Environmental Science and Pollution Research (2023) 30:119925–119934
https://doi.org/10.1007/s11356-023-30657-8

RESEARCH ARTICLE

Linking energy crises and solar energy in China: a roadmap towards environmental sustainability

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Received: 2 July 2023 / Accepted: 20 October 2023 / Published online: 7 November 2023

Abstract
Fossil fuels are the primary energy sources of China, which are not only expensive but have adverse environmental impacts. To cope with this situation, the Chinese government wants to fulfil 25% of its energy consumption by non-fossil fuels by 2030. In this perspective, we selected the solar sources of the country and collected solar irradiation data for one year in the six big cities of China in 2022. For the analysis of data and assessing the effectiveness of photovoltaic (PV), RETScreen and MATLAB were utilized. A further step was taken by performing the life cycle assessment (LCA) to scrutinize the different features of solar energy, including fuel consumption, price, average lifetime, maintenance and operation expenses, land requirements, and greenhouse gas emissions. Results reveal that all these cities have enormous solar power potential. However, the highest solar power (0.27 kW) is generated in Nanchang city, while the lowest power (0.21 kW) is generated in Sanya city. Solar energy is durable and has a good average lifespan but can be costly, as PV panels lose efficiency due to dust and pollution. The regular cleaning of PV panels, in turn, demands substantial cost. Based on research results, significant policy suggestions have been recommended to fulfil the country's energy demand on its way to a future of sustainable development.

Keywords Solar energy · MATLAB, RETScreen · Life cycle assessment · China

Introduction

Advanced economies need a constant supply of energy (Duan et al. 2022; Yang et al. 2022). Education, transportation, agriculture, mining, and healthcare need a continuous energy source to operate properly (Khurshid et al. 2022b; Wang et al. 2023). Energy availability is crucial to the growth and development of every country's economy (Elavarasan et al. 2020; Wang et al. 2022a). The country's economy relies heavily on the production and export of energy and water (Khurshid et al. 2022a). However, developing viable alternatives for energy generation has always been a difficult issue (Qazi et al. 2019; Wu et al. 2021). Energy shortage glitches not only influence the life of residents but also hamper the country's economic development (Irfan et al. 2020b; Khurshid and Deng 2021). China's present power-generating system is reliant on thermal energy sources, including natural gas, oil, and coal (Irfan et al. 2021b; Wang et al. 2022b). Massive reliance on traditional energy sources has resulted in major environmental concerns, including unstable weather conditions, health complications, and climate change (Dagar et al. 2022).

Policymakers are considering the future of traditional energy sources in light of the fluctuating cost of fossil fuels, the unpredictable nature of oil prices, and emissions of greenhouse gases (Jin 2023; Khurshid et al. 2022a). Various countries around the world are pursuing contemporary methods of energy production and attempting to convert the traditional structure of energy to clean and renewable sources of energy, which may, on the one hand, mitigate climate change and, on the other hand, alleviate the burden of imported oil costs (Irfan et al. 2021c; Li et al. 2023). China has developed a different ministry for alternative energy sources to increase the nation's use of renewable energy (Akram et al. 2020). The Chinese government has demonstrated a significant commitment to the advancement of

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renewable energy, particularly solar energy, over the past two decades. The nation has an installed solar power capacity of 393,032 MW. Recent development in the solar business has been extraordinary due to technological improvements and aggressive government support measures (Hosseini and Wahid 2020).

Despite the remarkable advancement of the solar sector, a significant population still cannot meet their daily energy requirements (Bullerdiek et al. 2021). Rafique et al. (2020) compared the access to electricity and no-solid fuels among Pakistan, Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, and Sri Lanka and found that there are considerable differences in the access to electricity and no-solid fuels despite their similar economic level; there are differences in density of population, living standard, innovation, and geographical factors across these nations. Geographically, China is located in the sunny belt and receives abundant sunlight throughout the year. Some parts of the country get 2 MWh/m^2 solar irradiation and 3,000 h of sunshine per year, which is ideal for setting up solar energy parks to exploit the true potential of solar sources in the country (Kamran et al. 2019).

