



Assessing the socio-economic viability of solar commercialization and electrification in south Asian countries

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Abstract

Solar power is a promising alternative energy source for a sustainable environment for developing countries in the Asian continent. The assessment of its sustainability particularly in the South Asian countries necessitates a complete and rigorous statistical investigation. In the current study, we investigate solar energy profile and potential in Pakistan's Sindh province as a case study. Although the electrification of Sindh Province using off-grid solar PV systems is relatively easy and also most convenient, the challenge is to measure the province's capacity of solar power and its economic viability. Results show that the rural areas of Pakistan have sufficient solar irradiance in order to produce power. The suitable inclination angles of solar power modules contain the significant capacity of solar power for electricity production. