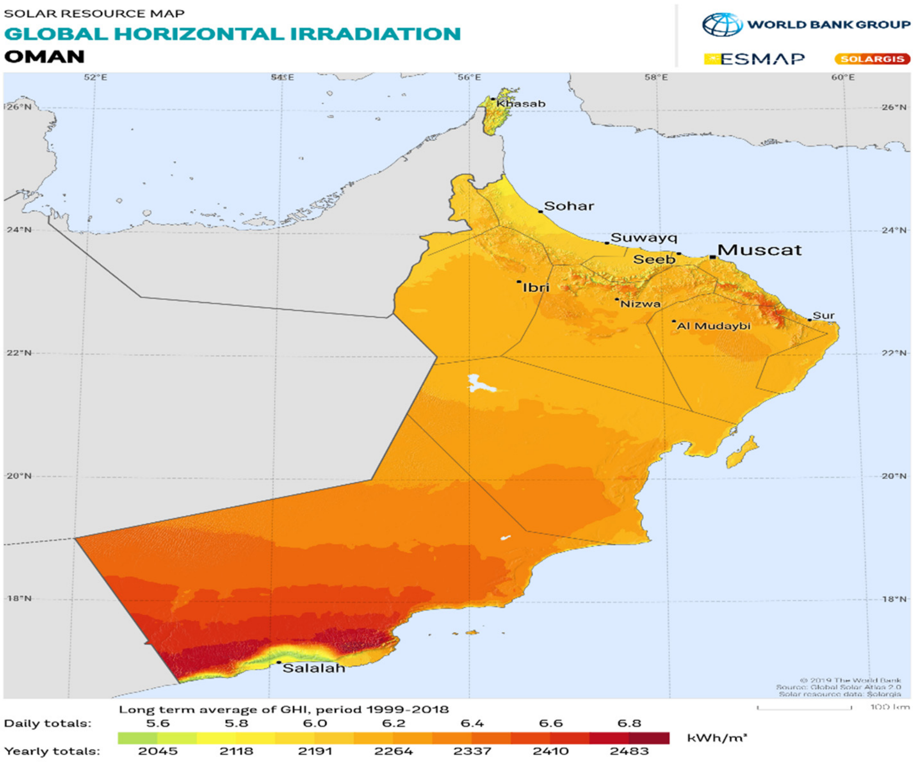


Figure 4. Average temperature in Nizwa [https://solargis.com/maps-and-gis-data/download/oman].

Al-Badi et al. has found the overall solar radiation is barely higher than 4 kWh/m^2/day at Sur and almost 6 kWh/m^2/day at Marmul. Still, the average value at Oman's twenty-five sites is more than 5 kWh/m²/day and around 5.3 kWh/m²/day, and the average sunshine is 9 hours per day at the selected project area (Nizwa), as shown in Figures (4 and 5) [30].

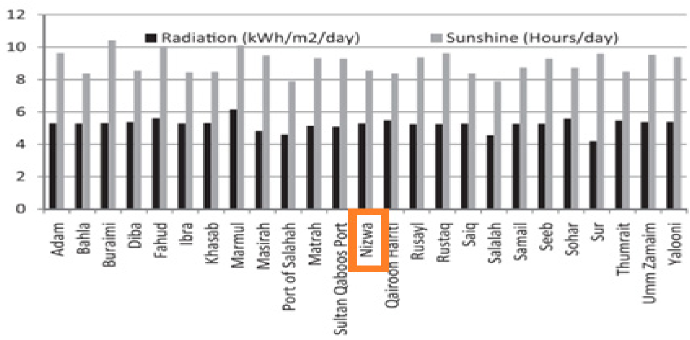


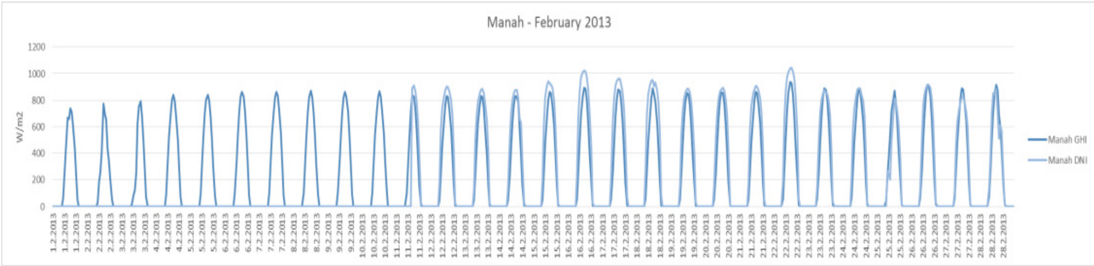
Figure 5. Global sunshine and solar radiation values [30].

The other latest study in 2016 in Nizwa station showed results of (GHI and DNI) as below in Table 2 [31].

Table 2. DNI and GHI data in Nizwa city in June in 2016 [31].

Date	Time	GHI W/m²	DNI W/m²	Zenith Angle Deg	DHI W/m²	Temp °C	Rel. Hum. %	Visibility m
13/06/2016	6:00	118	186	83.19	96	28.3	59.8	9,122.8
13/06/2016	7:00	337	412	70.25	198	30.9	44.8	9,639.3
13/06/2016	8:00	585	550	56.94	285	33.0	35.8	10,198.4
13/06/2016	9:00	781	623	43.41	328	35.7	26.2	13,153.0
13/06/2016	10:00	914	666	29.74	335	38.7	18.3	15,816.3
13/06/2016	11:00	1001	709	15.99	319	41.4	11.4	18,582.3
13/06/2016	12:00	1037	732	2.27	306	44.1	5.6	19,167.5
13/06/2016	13:00	1000	721	11.65	293	45.2	4.9	18,900.4
13/06/2016	14:00	893	695	25.41	265	45.1	5.1	18,542.1
13/06/2016	15:00	728	655	39.11	220	45.1	5.2	18,074.0
13/06/2016	16:00	522	582	52.69	169	44.6	5.8	17,103.0
13/06/2016	17:00	259	311	66.08	133	43.4	6.5	13,865.3

The annual average DNI measured at Nizwa-Manah station was 7.51 kWh/m²/day, as the figure below illustrates measured solar data in February 2013. Additionally, based on an old study through Atsu S.S Dorvloa and David B Ampratwum that Oman has more than 9 sun hours per day, is shown in the below Figures 6 and 7 [32].



Max measured DNI (W/m²)	1044.73
Max measured GHI (W/m²)	936.38

Monthly average DNI in (kWh/m2/day)	7.51
Monthly average GHI in (kWh/m2/day)	5.74

Figure 6. Measured solar data for the month of February for Manah-Nizwa [32].

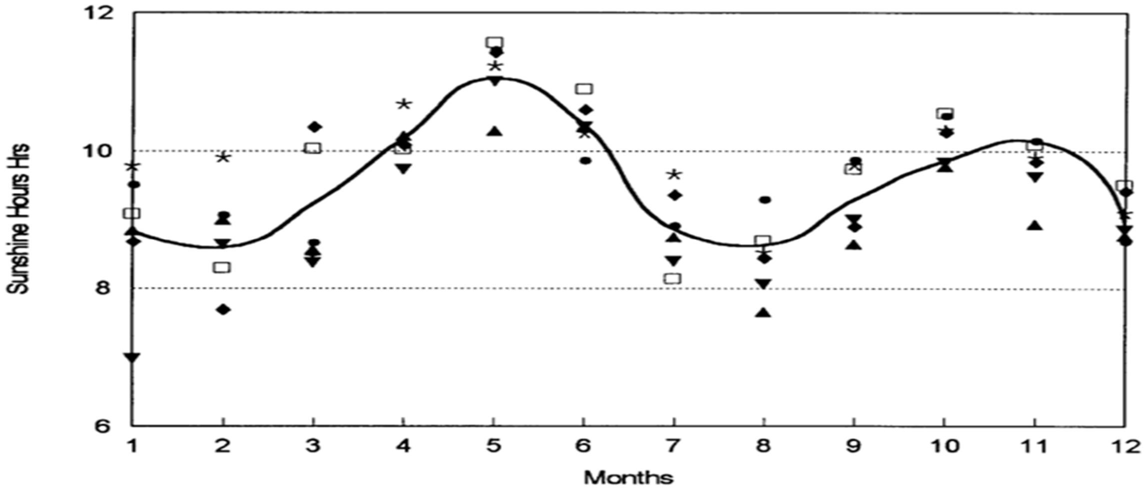
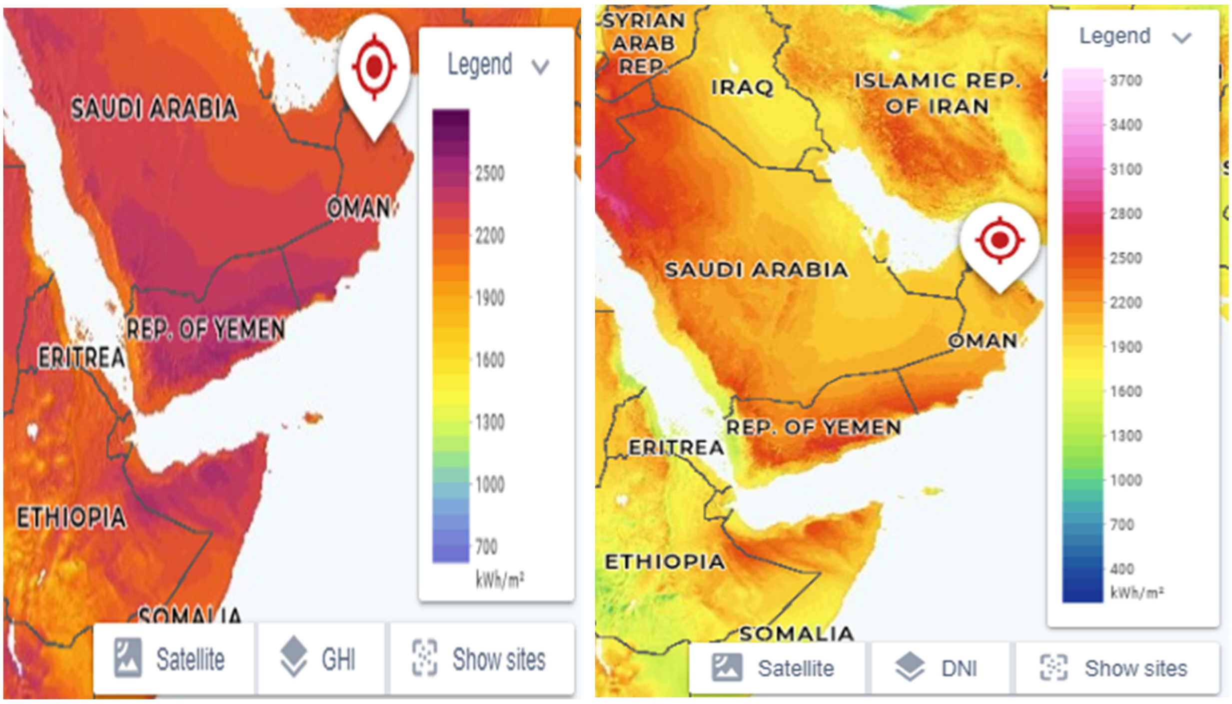


Figure 7. Sun hours per day in Oman aera [32].

Based on the Global Solar Atlas website, Nizwa city has a high amount of GHI and DNI, at 2,256.5 kWh/m^2 and 2,140.2 kWh/m^2, respectively, with an Optimum tilt of PV modules OPTA (25/180°) as seen in Figure 8.



Figuer 8. Amount of GHI and DNI in Nizwa city. [https://globalsolaratlas.info/map?s=22.932388,57.5311&m=site&c=24.2501,52.171236,6]

Another study by Ali Al-Lawati computed monthly average sunshine as below in Figure 9 [33].

Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Buraimi	8.63	8.65	9.29	10.56	11.81	12.30	12.05	11.56	11.04	10.43	9.83	8.97
Fahud	8.56	8.70	9.32	10.40	11.49	11.75	11.29	10.85	10.50	10.24	9.56	7.90
Marmul	9.28	9.64	10.18	10.60	11.16	10.47	9.88	10.33	10.59	10.29	9.59	9.29
Masirah	9.37	9.57	9.34	10.04	11.28	10.09	7.72	8.33	9.01	10.10	9.93	9.20
Salalah	9.57	9.28	9.36	10.24	11.05	6.61	1.87	1.35	5.65	10.21	9.96	9.55
Seeb	8.38	8.87	8.49	9.54	10.49	10.25	9.08	9.22	9.71	9.60	9.39	8.56
Sohar	8.38	8.51	8.46	8.81	9.12	9.08	8.76	8.75	8.85	8.81	8.70	8.35
Sur	8.53	9.18	8.61	9.98	11.30	10.79	8.97	9.28	10.03	10.07	9.83	8.80
Khasab	8.36	8.40	8.39	8.50	8.58	8.60	8.54	8.52	8.53	8.50	8.46	8.35
Saiq	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38
Nizwa	8.40	8.41	8.46	8.58	8.70	8.74	8.72	8.68	8.63	8.57	8.52	8.46
Yalooni	8.80	8.89	9.24	9.78	10.46	10.14	9.41	9.37	9.43	9.67	9.25	8.35
Thumrait	8.44	8.47	8.50	8.53	8.56	8.52	8.48	8.52	8.53	8.51	8.46	8.44
Qairoon Hairiti	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38	8.38
Mina Raysut	9.53	9.25	9.32	10.18	10.96	6.63	2.01	1.50	5.70	10.15	9.91	9.51
Diba	8.36	8.42	8.42	8.60	8.75	8.77	8.66	8.63	8.65	8.60	8.53	8.32
Rustaq	8.53	8.55	8.95	9.73	10.49	10.78	10.62	10.32	10.01	9.64	9.27	8.69
Samail	8.42	8.43	8.53	8.75	8.97	9.05	9.01	8.93	8.84	8.73	8.63	8.51
Rusayl	8.41	8.83	8.62	9.63	10.57	10.40	9.36	9.40	9.75	9.65	9.38	8.41
MSQ*	8.32	8.88	8.43	9.57	10.56	10.34	9.13	9.27	9.82	9.64	9.42	8.57
Bahla	8.38	8.38	8.38	8.38	8.39	8.39	8.39	8.39	8.38	8.38	8.38	8.38
Adam	8.54	8.60	9.03	9.80	10.56	10.81	10.61	10.32	10.02	9.69	9.26	8.48
Ibra	8.39	8.39	8.41	8.45	8.50	8.52	8.51	8.49	8.47	8.45	8.43	8.41
Umm Zamaim	8.80	8.89	9.25	9.94	10.80	10.51	9.62	9.53	9.56	9.84	9.39	8.22
MSQ* Buoy	8.32	8.86	8.42	9.53	10.48	10.28	9.12	9.25	9.78	9.59	9.39	8.56

Figure 9. Estimated monthly average daily sunshine hours for 25 meteorological stations in Oman [33].

4.3. Data sources

Any location for a solar energy generation facility must be assessed for feasibility using solar radiation and temperature data. Moreover, to progress and analyze data of solar radiation, numbers of hours of sunshine per day and temperature in particular areas and any related data that has been recorded and knowing the peak hours of sun radiation is essential. Solar energy resource evaluation applications require precise radiation data over a few years. Solar radiation gathering may be accomplished in two ways: by measurement or through (NASA) surface meteorology and solar energy database (sites geographical).

In Oman, the most common way to get the data is to use the data provided by The Meteorological Office Oman and for implementation, which is actively processing data collected from installed and monitoring stations sensors in meteorological stations located within potential project site locations. Another way to get sun data is to use satellite data. This data is available online, and the researcher can get it from NASA or other websites. This data is not measured and is from the satellite, so it might be less accurate than Meteorological Office Oman data.

Figure 10. Nizwa-Manah Met Station [Nizwa-Manah Environmental station].

Figure 11. Sun Tracker with pyrheliometer installed at Nizwa-Manah [Nizwa-Manah Environmental Station].

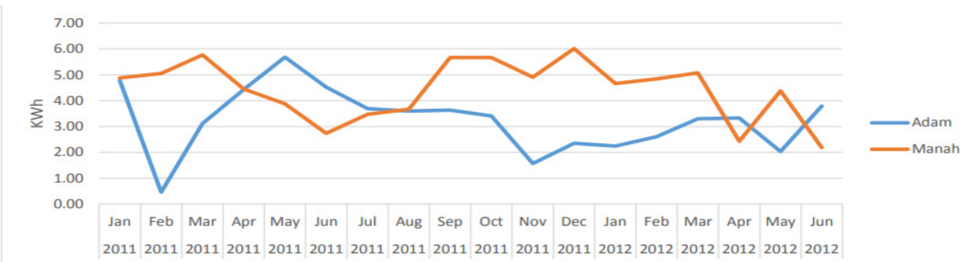


Figure 12. Adam and Manah (Nizwa) DNI Data [34].

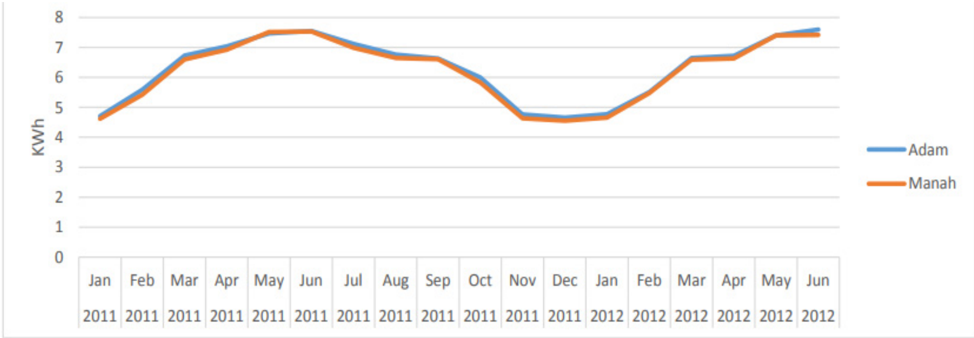


Figure 13. Adam and Manah (Nizwa) GHI Data [34].

The simplest method of obtaining solar radiation data is by on-site measurements. However, depending on readings from in-situ meteorological stations, there may be less opportunity. Thus, due to the high cost of monitoring construction, the Long-term meteorological observation stations are not always located in all places favorable for solar farm construction. Luckily, solar radiation monitoring was installed in 2013 and 2016 in my selected location from my project in Nizwa City-Manah. Moreover, the monitoring concluded that the area had the highest radiation among Oman's cities. The power law indicates high output power from PV panels when it imposes high solar radiation.

By analyzing the above data from the sources, it is observed that the potential for implementing solar power in Nizwa is feasible.

5. The configuration of the proposed solar energy system (SES)

The combined energy system must be feasible and sustainable, which means that at each time step, one or more energy systems must be available to fulfill electric load demand, such as primary generating, backup generation or storage. Components of a system can be designed and incorporated in various configurations. The sizing of system components using a probabilistic method has been carried out based on sun radiation, electric load demand and specific technical and physical parameters. The suggested (Renewable energy system) RES is schematically depicted in Figure 14.

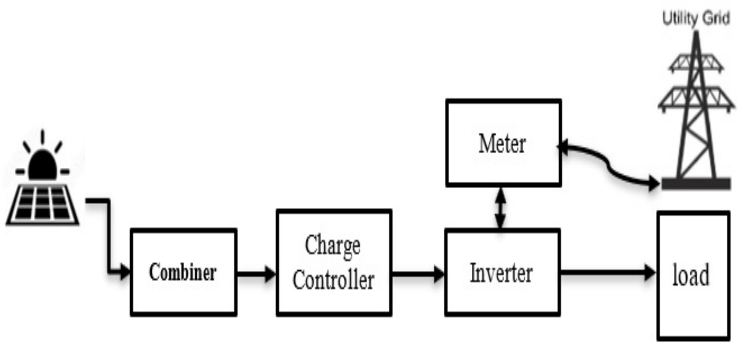


Figure 14. Schematic of the proposed RES.

5.1. Solar system with on-grid system

For various reasons, solar energy systems with on-grid are an excellent compromise for most houses. They are much more cost-effective than stand-alone setups, and as long as the grid is up and running, you can count on having access to power even in cloudy climates.

On-grid PV systems generate electricity from solar photovoltaic harvesters and transfer it to a utility. Off-grid solutions, on the other hand, are not designed to be a substitute for grid power. Grid-connected systems are often found in metropolitan areas where main power is readily accessible, and the energy produced by the PV system is sent back into the grid rather than stored in batteries. The Grid serves as a storage medium in this strategy, and electricity may be imported from the grid when required in the building. One of the key benefits is that, unlike an off-grid system, the system does not need to supply enough energy to meet the property's power requirements. The PV system, the energy grid or a combination of the two may power the property, with the system being as little or as big as the owner desires. Excess electricity produced by the PV system will be exported to the power grid, and the system owner will be reimbursed in many locations with the highest profit. The essential components of a grid-connected PV system are the PV array, inverter and metering system. Cables, combiner boxes, protection devices, switches, lightning protection and signs are also needed in addition to these essential components.

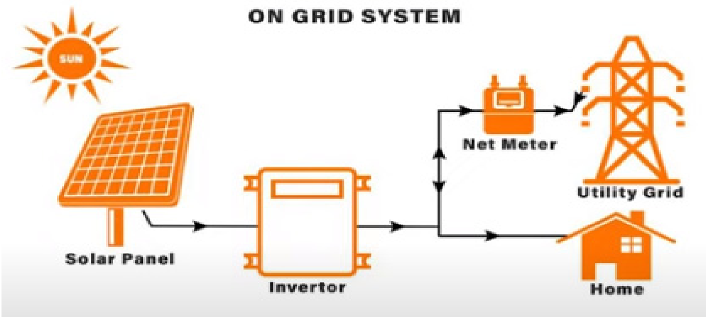


Figure 15. On-Grid system diagram.

5.2. Solar system with on-grid system concept

When solar power systems are connected to the grid, their operation remains virtually unchanged. Solar panels keep converting solar energy into electricity, which powers your home. When a house is linked to the power grid, any shortfalls in the amount of solar energy generated by the solar panels in the home may be made up for by drawing electricity from the power grid.

Similarly, if you generate excess electricity at any time, such as while your family is away at work or school, your panels can feed it back into the grid. You will typically obtain credits for creating power for your electrical grid, which will frequently be sufficient to offset any electricity you consume from it.

It is simple to connect solar systems to the Grid. They are constructed using various quantities of photovoltaic (PV) panels, a solar grid-tie inverter and a net meter. The electricity produced by the solar panels is direct current (DC), but the solar grid-tie inverter changes it into alternating current (AC) that your home and the Grid may use. Net meters process the current following and track how much electricity you supply to the Grid and how much you get from it to calculate your monthly billing and credits with specified tariff rates.

5.3. Fundamentals of solar power in residential systems with on-grid system

The solar panels mounted on roof space or on free land generate a direct flow of electrons producing direct current (DC). Electricity output is maximized based on average peak hours in a day, which is different for every state based on the solar irradiance levels. Since, using alternating current (AC) power supply in our households, (DC) electricity is converted to (AC) electricity through a macro-inverter connected to a distribution panel, which distributes electricity in our electrical devices and energy meters, displaying the amount of energy produced during the day. Sometimes to reduce the dependency on on-grid electricity, we install small battery banks to accommodate energy usage during night and off-peak hours.

6. HOMER methodology

(HOMER) stands as a popular software that was developed in the United States of America by the National Renewable Energy Laboratory (NREL) with the intention of constructing and evaluating off-grid and on-grid power systems for remote, stand-alone and distributed production operations. The tool was created in the United States of America. At the time that this paper was written, more than 200,000 people were using the program all over the world. Depending on the quantity of information presented, the software demands a range of inputs from the user. The following are some of them: the need for energy, the availability of resources (including the possibility of using the grid) and the producing components, such as turbines or generators (with varied degrees of detail for each). In addition to this, the emission forecast is examined. Finally, the model can be constrained by several different constraints (such as a production limit or a scheduled output). HOMER performs mathematical computations and provides a list of viable configurations ordered by net present cost (NPC) and (COE) to assess alternative design combinations based on operational and economical rates. This list may then be compared to one another and then recommends, through the optimal configuration, one among them. HOMER's optimization and sensitivity analysis may be used to analyze different system configurations. HOMER models three primary activities in total: simulation, optimization and sensitivity analysis.

Dr. Peter Lilienthal initially devised the HOMER software at the NERL Laboratory in the United States. The software was refined into HOMER Pro® in 2014 (HOMERenergy.com, 2018). Using this software, we can model, optimize and analyze an integrated energy system primarily utilizing renewable and non-conventional resources. Modeling, optimization and analysis are available for both grid-connected and autonomous systems. The software can optimize the cost of the system by considering all relevant factors [35].

Any system's power consumption profile can be entered into HOMER Pro®, and renewable energy generation can be matched to the required demand. It allows users to evaluate microgrid potential, peak renewables penetration, renewables-to-total-energy ratio and grid resilience, especially for medium to large-scale projects. HOMER then determines if a design is practical, such as whether it can fulfill the needed power consumption. It estimates the cost of installing and running the system throughout the project's lifetime. The cost analysis approach includes capital, replacement, operation and maintenance, fuel and interest. This feature allows for cost savings and scenario optimization depending on several criteria. HOMER displays a list of configurations sorted by net present cost (life cycle cost) that can be utilized for comparing system design options after simulating possible system configurations.

A Few of the advantages of HOMER Pro® are stated as follows [36]:

- Simulates a list of real technologies as a catalog of available technologies and components.
- Very detailed results for analysis and evaluation.
- Determines the possible combinations of a list of different technologies and their size.
- It is quick to run many combinations.
- Results could be helpful to learn system configuration and optimization.

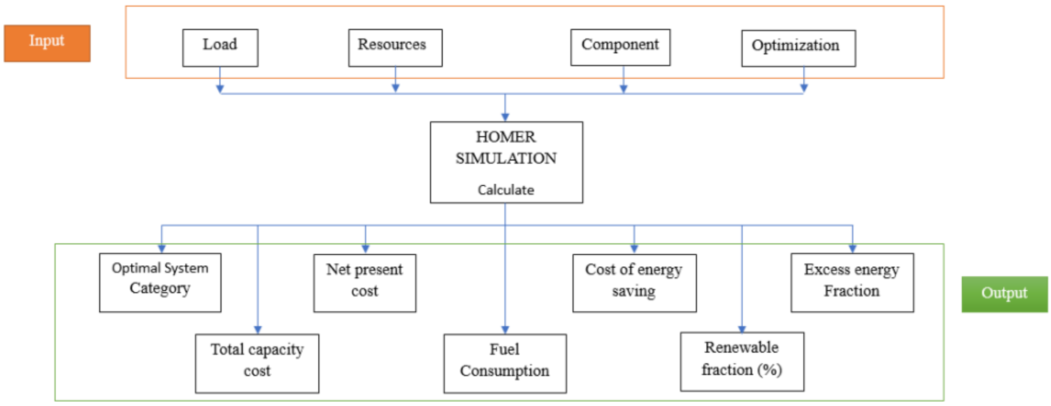


Figure 16. HOMER simulation concept.

The HOMER simulation paradigm is illustrated in Figure 16. For the modelling of hybrid renewable energy sources, simulation, optimization and sensitivity analysis are the three major functionalities of HOMER software. The output replicates all potential element combinations according to different conditions. HOMER filters and optimizes the optimal configuration before presenting a list of configurations based on lifespan cost. As in this study, the proposed hybrid PV system was developed around a PV system connected on-grid and a load profile. The HOMER model fed estimated daily load data, which are different in each hour per day, and supposed this data for one year and an average sun radiation. The program then does analysis and optimization, after which it selects the best and optimal feasible configuration based on previously stated economic parameters, such as (NPC) and (COE).

7. The proposed energy system

The proposed research aims to analyze a simulated model for hybrid systems with a capacity of 30 kwh/day to meet the demand of residential buildings. Figure 20 presents the schematic diagram of 9-kW PV solar panels model (LONGi) Solar LR6-72PE 370 W is as part of a long-term energy system, this is envisioned. This PV module generates DC electricity directly linked to the inverter and converted to AC power to feed the load. This configuration provides the most efficient and effective use of the produced electrical energy, resulting in a decrease in using energy from grid, and the system also draws and exports the energy from or to the grid in a more efficient manner for controlling the generated electricity, resulting in a shorter payback period. This also provides a versatile and readily maintained system that may be used in a residential building as consumption of 30 kWh/day as shared in Figure 17.

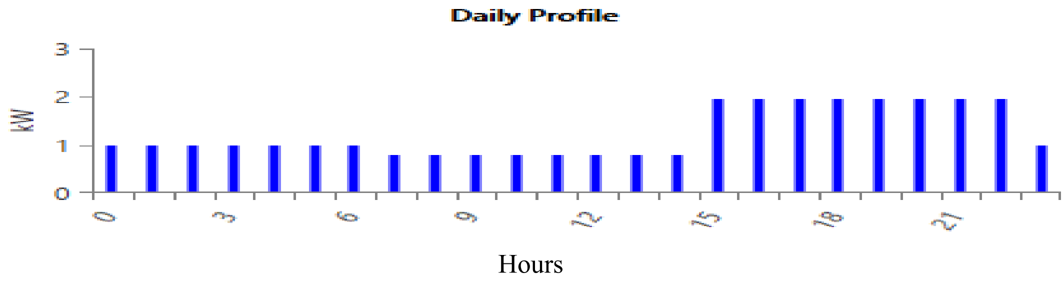


Figure 17. Daily load consumption in kWh.

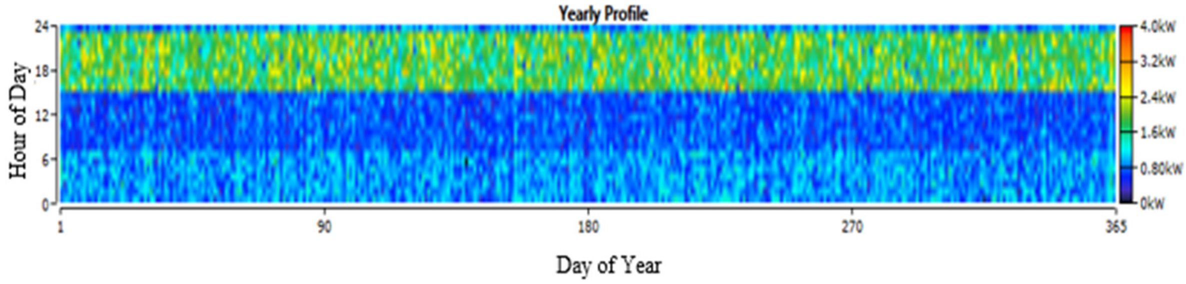


Figure 18. Yearly load consumption in kWh.

Metric	Baseline	Scaled
Average (kWh/d)	30	30
Average (kW)	1.25	1.25
Peak (kW)	3.51	3.51
Load Factor	.36	.36

Load Type: AC DC

Figure 19. Average load consumption in kWh/d.

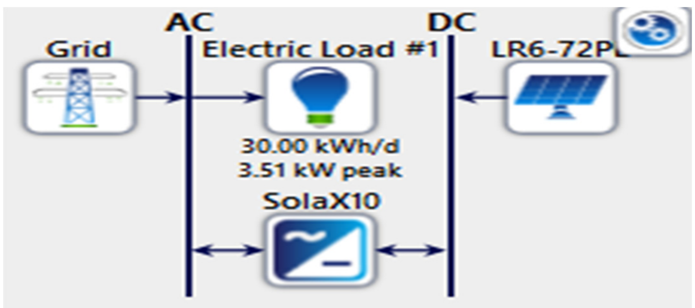


Figure 20. The Schematic diagram for the system.

Table 3 shows the system architecture. It illustrates that the optimized system consists of 25 panels of 0.370 kW PV panels with a total capacity of 9 kW and one inverter 9 kW.

Table 3. RES architecture.

Component	Name	Size	Unit
PV panels	LONGi solar LR6-72PE 370 W	25 Pieces	kW
System converter	System converter SolaX X3-Hybrid10 800-9 KW	1 Piece	kW
Dispatch connected	HOMER load following	-	-

The proposed system is a small PV Panels system placed in an open area but close to the residential buildings. The placement of 25 PV panels allows the system to generate a good amount of energy through peak hours throughout the year.

8. Techno-economic model

To conduct techno-economic assessment, the capital cost, replacement cost, operation and maintenance (O&M), real interest rate, cost recovery factor, net present cost (NPC), internal rate of return (IRR), annual cost, annual benefit and cash flow calculations are shown for the most applicable PV system total of 9 kW, where each PV panel is a 0.370 kW with On-grid. Table 4 shows the technical data for RES.

Table 4. Technical data for RES.

PV solar system	
Model	LONGi Solar LR6-72PE-370W
Capital cost	$ 3,408.99
O&M cost	$ 340.899
Replacement cost	$ 2,556.7425
Power	0.370 KW
Levelized cost	0.044 $/kW
Lifetime	25 years
Converter	
Capital cost	$ 3,408.99
O&M cost	$ 340.899
Replacement cost	$ 2,556.7425
Lifetime	15 years

The following parameters are used to make the techno-economic model results more accurate.

- The nominal interest rate is taken as 7.5%.
- The annual inflation rate is 2.06%.
- Overall project lifetime is 25 years.

Table 4 shows that the proposed PV energy system is a small solar generation plant placed on an open area to receive more solar irradiation and continues PV energy generation. The combined capital cost for (25 PV panels with each 0.370 kW) PV panels of the equipment is priced at only $ 3,408.99, replacement cost estimating to be 75% out of capital cost is $ 2,556.7425, and operation and maintenance that are approximately 10% out of the capital cost around $ 340.000, with an estimated average lifetime of 25 years for the entire system per piece of equipment. This allows time for the system to break even and start producing profit before any major repairs or changes are needed. One inverter with 9 kw and it has a capital cost of $ 3,408.99, a replacement cost of $ 2,556.7425 and (O&M) cost of $ 340.000. Though the full economic feasibility of the model will be discussed in further detail later, it is crucial to look at the main driving factor for increased production and thus increased profit, which is number of sun peak hours, and can still be unpredictable from time to time especially daily, regardless of intensive research. Establishing the system in open areas eliminates some of that uncertainty. Figure 21 shows the amount of power generated by the solar system throughout the day, the period between the hour 8 am and 5 pm around total 10 hours per day.

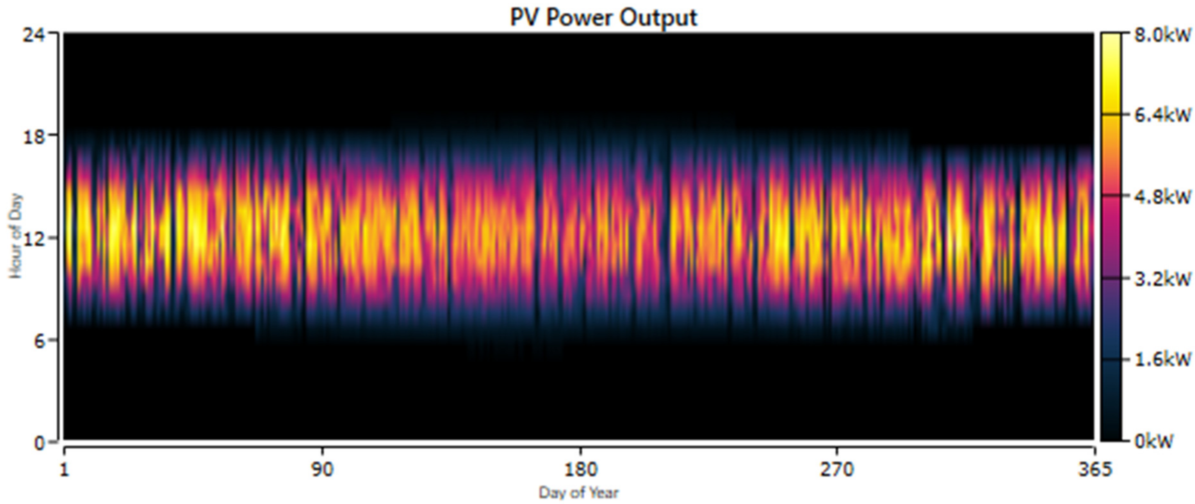


Figure 21. PV power output through day of the year.

9. Optimization

The proposed research considers various constraints involving load demand, radiation, temperature panel rating, interest rate and inflation rate. For optimization, simulation is performed using HOMER software. The target results obtained using the simulation are the energy cost, net present cost and amount of greenhouse gas produced.

HOMER can simulate a variety of equipment possibilities under a variety of limitations and sensitivities to optimize small power systems. The optimization result window will offer possible system configurations based on the Net Present Cost (NPC).

The system components are grouped in order of decreasing cost effectiveness. Table 5 below shows the most optimized system according to HOMER.

Table 5. Optimized system result based on homer simulation.

Label	Value
LONGi Solar LR6-72PE 370 W	25
Grid	-
Convertor-SolaX X3-Hybrid10	9 kW
Dispatch	FL
COE ($)	$ 0.044
NPC ($)	$ 12,806.58
Operation cost ($/yr)	$ 462.68
Replacement cost ($)	$ 5,113.48
Ren frac (%)	67.3
Total fuel (L/yr)	0
Capital cost ($)	$ 6,818
Production (kWh/yr)	21,712
O&M cost ($)	$ 5,048.02
Hour's operation LONGi solar	4,362 hrs/year
Annual total production (kWh/yr)	14,756
Primary load kWh/year	10,950

The proposed HOMER model allows for the most optimal generation structure with a complete outlook on its economic effect, allowing for a more comprehensive look at the feasibility and economic usefulness of such systems. Considering the cost of investment and maintenance, HOMER provides the means to make a precise assessment of the extent to which the installation is beneficial and allows for an accurate outlook about the time it might take for a return on investment to materialize. Table 5 above shows the optimized results of the proposed system. It shows that the system has a COE of O.R 0.017 or $ 0.044/kWh and compares this number with the Tariff from the Authority for Public Services Regulation, which is O.R 0.020 or $ 0.052/kWh [34]. It concludes that the system is feasible as its energy cost is almost the same or slightly below the Tariff the Authority for Public Services Regulation charges for each kWh usage.

10. Electrical evaluation

To optimize and enhance the electrical production and demand system, it is necessary to consider the amount of surplus produced power or unmet load demand. There does not seem to be any systemic surplus or untapped power in this instance. Excess electricity is extra electrical energy that cannot be utilized to power a load and must be disposed of (or limited). Surplus power is produced when more energy is produced than is needed (whether from renewable sources or when the generator's low output exceeds the demand). The quantity of electricity the power system cannot deliver is an unmet load. This happens when the supply of power is insufficient to meet demand. It rarely occurs due to the combined system with the On-grid system, which generates power required to demand load for a long period of time.

10.1. PV data part—LONGi Solar LR6-72PE-370W

The solar panel is the main part in the system that is used to absorb the sun's rays and convert them into electricity. In this study, we are using LONGi Solar LR6-72PE-370W. The PV panel's datasheet and details are in Figures 22–24.

Electrical Characteristics										Test uncertainty for Pmax: ±3%
Model Number	LR6-72PE-360M		LR6-72PE-365M		LR6-72PE-370M		LR6-72PE-375M		LR6-72PE-380M	
Testing Condition	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax/W)	360	266.7	365	270.4	370	274.1	375	277.8	380	281.5
Open Circuit Voltage (Voc/V)	47.9	44.7	48.0	44.8	48.3	45.1	48.5	45.3	48.7	45.5
Short Circuit Current (Isc/A)	9.70	7.82	9.74	7.85	9.84	7.93	9.90	7.98	9.99	8.05
Voltage at Maximum Power (Vmp/V)	39.2	36.2	39.3	36.3	39.4	36.4	39.6	36.6	39.8	36.8
Current at Maximum Power (Imp/A)	9.18	7.36	9.29	7.45	9.39	7.53	9.47	7.59	9.55	7.66
Module Efficiency(%)	18.6		18.8		19.1		19.3		19.6	
STC (Standard Testing Conditions): Irradiance 1000W/m², Cell Temperature 25 ℃, Spectra at AM1.5										
NOCT (Nominal Operating Cell Temperature): Irradiance 800W/m², Ambient Temperature 20 ℃, Spectra at AM1.5, Wind at 1m/S										

Figure 22. Electrical characteristic datasheet [LONGi Solar LR6-72PE-370W data sheet].

Temperature Ratings (STC)		Mechanical Loading	
Temperature Coefficient of Isc	+0.057%/℃	Front Side Maximum Static Loading	5400Pa
Temperature Coefficient of Voc	-0.286%/℃	Rear Side Maximum Static Loading	2400Pa
Temperature Coefficient of Pmax	-0.370%/℃	Hailstone Test	25mm Hailstone at the speed of 23m/s

Figure 23. Temperature rating (STC) [LONGi Solar LR6-72PE-370W data sheet].

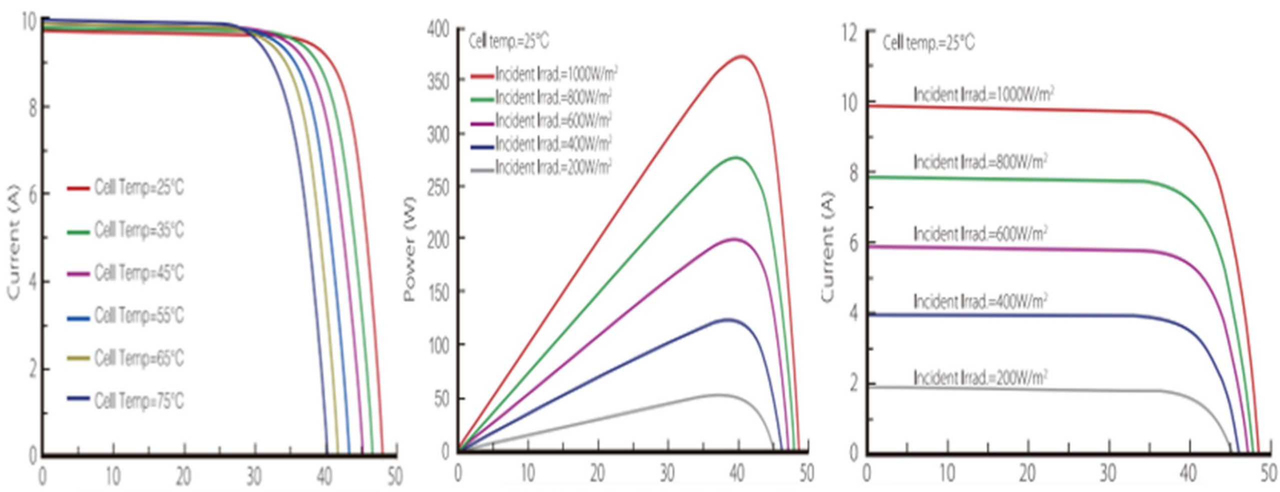
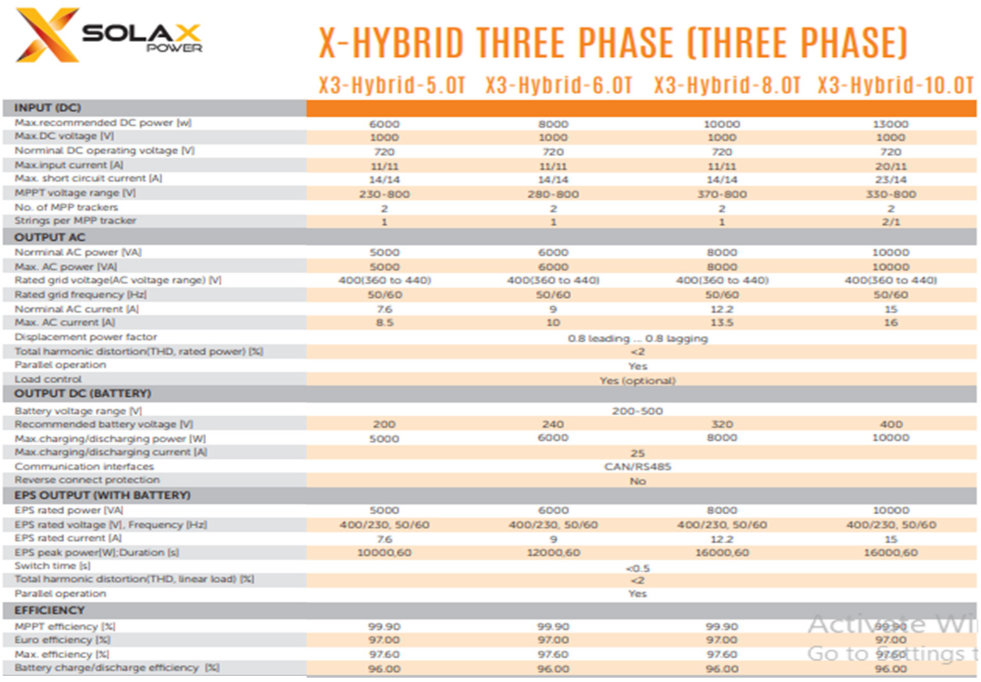


Figure 24. I-V curve [LONGi Solar LR6-72PE-370W data sheet].

10.2. Converter data part—SolaX X3 Hybrid10-800-9KW

The converter is an essential part of the ESS system implemented as it converts the output DC power from PV panels to AC power that will flow and be utilized to the load. The datasheet with the rating is given below in Figure 25.



SOLAX POWER

X-HYBRID THREE PHASE (THREE PHASE)

	X3-Hybrid-5.0T	X3-Hybrid-6.0T	X3-Hybrid-8.0T	X3-Hybrid-10.0T
INPUT (DC)				
Max.recommended DC power [w]	6000	8000	10000	13000
Max.DC voltage [V]	1000	1000	1000	1000
Norminal DC operating voltage [V]	720	720	720	720
Max.input current [A]	11/11	11/11	11/11	20/11
Max. short circuit current [A]	14/14	14/14	14/14	23/14
MPPT voltage range [V]	230-800	280-800	370-800	330-800
No. of MPP trackers	2	2	2	2
Strings per MPP tracker	1	1	1	2/1
OUTPUT AC				
Norminal AC power [VA]	5000	6000	8000	10000
Max. AC power [VA]	5000	6000	8000	10000
Rated grid voltage(AC voltage range) [V]	400(360 to 440)	400(360 to 440)	400(360 to 440)	400(360 to 440)
Rated grid frequency [Hz]	50/60	50/60	50/60	50/60
Norminal AC current [A]	7.6	9	12.2	15
Max. AC current [A]	8.5	10	13.5	16
Displacement power factor	0.8 leading ... 0.8 lagging			
Total harmonic distortion(THD, rated power) [%]	<2			
Parallel operation	Yes			
Load control	Yes (optional)			
OUTPUT DC (BATTERY)				
Battery voltage range [V]	200-500			
Recommended battery voltage [V]	200	240	320	400
Max.charging/discharging power [W]	5000	6000	8000	10000
Max.charging/discharging current [A]	25			
Communication interfaces	CAN/RS485			
Reverse connect protection	No			
EPS OUTPUT (WITH BATTERY)				
EPS rated power [VA]	5000	6000	8000	10000
EPS rated voltage [V], Frequency [Hz]	400/230, 50/60	400/230, 50/60	400/230, 50/60	400/230, 50/60
EPS rated current [A]	7.6	9	12.2	15
EPS peak power[W];Duration [s]	10000,60	12000,60	16000,60	16000,60
Switch time [s]	<0.5			
Total harmonic distortion(THD, linear load) [%]	<2			
Parallel operation	Yes			
EFFICIENCY				
MPPT efficiency [%]	99.90	99.90	99.90	99.90
Euro efficiency [%]	97.00	97.00	97.00	97.00
Max. efficiency [%]	97.60	97.60	97.60	97.60
Battery charge/discharge efficiency [%]	96.00	96.00	96.00	96.00

Figure 25. Inverter datasheet [SolaX X3 Hybrid10-800-9KW data sheet].