Several scholars have analyzed the growth of solar energy in the Chinese context from various angles. Irfan et al. (2019a, b) emphasized the significance of solar energy for power production in China and evaluated the potential of electricity generation from solar sources. Akhtar et al. (2018) exposed that solar thermal is the best choice to overcome the prevailing energy crises in the country. Smouh et al. (2022) reported the possible applications of solar thermal for the textile sector. Iram et al. (2021) presented a feasible off-grid PV system for residential electricity. Nevertheless, scholars did not stress the need to examine the viable evaluation of solar energy in the main Chinese cities and develop appropriate action plans. Therefore, extensive investigation is necessary to close this gap. Furthermore, solar energy's life cycle assessment (LCA) has not been thoroughly studied, which is an additional reason for conducting this study. For this purpose, we have chosen six major cities in China. The choices of these cities are predicated on the fact that the structure of energy of such cities is mostly reliant on traditional power that is not only expensive but has additionally created environmental issues. Another rationale of choosing these cities is that they are located in a region that receives continuous sun radiation throughout the year. Solar energy might become a potential renewable energy option for such communities if efficiently harnessed.

The following are the contributions made by the research: (i) To address a gap in the literature, the viable evaluation of solar energy in China was examined. (ii) Furthermore, a life cycle assessment (LCA) of solar energy was conducted to evaluate its unique characteristics. This research not only has the potential to add to the current body of knowledge by examining the practical assessment of solar energy in the Chinese environment, but it may also be of assistance to the government and other stakeholders by giving them a thorough explanation of solar energy and allowing them to formulate appropriate procurement strategies.

The remaining sections are structured as follows: The situation of China's solar energy is discussed in Section "The solar energy situation in China". The research methodology is shown in Section "Research methodology". Analysis and outcomes are covered in Section "Analysis and results". The results of the study are discussed in Section "Discussion". The last component of the research, Section "Conclusion and policy implications", finishes with policy implications.

The solar energy situation in China

China's energy sector has undergone significant developments in recent years, with a particular focus on expanding its solar energy capacity and transitioning towards cleaner and more sustainable energy sources (Hao et al., 2023). China's role in global solar energy generation is substantial and continually growing, fueled by domestic policy initiatives and international technological advancements (Lanre et al. 2022). China is actively working to reduce its reliance on coal, which has been a major source of energy for decades and a significant contributor to air pollution and greenhouse gas emissions. As part of this transition, the country has been rapidly increasing its use of renewable energy sources, with solar energy playing a pivotal role. China is the world's largest producer and consumer of solar energy. The country has aggressively expanded its solar capacity, making it a global leader in solar power generation. Large-scale solar farms, distributed solar installations, and rooftop solar panels have all contributed to this growth (Chen et al. 2023).

The Chinese government has implemented a range of policies and incentives to promote solar energy adoption. These include feed-in tariffs, subsidies, tax incentives, and competitive bidding mechanisms to support the development of solar projects. China has invested heavily in solar technology research and development. Chinese companies have made significant advancements in solar panel efficiency and manufacturing processes, leading to cost reductions and increased competitiveness in the global solar market (Evro et al. 2023). China is the world's largest producer of solar panels and components. Chinese companies, such as JinkoSolar, Trina Solar, and LONGi Solar, are major players in the global solar industry and supply solar products to markets worldwide. China is working on improving the integration of solar energy into its power grid. This involves upgrading grid infrastructure to accommodate the variable nature of solar power and enhancing grid reliability (Li et al. 2022).

China has encouraged the development of distributed solar energy systems, including on rooftops, in industrial parks, and in rural areas. Distributed generation helps reduce transmission losses and can enhance energy resilience. China has faced environmental challenges related to the solar industry, such as pollution from manufacturing processes and the management of end-of-life solar panels (Ali et al. 2023). Efforts are being made to address these issues through stricter regulations and recycling initiatives. China's leadership in solar energy has extended to international partnerships and collaborations. The country is involved in global initiatives and projects related to clean energy development, including the Belt and Road Initiative, which promotes solar and renewable energy investments in partner countries. China's commitment to reducing carbon emissions and achieving its climate goals is expected to drive further growth in its solar energy sector. The country is likely to continue expanding its solar capacity, investing in technological innovation, and promoting sustainable energy practices (Fang 2023).

