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A Technical and Economic Feasibility Study for on-Grid Solar PV in Libya

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ABSTRACT

In this research, the technical, economic and environmental feasibility of a grid-connected solar photovoltaic (PV) system for a single-family residential home in several Libyan cities with separate locations was studied. In Libya, the rate of electricity consumption is the largest in the domestic sector, with 60% of the total electricity consumption. Due to the frequent power outages in Libya, and the dependence of power generation mainly on traditional sources, pollution problems, and energy alternatives are an important priority. To overcome these problems, we propose maximizing the exploitation of renewable energy sources for energy production. In this paper, the HOMER Pro Renewable Energy Modeling Software was used to conduct a technical evaluation of a grid-connected solar PV system's economic viability, where the design was proposed for a residential house for six Libyan cities. The size of the PV system for a residential home is estimated at 15 kW. The findings indicated that the suggested design could supply 85% of the household's electrical requirements. AlKufra was the best location in terms of economics and the environment for a grid plus PV system, as the initial cost of the system was $9,570, the Cost of Energy (COE) was $0.0314, and the carbon dioxide emissions were 56,982 kg/year. Overall, lower prices for PV modules and PV components combined with long life, less maintenance needs, and minimum parity near the grid. The results show that PV systems connected to the residential grid are an effective energy management option in most Libyan cities.

1. INTRODUCTION

During the past years, the construction of residential schemes and the population increase has led to an increase in energy consumption and frequent blackouts. Power generation in Libya depends on fossil fuel sources (natural gas and crude oil) [1] where reports indicate that fossil fuels and petroleum raw materials are in constant decline over the years and will soon be depleted [2, 3]. Power plants in Libya depend heavily on fossil fuels, which are a major problem for greenhouse emissions such as carbon dioxide and nitrate oxides. Sulfur oxides are particles that affect the environment and human health. One of the best solutions to overcome the problem of increasing demand for electricity is the use of solar energy [4]. The average annual solar radiation in Libya is 250 kW/m^2 and hence, Libya has great potential for solar energy. It is also characterized by long hours of average sunshine of about 8 hours per day, large areas of land, and an atmosphere free of clouds [5]. These capabilities make Libya an encouraging medium for the use of solar PV systems, as can be seen in Table 1 the potential of solar energy in Libya [6, 7].

Table 1. Solar energy potential in Libya computed using SOLARGIS

Solar Resources and Air Temperature	Per Year	Per Day
Horizontal global radiation [kWh/m^2]	1956	5359
Direct normal irradiation [kWh/m^2]	1937	5307
Horizontal diffuse irradiation [kWh/m^2]	708	1940
Global tilted irradiation [kWh/m^2]	2142	5868 for surface tilted at 26° facing 180°
Temperature of air	18.5	-

Several feasibility studies have been conducted in recent years, stating that solar PV systems are cost-effective [8, 9]. The overview of some of the researchers who examined the technological and economic viability of a grid-connected PV system worldwide can be seen in Table 2. From the studies, we may conclude that, particularly for a grid-connected system, grid-connected PV systems are technically feasible and economically successful. In recent years, there have been several feasibility studies stating that solar PV systems are cost effective [8, 9]. Researchers have looked at the technology and financial viability of a grid-connected PV system for various regions of the world. An economic evaluation of a grid-connected PV system was done for a facility in South Korea for a number of configurations, taking into account system components and network connectivity. The grid-only system is the option that is least economically feasible, according to the analysis [10]. Examine the PV system that is connected to the network for the usage of HOMER economic analysis and the various Makkah tracking systems. They found that the axis tracker system with continuous adjustment offers the least value for NPC and the highest COE [11]. Using HOMER, a study was conducted to determine the technical and financial viability of a linked PV system to produce electricity for a location in Nigeria where the system's initial cost was a significant factor in the electricity tariff [12]. A PV system is a smart approach to lower electricity costs and greenhouse gas emissions, according to research done in Australia on an apartment building [13]. He investigated the technical and financial viability of a grid-connected PV system for 35 sites in Ethiopia, each with a 5 MW PV capacity. It has the capacity to produce 7,658 MW of energy and could prevent 1,089 tons of greenhouse gas emissions every year [14].

Table 2. The summary of the PV system economic feasibility research that has been conducted worldwide

Location	Type of Study	Findings	Ref.
South Korea	Considering network connectivity and system components, an economic study of a grid-connected PV system for a site in South Korea is performed.	Grid only system is the least viable option in terms of the lowest costs for all other systems.	[10]
Makkah, Saudi Arabia	PV systems with network connections for Makkah's numerous tracking systems and the usage of HOMER for economic analyses.	The axis tracker system with continuous adjustment, gives the smallest value for Net Present Cost (NPC) and the largest COE.	[11]
Nigeria	The technical and economic feasibility of a PV system using HOMER	The initial cost of the system was playing an important role in the electricity rate.	[12]
Australia	A study on the economic analysis of the utilization of PV system on an apartment building.	PV systems are an effective option for apartment buildings to lower their electricity costs and greenhouse gas emissions.	[13]

Over the coming decades, while fossil fuel prices are unstable, photovoltaic price is predicted to decline [15], which will further encourage PV implementation in wider scale. The purpose of the reference [16] is to develop a database for wind sources in Libya and analyze the potential of wind energy as a source of power. The findings used for this study are based on monthly data for the four-year period from 2017 to 2020. The highest energy density was 148.65 W/m^2 in May, as well as 142.34 W/m^2 in Derna and Tobruk. The Ajdabiya websites in Benghazi have the lowest month-to-month average wind speeds, with 3.7 and 4.5 m/s respectively. Large wind turbines provide more electricity than small windmills. Libya is investing in traditional power plant construction, but the ecological effects of power generating would increase if fossil fuels were used [17]. To address this, a grid-connected solar PV-wind hybrid energy system with a mean daily public load demand of 12,000 kWh and a maximum daily demand of 20,000 kWh has been planned. Simulation results showed the system has the lowest Net Present Cost (NPC) and Levelized Cost of Energy (LCOE), the highest amount of available total energy, and the lowest emissions of CO_2.

The purpose of this paper is to develop a database of solar energy sources in Libya and analyze the potential of solar energy as an energy source. Libya invests in building traditional power plants, but the environmental impacts of power generation will increase if fossil fuels are used, with a shortage in the production of electric power [17]. To address this matter, a solar photovoltaic system connected to the grid was planned, as this system is not applied in the State of Libya and lacks previous practical and theoretical studies, compared to a system separated from the grid.

The increasing energy demand in Libya negatively affects oil and gas exports. This paper is aiming to investigate the technical and economic feasibility analysis of a grid-connected solar PV system, where the design was proposed for a residential house for six Libyan cities. The selected sites include the east, west, central, and south regions of Libya are Al-Marj, AlKufra, Sirte, Benghazi, Tripoli, Murzuq.

2. MATERIALS AND METHODS

In this paper, to conduct the study, HOMER Pro Renewable Energy Modeling Software was used. Analysis of the technical and financial viability of a grid-connected solar PV system, for a residential house in the selected six Libyan cities, was analyzed by taking into account the index of different technologies and the economic cost of the system components. These indicators evaluate the performance of the system at a given site against the performance of the system against default operating standards. In this study, we first describe and present the proposed design. Next, the performance of the data which is used in evaluating the performance of the proposed design is discussed.

2.1 Description of the proposed system

The report of the General Electricity Company indicates that household consumption constitutes 60% of residential energy in the regions of Libya [18]. The specific building examined in this study is the typical residential housing in Libya. The building is one floor, four rooms, and it is occupied by seven people. The building has a flat roof area of 400 m^2, and 50% of the building area can be used for photovoltaic installation.

2.1.1 Climatic information for the study areas

The data on solar radiation index data at the study sites were taken from the NASA Meteorological and Solar Energy Database [19]. The following graphs represent the measured average monthly values of the Global Solar Clarity (KT) index for the six cities' locations. These scattered cities in Libya were chosen to give a complete survey of the country from east, west, and south. Figures 1 and 2 show the clarity and average monthly solar radiation for all six cities, respectively. We note that the cities of the south have the greatest intensity of solar radiation than the central regions of the country. Also, the distribution of solar radiation over the months of the year is in the month of May to November.

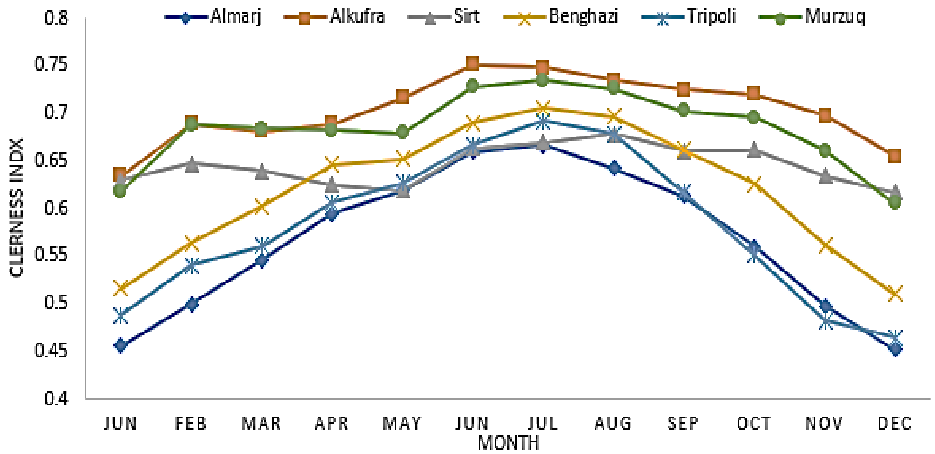


Figure 1. Global Solar Clarity (KT) index for the selected six cities

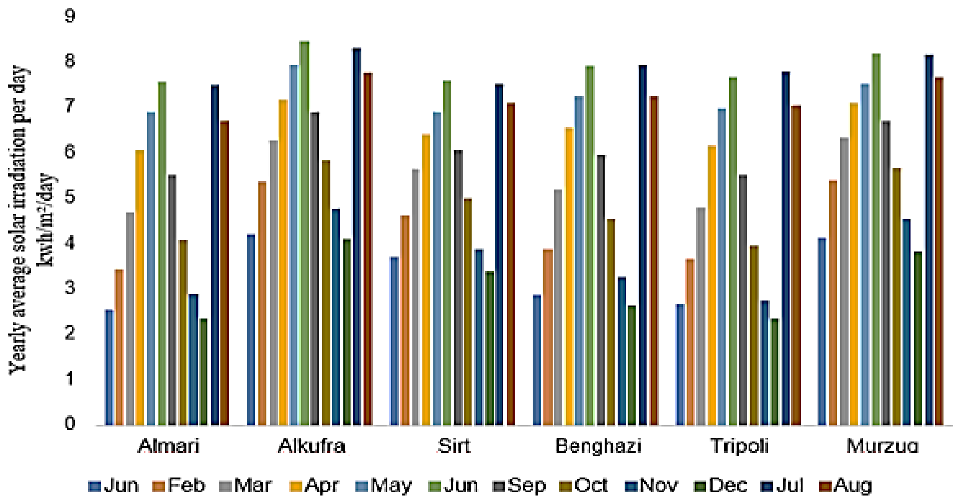
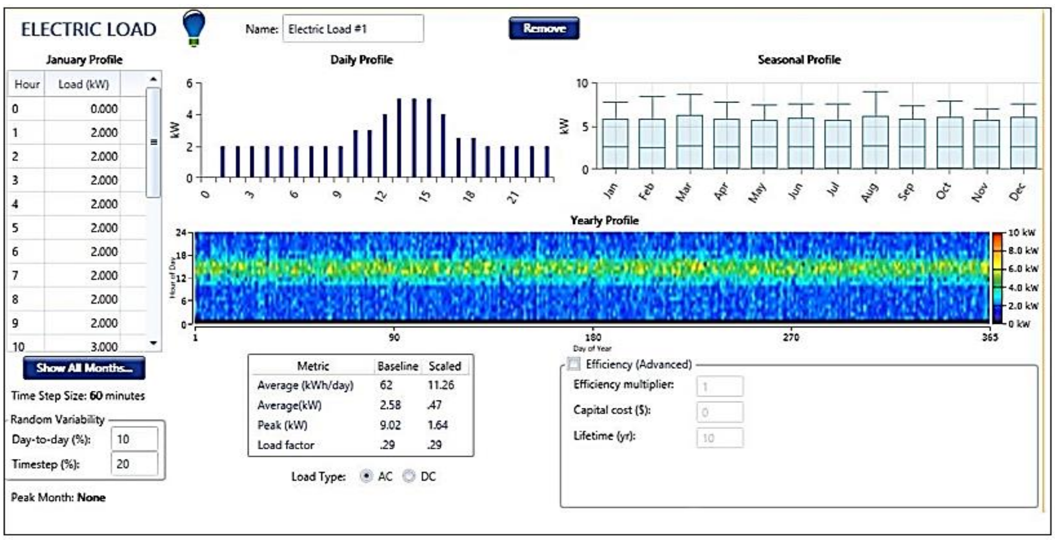