To further understand the equipment used, Table 6 provides the characteristics of the converter model used.

Table 6. System converter SolaX X3-Hybrid10-800-9 KW-Electrical summary.

Quantity	Value	Units
Maximum output	7.66	kW
Hours of operation	4,362	hrs/yr
Energy out	14,313	kWh/yr
Energy in	14,756	kWh/yr
Losses	443	kWh/yr
Capital cost	378	$/kW
Lifetime	15	Year

According to Table 6, the annual total of energy production is 4,362 hours. The total energy taken from the setup each year is 14,313 kWh, whereas the total energy fed into it each year is 14,756 kWh. Due to the inverter efficiency of 98%, the total energy lost in the device is 443 kWh/year.

The number of losses can be considered negligible, considering the amount of power the converter moves between the PV modules and the load. It can also be noticed that the converter is abundantly used throughout the year. With a lifetime of only 15 years, converters are the most vulnerable of the devices to breaking down or to be replaced. Solar generation requires the converter to run all the time, so the device can be expected to not last as long.

The inverter works at the same period and matches and parallels with PV solar panels from 8 am to 6 pm throughout the day, as shown below in Figure 26.

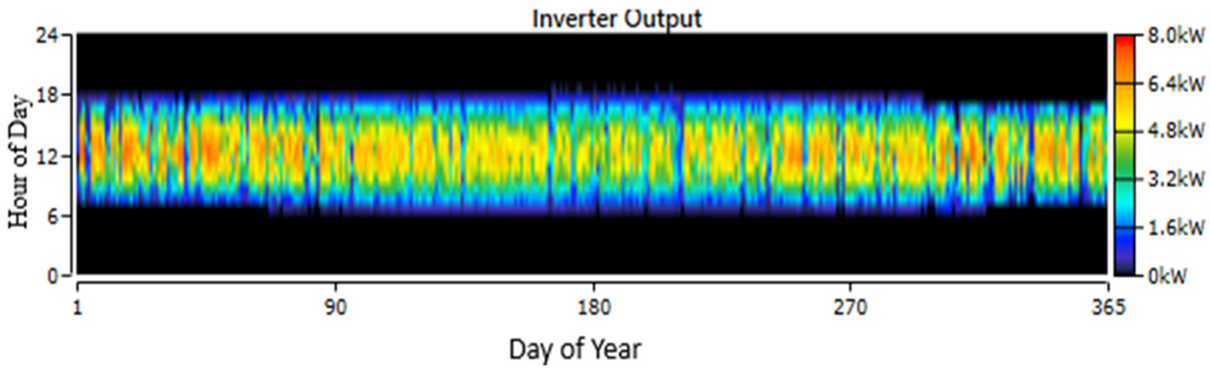


Figure 26. Inverter power output (kW) through the day of the year.

11. Economical evaluation

11.1. Capital cost

The capital cost is calculated by adding the PV panels system costs and the station's balance. Neither cost includes construction finance or financing costs, computed and applied separately via the fixed charge rate. Additionally, the expenses exclude a fund for debt payment reserves, which is assumed to be zero for balance sheet financing. The initial investment cost for each group is given independently in Table 7, and according to the capital cost of PV solar in Oman, that is around $ 0.378 US per Watt. Therefore, the system has (25) PV panels 0.370 kW for each and the total capital cost for PV solar is $ 3,408.99. In addition, 1 piece (9 kw) of the converter is used, and the capital cost per kW is $ 378.6 US in Oman.

Table 7. Capital cost summary.

Devices	Size	Capital cost
PV	(9 kW) 25 Panels	$ 3,408.99
Converter	(9 kW) 1 Inverter	$ 3,408.99
Total capital cost of the system		$ 6,817.97

11.2. Replacement cost

As illustrated in Table 8, the replacement cost is a decreasing fund factor that accounts for long-term replacements and repairs of important PV panel components. However, much effort is being made to develop more of the PV panels model's efficiency worldwide. Considering the replacement costs of PV solar and converter are 75% of the capital cost for each. That is (75% of $ 3,408.99 for PV solar and the same case with converter 75% of $ 3,408.99), equal to $ 2,556.75 as replacement costs for each of them.

Table 8. Replacement cost summary.

Devices	Replacement cost
PV	$ 2,556.74
Converter	$ 2,556.74
Total replacement cost of the system	$ 5,113.48

11.3. Operations and maintenance cost (O&M Cost)

Operations and Maintenance O&M costs include all regular and unscheduled maintenance and operations costs associated with operating the PV panels system. Due to the various PV connections and installation designs, O&M expenses may vary. This enabled researchers to quantify the effect of various technical features on the cost of energy COE without considering the influence of operations and maintenance costs, which were exceedingly difficult to predict at the time. While more work is being conducted to determine O&M costs for existing PV energy conversion systems, the operating and maintenance costs are presented in Table 9 for this study. Considering (O&M) cost for both PV solar and converter is 10% of capital cost. Thus, 10% of $ 6,817.97 is $ 681.8.

Table 9. Operation and maintenance cost summary.

Devices	O&M cost
PV	$ 340.90
Converter	$ 340.90
Total O&M cost of the system	$ 681.8

The decided-upon O&M costs are theoretical. To find a more realistic estimate, a lot of factors should be taken into account, from the location of the plant, average salaries of technicians and equipment costs if the equipment fails, thus making this estimate to be representative of the highest expected O&M cost and is subject to change and be reduced as the technology spreads wider and becomes cheaper to produce and repair.

11.4. Annual energy cost saving

The system's annual energy-saving cost can be determined from the annual energy production of the system. As indicated in Table 5, the annual energy production is 21,712 kWh per year. Then, using this annual cost saving can be determined using the current energy tariff in Oman for residential usage of $ 0.052 per kWh. Then, annual benefit can be calculated as:

- Annual grid rate = 21,712 kWh × $ 0.052 = ($ 1,129.024)
- Annual proposed system rate = 21,712 kWh × $ 0.044 = ($ 955.328)
- The annual benefit of the system is ($ 173.696).

11.5. Cash flow diagram for the system

This cash flow is operational in nature and depicts the capital, replacement, salvage and operating costs associated with the proposed system design. The discount factor is a ratio based on the discounted rate that is used to determine the present value of a cash flow that happens in any year of the project's lifetime. A discounted cash flow is a cash flow that has been discounted to zero for years. The results of the Cash Flow simulation are depicted in Figure 27. Each bar in Figure 27 reflects a single year's total cash inflow or outflow. The first bar, for year zero, represents the system's capital cost, which is also reflected in the optimization outcomes. A negative number indicates an outflow, expense for equipment replacements, or operations and maintenance (O&M). Furthermore, Figure 28 illustrates the cash flow for the project for each component in the configuration.

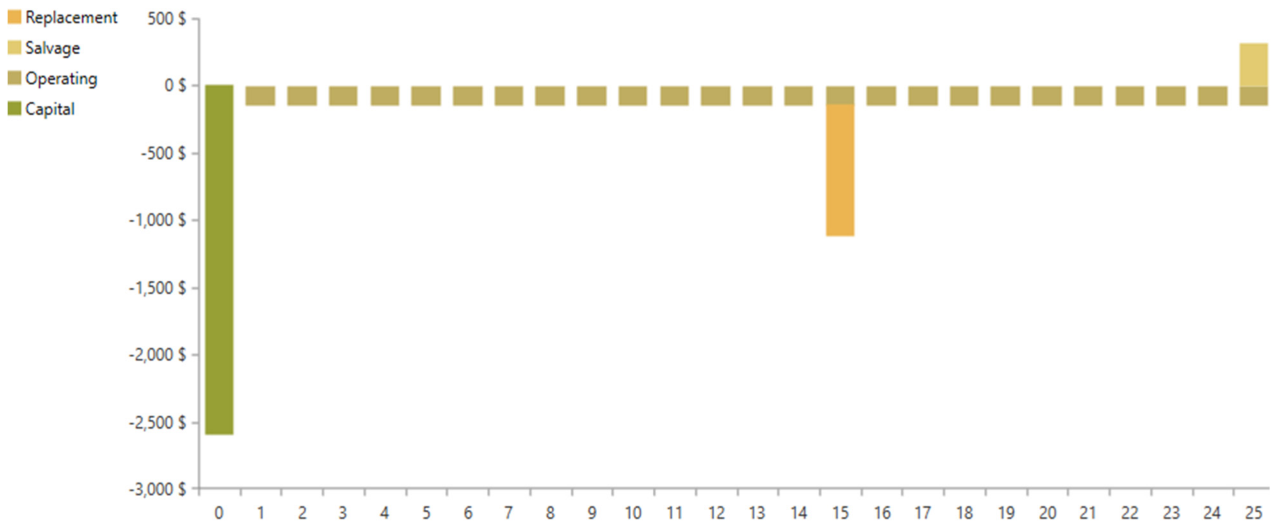


Figure 27. Cash flow diagram.