Several scholarly sources provide crucial insights into the evolving solar energy landscape in China, revealing a complex interplay between environmental needs, technological development, economic interests, and political maneuvering. In their seminal work, Zahoor et al. (2022) examined China's solar energy policies within the framework of their wider environmental goals, highlighting the country's commitment to renewable energy as part of its pledge to become carbon–neutral by 2060. The authors emphasized that national policy, often responding to international pressure, significantly influences China's solar energy growth. In a different approach, Zhou et al. (2021) delved into the geopolitical implications of China's dominance in the global solar PV manufacturing sector. Their analysis highlighted the global interdependencies and potential conflicts stemming from China's leading position in the sector.

Zhang and Chen (2022) provided an overview of technological innovations and advancements in China's solar energy sector. The authors found a rapid increase in the efficiency of solar panels manufactured in China, which has helped reduce the cost of solar energy and spur its increased adoption. On market dynamics, Yao et al. (2023) explored the impact of global solar energy market fluctuations on China's economy. They concluded that although China is a major player in the sector, it is not immune to global market pressures, including shifts in demand and pricing. Gao and Chen (2023) addressed the environmental sustainability of China's solar energy expansion. They found that although solar energy significantly reduces carbon emissions, the manufacturing process of solar panels and disposal of end-of-life panels can still lead to considerable environmental impact. A similar conclusion was reached by Huo et al. (2022), who investigated the life-cycle environmental impacts of solar energy in China. They emphasized the importance of developing efficient recycling systems for solar panels to minimize their environmental footprint.

Irfan et al. (2021a) offered an insight into public attitudes towards solar energy in China, indicating a generally positive view, but highlighting the need for further education and public engagement to increase the adoption of solar energy in residential areas. In a broader societal context, Bai et al. (2020) analyzed how the adoption of solar energy could influence job creation and economic inequality in China. Their study suggested that while solar energy development does create new jobs, it may also exacerbate regional and urban–rural inequality.

Research methodology

RETScreen and MATLAB simulations are powerful tools used in the field of solar energy for calculating power generation at different locations. RETScreen excels in user-friendliness, data accessibility, and quick project assessments, making it suitable for decision-makers and project developers (Ferrari et al. 2019). MATLAB, on the other hand, offers greater customization, advanced modeling capabilities, and extensive data analysis tools, making it a valuable tool to explore and optimize complex solar energy systems (Ozgur et al. 2017). In China's six largest cities (Wuhan, Nanjing, Chongqing, Nanchang, Sanya, Guangzhou), monthly data on sun irradiance were gathered and shown against 1 kW PV for one year in 2022. After graphing the data versus PV, computations were conducted. The simulation findings have been presented in the form of the average power generation on a monthly basis in all six cities. Monthly solar cell power production is displayed in Fig. 1 through Fig. 6. In addition, an LCA was undertaken to evaluate the various characteristics of solar energy. Conducting LCA as a research methodology offers several significant benefits.

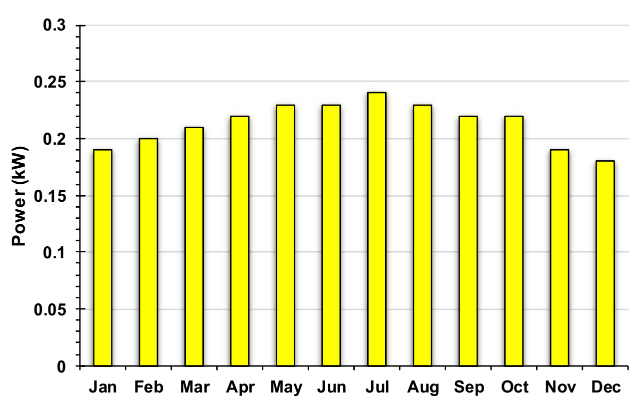

Fig. 1 Power generation of the solar cell in Wuhan

LCA is a systematic approach to evaluating the environmental, social, and economic impacts of a product, process, or system throughout its entire life cycle, from raw material extraction to production, use, and disposal (Khan et al. 2021). Utilizing this technique, analysts estimated the future energy flows of a sector based on economic development and legislative considerations.