Figure 2. Yearly average solar irradiation per day kWh/m^2/day



Hour	Load (kW)
0	0.000
1	2.000
2	2.000
3	2.000
4	2.000
5	2.000
6	2.000
7	2.000
8	2.000
9	2.000
10	3.000

Metric	Baseline	Scaled
Average (kWh/day)	62	11.26
Average(kW)	2.58	.47
Peak (kW)	9.02	1.64
Load factor	.29	.29

Figure 3. The interface of the load profile simulated in HOMER

2.1.2 Electric load

The monthly home energy consumption obtained from utility bills of the General Electricity Company is shown in Table 3 [20]. With HOMER, the daily household electrical load profile for six locations with different climates in Libya can be obtained. Household electrical appliances were used to estimate the electrical load consumed for all regions. Due to the fact that this is a household electrical load, the hours with the lowest load demand were from 7 AM to 4 PM, and the hours with the largest load requests were from 6 PM to 11 PM and 6 AM to 7 AM. The annual and monthly load profiles illustrated in Figure 3 are calculated by HOMER using the total monthly power use. The electrical load on Libyan homes is about compatible with this load profile. When connecting photovoltaic cells with an inverter, the main goal is to convert the photovoltaic energy generated from the cells into electrical energy that can be used in homes, buildings, or factories.

Table 3. The electrical load for a typical home simulated in HOMER

Capacity			**Operating**	**Daily Consumption**
Device	Number of dev	Ices (W)	h/day	kWh/day
lighting	16	50	8	6
TV	2	120	12	1.44
Refrigerator	1	150	10	1.5
Refrigerator freezer	1	180	12	2.16
Computer	1	100	5	0.5
Washing Machine	1	500	2	1
Water heater	2	1500	10	30
Conditioner	1	1850	10	18.5
Pump	1	750	1	0.75
Total		5200		61.85

2.1.3 System design in HOMER

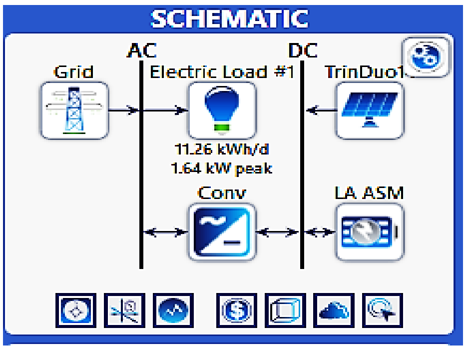


Figure 4. The schematic of the on-grid PV system design in HOMER software

Among the key factors to consider while designing a PV system are the average monthly energy consumption and maximum sunshine hours. The average daily energy consumption must be determined by analyzing the peak sun hours at the site. Hours of daily sun brightness divided by average daily energy use. A household system using photovoltaics is connected to the grid. A grid-connected household PV system is shown in Figure 4. A system with a capacity of 11.26 kW has been proposed, consisting of 32 monocrystalline silicon units, with rated power of 320 watts each, with an efficiency of 21.49%, and a total unit area of 45 m^2. In addition, two inverters with a capacity of 10 kW were used at top of AC power. Photovoltaic cells are interconnected with an inverter by connecting electrical wires from the cells to the inverter, which transmit the photovoltaic energy to the inverter. Cells are connected in series or parallel to increase the current or voltage generated by the cells. In this case, the inverter is used to convert the direct current (DC) generated by the cells into alternating current (AC), which can be used in different homes or buildings. The inverter's outputs are connected to electrical panels in homes or buildings, which distribute electrical power to various appliances.

3. RESULTS AND DISCUSSION

3.1 Energy produced

The analysis from HOMER (see Figure 5) shows that the total monthly electricity production during the first year ranged between 2.1 MW and 1.5 MW find that the energy production in the fall season (November and December) and the winter season (January and February) is low due to the clouds cover, and short periods of sunshine. In the summer and winter seasons, the energy produced from the photovoltaic system is insufficient to meet the energy demand, due to the excessive loads of air conditioners and heating devices. As a result, clients will be reimbursed in line with mutual agreements with the public network after the PV energy is transmitted into the distribution network. The discrepancy between the proposed PV system's monthly output and residential use is depicted in Figure 5.