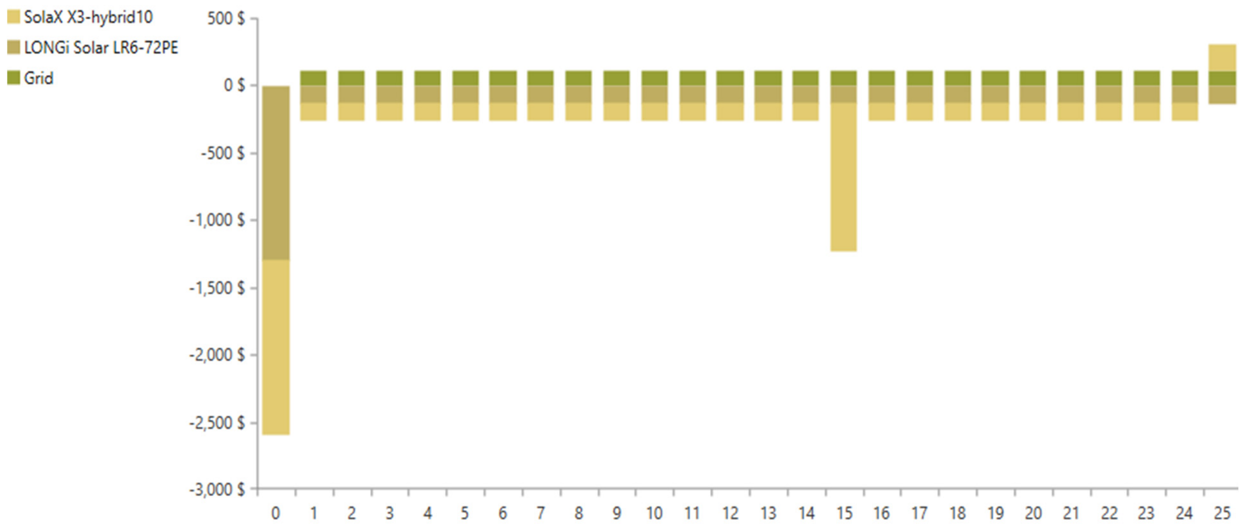


Figure 28. Cash flow for each system component.

Figure 28 shows that the cost is drastically reducing as the operations get into action. With theoretical replacements being expected occasionally, the operating costs are relatively low and consistent, aside from the initial investment. As mentioned earlier, the converters are the part most prone to damage and this is considered as can be seen in Figure 28. The most expensive part to generally repair or replace would be the PV parts due to exposure to external environmental conditions. They are expected to require minimal maintenance or repairs unless there is an extreme weather phenomenon.

12. CO_2 emission investigation

Deployment of renewable energy and improvement in energy efficiency is an effective carbon offset strategy, which can contribute to achieving carbon-neutrality targets worldwide [37]. Solar energy resources can be used for spatiotemporal energy sharing and decarbonization, which show promising prospects in many countries around the world [38]. Energy-efficient buildings with onsite renewable energy supply, such as solar energy sources, are effective to address the energy shortage crisis, reduce the consumption of fossil fuels and achieve carbon neutrality [39]. Carbon dioxide (CO_2) is one of the most significant pollutants among greenhouse gases. It is released when power plants that operate on fossil fuels produce emissions, and these emissions are to blame for environmental problems. As the demand for fossil fuels continuously rises, carbon dioxide (CO_2) emissions in Oman are rising, with 100 million tons in 2018 [40]. Therefore, diminution of carbon dioxide levels by entering renewable energy sources, such as PV solar, into the network system. Emission of CO_2 is now a serious concern worldwide.

Further, the proposed project revealed that it reduces the emission of greenhouse gases such as (CO_2) by a sufficient number of grams. According to the statistical report issued recently in 2020, to generate 1 kWh in Oman, 490 grams of (CO_2) will be released. Using conventional sources to generate 14,756 kWh/yr will emit (490 gm X 14,756 kWh/yr), which is about 7,230,440 kg, whereas using and entering the PV solar to the grid system will reduce to 4,396.001 kg to generate the same amount of electrical energy as illustrated in Figure 29.

Quantity	Value	Units
Carbon Dioxide	4,396	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	19.1	kg/yr
Nitrogen Oxides	9.32	kg/yr

Figure 29. Amount of CO_2 emission.

13. Conclusions

The global and Oman demand for electric generation is rising daily. This increase has begun to place a new strain on the grid's electrical energy supply. The design and optimization of a PV solar system-powered station was examined in this paper using Nizwa, Oman as a case study. Although the size research was conducted on a specific location, the conclusions and technique may be used globally by just modifying the solar irradiation energy statistics. Oman has renewable energy targets with Oman's vision 2040. Still, there are insufficient solar energy project stations to achieve this target, necessitating the development of a national road map for installation and production station size, regulation and other considerations. The first task was site survey and selection, and then collecting necessary data for the work, including power consumption in the residential building which is 30 kWh daily base consumption and having 3.51 kWh peak load consumed to feed the residential building in the proposed site.

According to measured HOMER software data, daily radiation at Nizwa is about 6 kWh/m^2/day. Additionally, the current electricity tariff for residential consumers in Nizwa is about $ 0.052 per kWh and the grid sell-back is $ 0.066. These are key parameters in determining the feasibility of the PV project. Therefore, using this as a site-specific parameter, the feasibility study was undertaken using a software package HOMER to investigate the feasibility.

The following conclusions are derived based on all above calculations:

-The hybrid system produces 21,712 kilowatt-hours of electricity each year.

-The energy system is comprised of a 9 kW PV solar system.

-The hybrid system's Total Capital Cost is $ 6,817.97

-The hybrid system's Net Present Cost is $12,806.58

-The Cost of power generated is $ 0.044 per kilowatt-hour.

-Using and entering the proposed PV solar to the grid system will reduce (CO_2) emission from 7,230,440 kg to 4,396.001 kg to generate 14,756 kWh/yrs.

The study established that the suggested small-scale PV solar is technically possible, economically and environmentally viable as a renewable energy source using 9 kW PV combined with the public grid.

The proposed research work can be extended in future by adding wind energy systems to reduce the production cost further. Using advanced technology battery systems to store solar energy effectively is also recommended. Solar energy system performance can be improved by making the system more innovative, like solar tracking systems and automatic solar panel dust cleaning systems.

This work illustrates how sites with viable sun radiation resources can be economically feasible for the applying small-scale hybrid PV solar with On-grid system. This research used solar radiation data collected from measuring equipment in the site, previous research and concerned websites. There is probably missing and unrecorded data; therefore, acquiring the maximum degree of assurance regarding possible yields and the PV panel's environmental impact from increasing temperature and dust, especially in Oman's terrain, is essential.

Various recommendations are outlined in this section. We recommend the immediate implementation of certain types of renewable pilot projects, the development of policies to support and encourage renewable energy, and that the authority and other entities undertake further research and monitor developing renewable technologies. Our recommendations relate to different categories, and small scale and large scale of hybrid renewable energy sources should be implemented in Oman. These initial renewable energy projects would help demonstrate the technical and economic performance of renewable energy technologies under local conditions, and would, if implemented appropriately, facilitate the transfer of knowledge and know-how to relevant institutions and entities in Oman. The proposed project above is the type of renewable energy project we believe the Authority could approve for immediate implementation by the Rural Areas Electricity Company SAOC.

Before implementing these types of projects, we recommend that further detailed technical and economic analysis is undertaken to verify assumptions in this report and confirm the suitability of individual project locations.

The study has identified a significant potential source of renewable energy in the Sultanate of Oman. However, if solar energy resources are to be utilized on a large scale, as we believe they could, new policies and funding mechanisms will be needed to support and encourage renewable energy investment.

In addition, the implementation of Tax Credits and Investment Subsidies would be a matter for the tax authorities in Oman and the Ministry of Finance. However, we recommend the Authority in conjunction with relevant government authorities take steps in this field.

An additional thing is renewable energy quotas; the government might require, for example, renewable energy projects to account for X% of total system capacity by the next specified years. The authorities would then have to ensure that PWP and RAEC complied with the quotas in a cost effective and efficient manner, with regards to security of supply considerations and other relevant license conditions. Moreover, the Feed in tariffs; for large scale projects, we recommend authorities to develop feed in tariffs to support projects over several stages of development (in the expectation that tariffs in the latter stages of a project would be lower than in the initial stage due to the technology being proven, economies of scale and so on).

In summary, we recommend that the authorities act to remove barriers for utilizing renewable energy, whether these be technical, economic or legal barriers, so as not to hinder policy initiatives that aim to facilitate and promote renewable energy projects.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare that there are no conflicts of interest in the execution and publication of this work.

Author contributions

Humaid Abdullah ALHinai and Azrul Mohd Ariffin conceived the review idea and developed the research theory, methodology and draft manuscript preparation.

Humaid Abdullah ALHinai drafted the manuscript and Azrul Mohd Ariffin and Miszina Osman performed study conception and reviewed the manuscript.

Humaid Abdullah ALHinai, Azrul Mohd Ariffin and Miszina Osman designed the proof outline and contributed to the implementation of the research.

In summary, all authors have participated in the conception and design, analysis and interpretation of the data and approval of the final version.