There have been multiple LCA applications in various energy contexts, such as polymer solar cell modules, land usage and power generation of PV, solar module disposal, and metallic utilized in new PV systems (John et al. 2021). Scholars have examined several characteristics of solar PV which includes cost, fuel usage, average lifespan, service, and operating costs, land needs, and greenhouse gas emissions. The economic feasibility (ECF) of solar technologies and the levelized cost of electricity (LCE) were emphasized. In the present study, LCE was utilized to calculate the power cost produced by PV for residential applications. Various dimensions (energy voltage, the effectiveness of PV, PV area, the energy rating, current, the PV's life, the PV's capital cost, temperature, rate of inflation, the battery performance, battery cost, and the battery life) were also considered when determining the ECF of a PV system.

Table 1 Price of individual solar photovoltaic (PV) system parts

Parts	Amount	Price (USD)	% Share of the price
Battery	1	200	18
PV panel	1	63	6
Circuit breaker	1	4	0.35
System controller	1	6	0.53
Inverter	1	3	0.26
Civil work	-	11	1
Charge regulator	1	4	0.35
Maintenance and operation expenses	-	45	4
Battery replacement	4	800	71

Table 2 Solar energy life cycle assessment (LCA) parameters

Parameters	Solar panel
Price	USD 0.04/kWh
Average life duration	25 y
Consumption of fuel	Nil
Land use	2.2–12.2 acres/MW
CO_2 emissions	Nil
SO emissions	Nil
NO emissions	Nil

Analysis and results

Life cycle assessment (LCA) analysis of solar energy

Levelized cost of electricity (LCE)

LCE is an essential statistic for analyzing the cost of energy produced through any source. The following equation determines the LCE/kWh of PV systems operating alone (Sadiqa et al. 2022):

$$LCE = \frac{\sum_{k=1}^{n} \frac{I_k + M_k + F_k}{(1+d)^k}}{\sum_{k=1}^{n} \frac{E_k}{(1+d)^k}} \quad (1)$$

Here, I_k represents the investment cost, M_k represents the maintenance cost, F_k represents the fuel cost, k represents a year, E_k represents the quantity of energy produced in kWh, d represents the discounted rate, and n represents the working life of the technology (Abdelhady 2021). Regarding the cost of solar energy, batteries account for 18% of the overall cost of installation, whereas the cost of PV modules accounts for 6%. A conventional PV system is predicted to have a 25-year average lifespan. Nevertheless, batteries must be replaced every five years since their typical lifespan is five years (Ahmed et al. 2022), with the battery price accounting for 89% of the total cost of ownership of a PV system throughout its entire existence. China's major cities are plagued by serious pollution issues (Zia et al. 2021). The efficiency of PV panels is dramatically reduced by dirt and pollution. Thorough maintenance of photovoltaic panels, which imposes substantial service and operating costs, is essential for overcoming this issue. The cost of the PV system as a whole is affected by additional parts such as the inverter, charge regulator, circuit breaker, and system controller (Tahir et al. 2021). The cost of all PV system components is shown in Table 1. The LCE of the PV system was determined to be \$0.04/kWh using an Equation (Khosa et al. 2020).

Considering all elements of solar energy, Table 2 reveals that a 1 MW PV power plant needs between 2.2 and 12.2 acres of land and does not generate CO2 emissions while generating power. The outcomes are in line with the earlier investigation (Soomro et al. 2019).

Economic feasibility of PV system

An essential financial parameter for evaluating the ECF of a PV system is the net present cost (NPC). NPC is defined as "the value of all the costs incurred by a PV system throughout its complete lifecycle minus the value of profits earned over the lifecycle of a PV project." The following expression represents NPC (Irfan et al. 2020a):

$$NPC = \frac{C_{a.tot}}{CRF(i, Rproj)} \quad (2)$$

Here, $C_{a.tot}$ represents the yearly cumulative cost, *CRF* represents capital recovery factor, *i* represents the interest rate, and *Rproj* represents the lifecycle of a project (N). The CRF is computed by employing Eq. (3):

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (3)$$

$$i = \frac{i_{o-f}}{i+f} \quad (4)$$

In this equation, i_o represents the NIR, while *f* represents the INR. The rising INR diminishes buying power, making PV less cheap. If there is a greater INR, then the solar sector will develop less. Using Eq. (5), kWh's PV power production potential is calculated (Waris et al. 2022):

$$S_{pv} = P_{pv}E_{pv}S_tPR \quad (5)$$

Here S_{pv} is PV's power generating capacity. P_{pv} represents panel area, E_{pv} represents efficiency, S_t denotes the yearly solar irradiations, and *PR* denotes the performance ratio used to control costs. E_{pv} is computed using Eq. (6) (Irfan et al. 2019a).