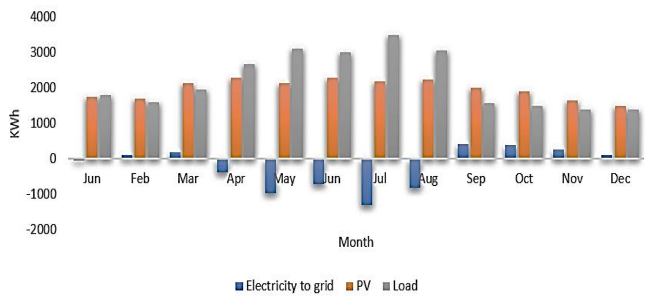


Figure 5. Monthly PV system production and load demand

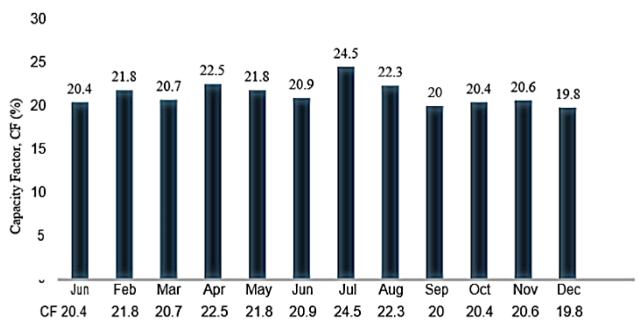


Figure 6. Monthly capacity factor

In most of the six cities, the system has an annual output of 2000 kWh/kWp, and it operates for 2,000 hours to supply the generated energy. As shown in Figure 6, the monthly capacity factor (CF) for this design is 21% which is considered as a reasonable value compared to studies in Saudi Arabia, Oman, and Kuwait 115 [21-23].

3.2 The economic costs of the system

The capital cost of the project as well as the cost of operation and maintenance determine the economic costs of a grid-connected residential PV system. Based on the International Renewable Energy Agency's (IRENA) guidelines, the system and installation prices were authorized [24] and compared to the prices in the Libyan market. The cost of the system is approximately $9,570. There is no operational cost for the PV system, as the maintenance costs are minimal for removing dust on the surface of the PV module. The cost of operation and maintenance is estimated at US $20 / kWh. Since the system is home and consists of 32 solar panels, therefore, it does not need a lot of cleaning and maintenance. In most solar systems, it is necessary to change batteries only, this system is connected to the network and does not need storage, and the life of the panels exceeds 25 years [25].

Table 4 shows the costs of the grid-connected PV system and the main financial inputs.

3.3 The grid-connected PV system

The production of electrical energy in this system depends on the electricity demand through the electricity produced by the PV arrays and the grid, and this depends on the intensity of radiation and the effect of temperature. From the results of the feasible improvement of this type of system listed in Table 5 and Table 6, we note that AlKufra, NPC, and COE are the least because this site also contains the lowest operating cost, which makes it the most economical city among the cities and the rest of the sites for this system. Tripoli also has the highest NPC and COE among the other six cities. The highest emissions were CO_2 emissions in Tripoli and the lowest in AlKufra in terms of environmental pollution (CO_2, NOx SO_2) in the grid + PV formation.

Table 4. Financial cost for the PV system

Components	Number	Cost ($)
PV panels	32	5797
Inverter	2	1400
Equipment installation total	9570	2326

Table 5. The environmental and economic feasibility of a grid-connected PV system

Location	PV (KW)	Grid (KW)	Initial Cost ($)	Net Present Cost ($)	Operating Cost ($)	Emissions kg/year		
						CO_2	NOx	SO_2
Almarj	6	60	9570	79499	4994	60523	270	132
Alkufra	6	60	9570	79133	4512	56982	274	128
Sirt	6	60	9570	79322	4520	59562	272	130
Benghazi	6	60	9570	79455	4770	60882	271	129
Tripoli	6	60	9570	85533	5000	62549	280	142
Murzuq	6	60	9570	79215	4925	60558	275	131

Table 6. Electricity produced and consumed from the grid and the PV system at the six sites