References

1. Zheng XY, Zhou YK (2023) A three-dimensional unsteady numerical model on a novel aerogel-based PV/T-PCM system with dynamic heat-transfer mechanism and solar energy harvesting analysis. *Appl Energy* 338: 120899. https://doi.org/10.1016/j.apenergy.2023.120899
2. Zhou YK (2022) Low-carbon transition in smart city with sustainable airport energy ecosystems and hydrogen-based renewable-grid-storage-flexibility. *Energy Rev* 1: 100001. https://doi.org/10.1016/j.enrev.2022.100001
3. Aisha S, Noura M (2022) Review renewable energy development in the gulf cooperation council countries: status, barriers, and policy options. *Energies* 15: 1923. https://doi.org/10.3390/en15051923
4. Praveen RP, Vishnu K, Ahmed G, et al. (2020) An insight to the energy policy of GCC countries to meet renewable energy targets of 2030. *Energy Policy* 147: 111864. https://doi.org/10.1016/j.enpol.2020.111864
5. Abdulmajeed W, Abdullah B (2022) Sizing of a hybrid energy system for Al Mazyouna area. *20th International Conference on Renewable Energies and Power Quality (ICREPQ'22) Vigo (Spain),* 20. https://doi.org/10.24084/repqj20.335
6. Sabah AW, Charabib Y, Abdul MM, et al. (2019) Selection of the best solar photovoltaic (PV) for Oman. *Sol Energy* 188: 1156–1168. https://doi.org/10.1016/j.solener.2019.07.018
7. Alharthi YZ, Siddiki MK, Chaudhry GM (2018) Resource assessment and techno-economic analysis of a grid-connected solar PV-Wind hybrid system for different locations in Saudi Arabia. *Sustainability* 10: 3690. https://doi.org/10.3390/su10103690
8. Yahya ZH, Siddiki MK, Chaudhry GM (2019) Techno-economic analysis of hybrid PV/Wind system connected to utility grid. *2019 IEEE Texas Power and Energy Conference (TPEC)*, College Station, TX, USA, 1–6. Available from: https://ieeexplore.ieee.org/abstract/document/8662156.
9. Fazlur R, Emdadul HMd, Muhammad A, et al. (2021) Investigation of optimal hybrid energy systems using available energy sources in a rural area of Bangladesh. *Energies* 14: 5794. https://doi.org/10.3390/en14185794
10. Kumari S, Kumar SY (2020) Modeling and analysis of hybrid distributed generation system using HOMER software. *Int J Power Syst.* Available from: https://www.iaras.org/iaras/filedownloads/ijps/2020/010-0006(2020).pdf
11. Kumari J, Subathra P, Moses JE, et al. (2017) Economic analysis of hybrid energy system for rural electrification using HOMER. *2017 International Conference on Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT)* Coimbatore, India, 151–156. Available from: https://ieeexplore.ieee.org/document/8116824.
12. Mannai H, Oueslati H, Mabrouk SB (2020) HOMER based optimization of PV-Wind-Grid connected hybrid system in administrative building. *2020 6th IEEE International Energy Conferene, (ENERGYCon)*, Gammarth, Tunisia, 830–835. Available from: https://ieeexplore.ieee.org/document/9236512.
13. Fahad A, Muhammad A, Yuexiang J, et al. (2020) A techno-economic assessment of hybrid energy system in rural Pakistan. *Energy* 215: 119103. https://doi.org/10.1016/j.energy.2020.119103

14. Mohammad A, Ghasempour R, Rahdan P, et al. (2019) Techno-economic analysis of a hybrid power system based on the cost-effective hydrogen production method for rural electrification, A case study in Iran. *Energy* 190: 116421. https://doi.org/10.1016/j.energy.2019.116421
15. Das BK, Mohammad SHK, Rakibul H, et al. (2021) Techno-economic optimisation of stand-alone hybrid renewable energy systems for concurrently meeting electric and heating demand. *Sustainable Citices Sco* 68: 102763. https://doi.org/10.1016/j.scs.2021.102763
16. Kanata S, Baqaruzi S, Ali M, et al. (2021) Assessment of economic and environmental for a hybrid energy system in Sebesi Island, South Lampung, Indonesia. *2021 9th International Conference on Smart Grid and Clean Energy Technologies (ICSGCE)*, Sarawak, Malaysia, 84–91. Available from: https://ieeexplore.ieee.org/document/9621446.
17. Mahmud DM, Hasan S, Ahmed SMM, et al. (2021) Techno economic feasibility analysis of grid-connected microgrid by using solar PV for residential usage. *2021 IEEE 9th Region 10 Humanitarian Technology Conference (R10-HTC),* Bangalore, India, 1–6. Available from: https://ieeexplore.ieee.org/document/9641732.
18. Mei SN, Chee WT (2012) Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia. *Renewable Sustainable Energy Rev* 16: 634–647. https://doi.org/10.1016/j.rser.2011.08.028
19. Alkaraghouli A, Kazmerski LL (2010) Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. *Sol Energy* 84: 710–714. https://doi.org/10.1016/j.solener.2010.01.024
20. Zeinab AM, Muhammad FMZ, Kamaruzzaman S, et al. (2012) Design and performance of photovoltaic power system as a renewable energy source for residential in Khartoum. *Int J Phys Sci* 7: 4036–4042. Available from: https://academicjournals.org/journal/IJPS/article-stat/0F7671518720.
21. Hoarcă C, Nicu B (2017) Design of hybrid power systems using HOMER simulator for different renewable energy sources. *2017 9th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*, Targoviste, Romania, 1–7. Available from: https://ieeexplore.ieee.org/document/8166507.
22. Lal DK, Bibhuti BD, Akellla AK (2011) Optimization of PV/wind/micro-hydro/diesel hybrid power system in HOMER for the Study Area. *Int J Electr Eng Inf* 3: 307–325. Available from: https://www.researchgate.net/publication/272390283_Optimization_of_PVWindMicro-HydroDiesel_Hybrid_Power_System_in_HOMER_for_the_Study_Area.
23. Makwana V, Kotwal C, Kriti A (2019) Optimum sharing of solar power and grid for an academic institute using HOMER. *2019 IEEE 5th International Conference for Convergence in Technology (I2CT)*, Bombay, India, 1–5. Available from: https://ieeexplore.ieee.org/abstract/document/9033648.
24. Swarnkar NM, Gidwani L (2017) Economic and financial assessment of integrated solar and wind energy system in Rajasthan, India. *2017 International Conference on Computation of Power, Energy Information and Commuincation (ICCPEIC)*, Melmaruvathur, India, 471–476. Available from: https://ieeexplore.ieee.org/document/8290413.
25. Sonali G, Sayed MA (2014) Cost analysis of solar/wind/diesel hybrid energy systems for telecom tower by using HOMER. *Int J Renewable Energy Res,* 4. Available from: https://dergipark.org.tr/tr/download/article-file/148200.

26. Abbasi KR, Adedoyin FF, Abbas J, et al. (2021) The impact of energy depletion and renewable energy on (CO_2) emissions in Thailand: Fresh evidence from the novel dynamic ARDL simulation. *Renewable Energy* 180: 1439–1450. https://doi.org/10.1016/j.renene.2021.08.078
27. Abbasi KR, Abbas J, Tufail M (2021) Revisiting electricity consumption, price, and real GDP: A modified sectoral level analysis from Pakistan. *Energy Policy* 149: 112087. https://doi.org/10.1016/j.enpol.2020.112087
28. Amoatey P, Amer AH, Abdullah AM (2022) A review of recent renewable energy status and potentials in Oman. *Sustainable Energy Technol Assess* 51: 101919. https://doi.org/10.1016/j.seta.2021.101919
29. Coyle E (2017) A case study of the Omani electricity network and readiness for solar energy integration. *J Sustainable Design Appl Res,* 5. https://doi.org/10.21427/D79X56
30. Albadi AH, Albadi MH, Al-Lawati AM, et al. (2011) Economic perspective of PV electricity in Oman. *Energy* 36: 226–232. https://doi.org/10.1016/j.energy.2010.10.047
31. Solar resource data, Oman power and water procurement Co (2016). Available from: https://omanpwp.om/PDF/Solar%20Data%202016%20Complete.xlsx.
32. Dorvlo SS, Ampratwum DB (2000) Technical note modelling of weather data for Oman. *Renewable Energy* 17: 421–428. Available from: https://maqsurah.com/uploads/items/75006/files/FULL/2021-07-05_10_50_045063519.pdf.
33. Allawati A, Dorvlo ASS, Jervase JA (2003) Monthly average daily solar radiation and clearness index contour maps over Oman. *Energy Conver Manage* 44: 691–705. Available from: https://www.academia.edu/5435946/Monthly_average_daily_solar_radiation_and_clearness_index_contour_maps_over_Oman.
34. Solar project (2013) Solar data acquisition. Available from: https://omanpwp.om/PDFAR/Solar%20Report%20update%20.pdf.
35. Bhattacharjee S, Chakraborty S, Brahma NT, et al. (2018) Modelling, optimization and cost analysis of grid connected solar-battery system for Tripura university campus. *Int J Adv Sci Res Manage* 3: 2455–6378. Available from: http://ijasrm.com/wp-content/uploads/2018/09/IJASRM_V3S9_814_23_31.pdf.
36. Kenneth E, Uhunmwangho R (2014) Optimization of renewable energy efficiency using HOMER. *Int J Renewable Energy Res* 4: 421–427. Available from: https://www.researchgate.net/publication/263765594_Optimization_of_Renewable_Energy_Efficiency_using_HOMER.
37. Zhou YK, Peter DL (2023) Peer-to-peer energy sharing and trading of renewable energy in smart communities—trading pricing models, decision-making and agent-based collaboration. *Renewable Energy* 207: 177–193. https://doi.org/10.1016/j.renene.2023.02.125
38. Zhou YK (2022) Incentivising multi-stakeholders' proactivity and market vitality for spatiotemporal microgrids in Guangzhou-Shenzhen-Hong Kong Bay Area. *Appl Energy* 328: 120196. https://doi.org/10.1016/j.apenergy.2022.120196
39. Zhou YK (2022) Demand response flexibility with synergies on passive PCM walls, BIPVs, and active air-conditioning system in a subtropical climate. *Renewable Energy* 199: 204–225. https://doi.org/10.1016/j.renene.2022.08.128

40. Luomi M, Aisha AS (2021) Oman's second nationally determined contribution (NDC). *King Abdullah Petroleum Studies and Research Center* (*KAPSARC*). Available from: https://www.kapsarc.org/research/publications/omans-second-nationally-determined-contribution-ndc/.