$$E_{pv} = S_e\left[\lambda_t\left\{A_t - R_t + \left(N_t - E_{a.n}\right)\frac{S_R}{S_N}\right\}\right] \quad (6)$$

Here, the PV efficiency is indicated by S_e, temperature by λ_t, ambient temperature by A_t, referenced temperature by R_t, the nominal operating temperature of PV cells, and ambient nominal operating temperature by N_t and $E_{a.n}$. S_R indicates solar irradiation, and S_N indicates solar irradiation for the nominal operating temperature of the PV cell. Temperature is a crucial factor for calculating the ECF of a PV system since optimal temperature gives the optimal tilt angles that reduce the PV system's LCE (Liang et al. 2022). The entire amount of power produced and required by a PV is shown in Eq. (7):

$$Electricity\ difference = \sum_{i=1}^{365}\left(E_{pv_i} - E_{d_i}\right) \quad (7)$$

In this equation, *i* represent the days, whereas E_{pv_i} and E_{d_i} indicate the total amount of electricity generated and demanded on that day. The essential yearly electricity preserved into a battery E_b is shown in Eq. (8) as follows:

$$E_b = \left(\sum SE - \sum DE\right).b_e \quad (8)$$

In this equation, extra electricity is denoted by *SE*, while electricity deficit is shown by *DE*, and the efficiency of the battery by b_e. On the other hand, the daily storage capacity of the battery B_d is computed as follows:

$$B_d = \frac{E_b}{365} \quad (9)$$

In this study, the ECF for residential usage was assessed by using Eqs. (2) through (9). It was discovered that the solar panel has a surface area of 1.2 m^2 and that its highest current and voltage are 7.65 A and 29,5 V. Ali et al. (2022) showed that solar panel with a 200-W generation capacity might easily power a single home. A 200-W solar panel with a 16% alteration efficiency and a battery of 140 Ah/12 V is sufficient to power a single residence. Nevertheless, the batteries lose their capacity with time and must be replaced. The simulation of the parameters is shown in Table 3.

Simulation results

For data analysis and the modelling of outcomes, we used RETScreen (version 6.0) and MATLAB (version R2019a). MATLAB is a widely used data analysis and visualization application. The program is dependable, effective, and readily generates computational codes. In contrast to standard programming languages, it easily examines and implements complicated algorithms. It offers robust, built-in algorithms for doing complex calculations. In addition, it has graphic instructions that enable the quick depiction of findings. RETScreen may similarly classify, analyze, and enhance future solar power installations' technical and financial feasibility. In addition, it evaluates and verifies the accurate results of facilities and identifies further power generation opportunities, resulting in more reliable results (Owolabi et al. 2019). We have utilized RETScreen and MATLAB for data analysis because of these advantages.

Table 3 Characteristics used in this study

Characteristics	Unit	Value
Area of panel	m^2	1.2
Power voltage: maximum	V	29.5
Power current: maximum	A	7.65
Solar panel efficiency	%	16
Solar panel power rating	WP	200
Panel life duration	Year	25
Capital cost of PV	USD/WP	105
Battery efficiency	%	85
Battery cost	USD/Ah	95
Life duration of battery	Y	5
Nominal interest rate (NIR)	%	6
Referenced temperature of PV	^{0}C	25
Inflation rate (INR)	%	12