Electricity (kWh/year)	Almarj	Alkufra	Sirt	Benghazi	Tripoli	Murzuq
Primary load	135780	135456	135423	135500	135543	135243
PV production	10240	10433	10222	10355	10560	10200
Consumption from grid	124465	124567	124345	124567	128343	124234
Grid sales	186	140	155	190	220	120
Total consumption	135966	135920	135578	135690	135763	135363

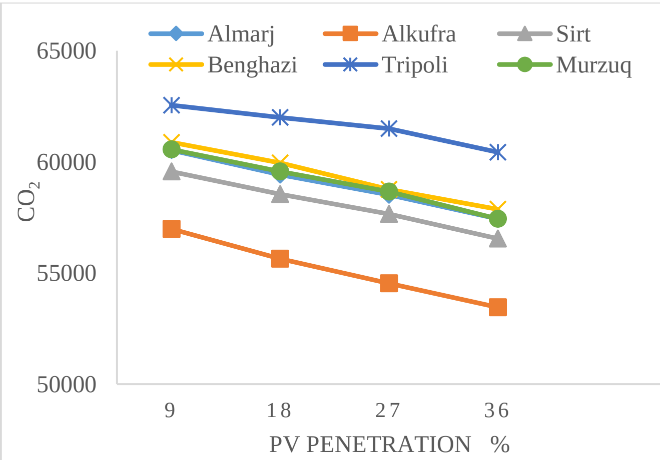


Figure 7. PV penetration impact on CO_2 emissions

The maximum annual generation capacity obtained through network purchase was in AlKufra and Tripoli, which accounts for approximately 92% of the total power output from the system. The effect of photoelectric penetration on CO_2 emissions of the grid-connected PV system can be observed in all six cities as shown in Figure 7. The system components include a PV panel with sizes of 6 kW, 12 kW, 15 kW, 20 kW. Whereas, as PV penetration increases, the cost of PV + grid assemblies increase while CO_2 emissions for all sites increase. By comparing the cases for all sites, we find that the system of 6 to 10 KW of photovoltaic arrays is the lowest cost and the lowest percentage of emissions.

4. CONCLUSIONS

Electricity generation in Libya suffers from poor production, which has obliged the electrical distribution sector to shed loads regularly. Adding new power plants requires a large amount of time and investment. The use of grid-connected solar PV systems is considered an attractive alternative to clean power generation using solar. In this paper, we have investigated the feasibility of a grid-connected solar PV system using HOMER Pro Renewable Energy Modeling

Software. The feasibility analysis was performed for a typical residential house in six Libyan cities. The following conclusions can be made from the analysis:

i. A grid-connected PV system was determined to have lower emissions than a traditional grid system in every city. As a result, it is determined that the grid-connected PV system is preferable to its competitors.
ii. For the grid-connected PV system, Al-Kufra was found as the most promising location economically, and environmentally. The initial cost of the system and COE is $9,570 and $0.0314 respectively, and the carbon dioxide emissions are 56,982 kg/year. A continuous general decline in the prices of PV modules and PV components combined with a long lifetime, virtually zero maintenance, and minimum allow close to grid parity.
iii. Voltage and frequency fluctuations: As solar systems generate electricity intermittently, it can cause fluctuations in voltage and frequency on the electrical grid, which can cause problems for other users on the grid.

5. RECOMMENDATIONS

- Variability of solar power output: The amount of power generated by solar systems varies depending on the time of day, season, and weather conditions. This variability can cause instability on the grid and make it difficult to balance energy supply and demand.
- Technical compatibility issues: Solar systems must be technically compatible with the electrical grid to ensure that they can operate safely and effectively. This can require additional equipment and engineering expertise to ensure that the systems are properly connected and integrated.
- Grid capacity constraints: The electrical grid has a limited capacity to absorb power from solar systems, which can limit the amount of solar power that can be integrated into the grid.
- Grid stability and security: Integrating solar systems into the electrical grid can affect the stability and security of the grid, particularly if there are issues with voltage regulation, control, and protection.
- Regulatory and policy challenges: The integration of solar systems into the electrical grid can be subject to regulatory and policy challenges, such as interconnection requirements, net metering policies, and incentives for distributed generation.

Addressing these challenges requires careful planning, technical expertise, and effective policies and regulations. Solutions may include better forecasting of solar power output, advanced grid management technologies, grid upgrades, and new policy incentives to encourage the integration of solar systems into the electrical grid [26, 27].

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