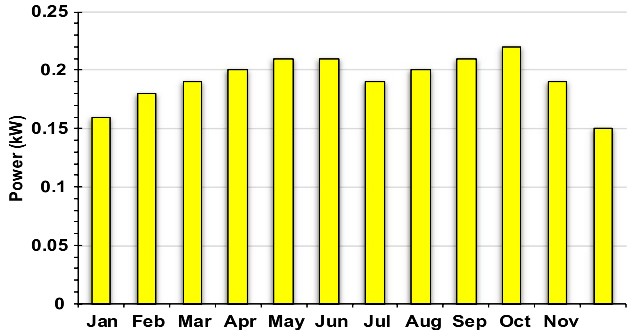

Fig. 2 Power generation of the solar cell in Nanjing

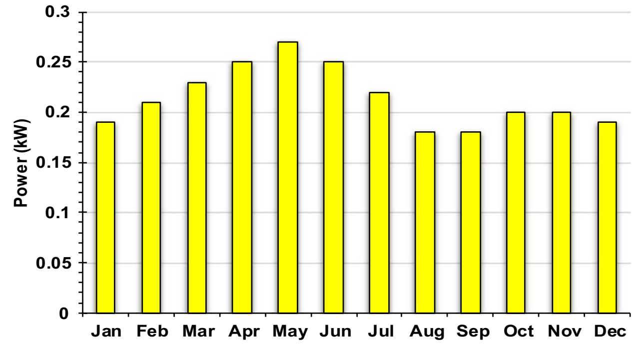

Fig. 4 Power generation of the solar cell in Nanchang

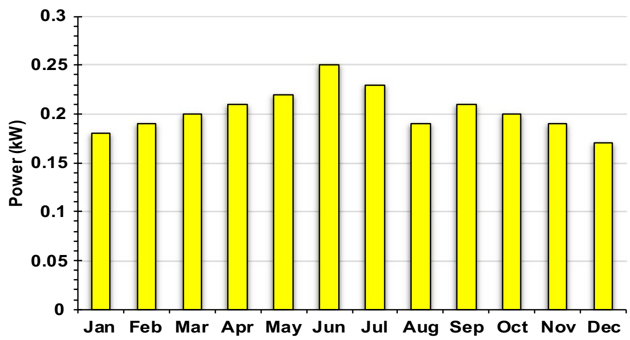

Fig. 3 Power generation of the solar cell in Chongqing

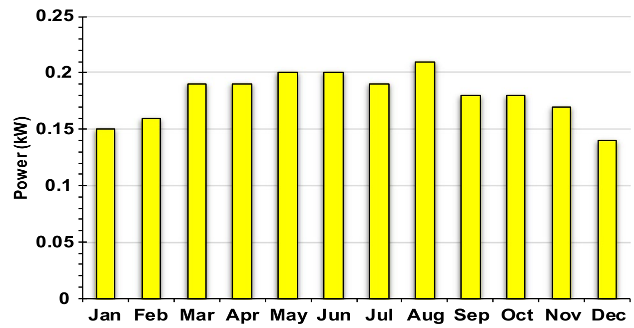

Fig. 5 Power generation of the solar cell in Sanya

To determine the exact locations of the sun's highest intensity in the measured regions, we used China's map of solar radiation (Irfan et al. 2020a). Simulation results have been presented as average monthly energy production (AMEP). Figure 1 depicts the study of AMEP from PV in Wuhan. Figure 1 demonstrates that in Wuhan, a 1 kW PV produces a 0.24 kW of electricity maximum in the month of September and minimum 0.18 kW energy in December. Except for winter, the city gets abundant sunshine over the year, making solar energy a viable option (December, January). Figure 2 shows the AMEP study of Nanjing's PV. Simulation outcomes indicate that a 1 kW PV generates 0.22 kW energy maximum in October and produces a minimum energy of 0.15 kW in December. Solar energy is an ideal energy source for Nanjing throughout the remainder of the year, despite the city's PV power output drastically decreasing during the winter.

As seen in Fig. 3, simulation results indicate that solar PV generates an enough energy in the city of Chongqing and is acceptable for use for the whole year. However, power generation decreased in December owing to lower solar irradiations. The AMEP research reveals that in June, not more than 0.25 kW of electricity is generated, whereas a minimum of 0.17 kW energy is generated in December. Figure 4 depicts the results of AMEP extracted from PV in Nanchang. In Nanchang, 1 kW PV generates not more than 0.27 kW in May and not less than of 0.18 kW in August and September. Usually, solar PV can meet the city's power needs throughout the summer months. According to the monsoon season, the city gets reduced sun irradiation throughout August and September.

Likewise, simulated findings (Fig. 5) show that in Sanya, a 1 kW PV generates not more than 0.21 kW in August and not less than of 0.14 kW in December. During five months (March, April, May, June, and August), the city gets abundant solar irradiation, which is ideal for meeting the electrical demands of families. The results of the simulation in Guangzhou are shown in Fig. 6. The AMEP research showed that the highest amount of electricity generated was 0.23 kW in July and the lowest amount was 0.17 kW in January. The average power stays over 0.20 kW for four months (May, June, July, and October). Alternatively, solar power decreased somewhat throughout November, December, and January.

Discussion

Energy problems have seriously hit China's economy. A sufficient energy supply is essential for a nation's sustainable economic growth and offers a vital stimulus for all facets

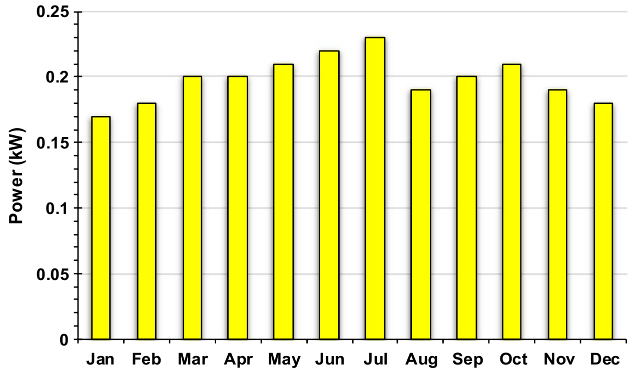

Fig. 6 Power generation of the solar cell in Guangzhou

of existence (Liu et al. 2021). There is always a close relationship between GDP per person, energy consumption per person, and style of living. Greater energy consumption per capita is related to fast economic growth. In contrast to affluent nations, China has a poorer per-capita income, per-capita usage of energy, and GDP, severely impacting its socioeconomic growth. It is difficult for the Chinese economy to advance without appropriate energy generation and consumption. The nation has various obstacles in achieving the highest opportunity for its power industry, the most significant of which is the industrial sector's lack of access to fuel. The insufficient supply of fuel has increased the price of energy production. The financial performance of government distribution companies (discoms) has also been negatively impacted by declining operational efficiency and mounting indebtedness (Saleemi 2023a, b). The situation will deteriorate further if the nation continues to depend on traditional energy sources.

The results of this study indicate that solar power may be used as a practical energy source in the areas analyzed. Globally, PV provides sufficient energy to power all six cities. In these locations, a 1 kW PV system generates not more than of 0.27 kW and not less than of 0.14 kW daily, according to the simulation findings. Daily, 0.20 kW of power may be created to help reduce electricity shortage times and reduce the pressure on the nation's energy infrastructure. Nevertheless, there are also difficulties. For example, huge PV power plants require enormous batteries whose capacity diminishes over time. Batteries are costly to replace and place a major strain on the government budget. Dirt and poor air quality are important issues in China's main cities (Rehman et al. 2020). Several weeks after deployment, PV power plants lose up to 30% of their energy production due to dust particle deposition (Rehman et al. 2019). Cleaning regularly of photovoltaic panels is needed at least every other day, which is prohibitively expensive for a nation like China. Furthermore, the complete absence of a comprehensive policy framework and renewable purchase obligation (RPO), greater rates of interest of solar energy plants, extremely high expenditures (Primanthi and Kalirajan 2023), improper eligibility requirements of choosing development companies, costly panels, bank debt, corrupt practices, misappropriate of the bureaucratic system, inefficient taxation system, insufficient infrastructure, complexity in acquiring land, poor roadways, the ineffective transmission and distribution (T&D) connection, the improper billing process, and lacunae in the regulatory framework all hinder the growth of solar energy (Shah et al. 2018).

According to the research results, China's solar power sector must be developed for four significant reasons. First, most of China's energy generation system relies on fossil fuels, which not only harm the environment but are also quite expensive and put a tremendous strain on budgetary resources. The Chinese economy cannot support such an enormous cost. Therefore, the nation's future supply of fossil fuels is questionable. Second, the prior strategy of relying on fossil fuels for power generation collapsed since it did not achieve the desired results in addressing the country's energy shortage concerns. China has been ranked among the most climate-vulnerable nations. Continuous dependence on fossil fuels may enslave the nation to climate change, which is unacceptable. Due to rising awareness and technological advancements, solar power is being increasingly invested in throughout the world. China has an abundance of solar energy resources. If the resources of energy are adequately used, it can resolve any energy difficulties.

Conclusion and policy implications

Energy is the foundation of a nation's socioeconomic progress. China's principal sources of energy are fossil fuels. Fossil fuel prices fluctuate regularly. In light of recent economic and large population growth, electricity consumption has increased, leading to a deficit (Ummadisingu and Soni 2011). The nation's deficiency of 1062 MW at the end of 2019 (Liang et al. 2022) has adversely impacted the residential and commercial sectors. Globally, politicians and authorities are searching for alternate energy-generating methods to alleviate energy scarcity issues. The authors evaluated China's possible renewable energy options in this research and picked the country's solar resources. During 2019, solar irradiation data was gathered for one year in six major cities of China: Wuhan, Nanjing, Chongqing, Nanchang, Sanya, and Guangzhou. Data processing and PV efficiency assessment were performed using MATLAB and RETScreen. Solar power is an ideal option in these places because they are situated in an area where year-round sun irradiation is steady, according to the findings of this study (except for winter and monsoon season). Such locations' weather conditions and geography have proven favorable for solar energy uptake. Through LCA research and investigation of the many characteristics of solar energy, it was determined that the cost of producing 1 kWh of solar power is just USD 0.04. A 1 MW PV power plant requires between 2.2 and 12.2 acres of land. Twenty-five years is the average lifespan of PV panels. Nevertheless, dirt and contamination may rapidly reduce the efficiency of PV panels. In consequence, the frequent cleaning of PV panels incurs enormous costs.

For the rapid growth of China's solar sector, it is suggested that local manufacturing facilities be enhanced via ongoing R&D to minimize operational expenses and reliance on expensive batteries and imported solar panels. To expedite the development of a project, quick allocation of adequate capital and subsidies is essential. In wealthy nations, there are several costly methods for maintaining PV panels, such as mechanized washing. The authorities could explore implementing the manual method of maintaining PV panels in China, where human resources are very inexpensive. PV panels must be cleaned three times per week and washed once per month in the locations surveyed to retain their effectiveness. Rapid solar energy growth demands a robust and proactive policy framework. The government ought to formulate a national policy that is broad and coherent. RPO should be implemented on a nationwide scale. The financing rate on solar energy projects should also be cut to encourage local and international entrepreneurs to participate in solar power programs. Solar energy initiatives are capital-intensive and need substantial initial expenses. The government ought to provide smaller entrepreneurs with cheap and long-term funding until the substantial up-front expenditures recoup. Technological advancements have made PV installations more viable (Irfan et al. 2020a). Rather than the lowest and highest capacity, entrepreneurs' selection criteria should depend on their financial health and track history.

Additionally, people, purchasers, and energy groups should have access to inexpensive solar panels. The problem of bank loans must be addressed. It should be suggested that financial institutions such as banks set up specific lending restrictions for projects involving solar energy. For sustained growth, the system must be open and devoid of corruption. Every government program should have appropriate democratic accountability, the authority of the bureaucratic system should be stable, and an efficient taxation system should be incorporated, stipulating that development teams and purchasers are subject to tax holiday breaks and accelerated depreciation for the development of solar power initiatives. Solar energy infrastructure in China needs considerable upgrades. Land purchase is expensive and requires approval from many government agencies. A notable lack of openness exists in the land purchase process.

The land purchase procedure should be streamlined. This may be accomplished by reducing administrative procedures and using acceptable acquiring land methods. Nevertheless, many nations globally face comparable difficulties. Infrastructure should be constructed to safely transit photovoltaic panels and associated materials to the locations of new solar power plants. To reduce T&D losses, the outdated and ineffective T&D network must be upgraded. In particular, due to expensive solar cells and local modules and poor excellence, an adequate payment management system should be created. Cooperation with international organizations and nations knowledgeable in solar power technology is crucial, but it must be based on shared advantages. Based upon the findings, this report may serve as a suggestion to expeditiously grow the solar power sector and increase the proportion of solar energy in the nation's overall energy mix. Nevertheless, securing adequate early investment, which often requires subsidies, is a crucial challenge.

Author contribution K. H.: conceptualization, writing-original draft, methodology, formal analysis, data handling. S. C.: methodology, writing-review and editing, writing-review and editing, supervision, funding acquisition, variable construction.

Data availability All data generated or analyzed during this study are included in this article.

Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

Consent for publication Consent is given for publication.

Competing interests The authors declare no competing interests.

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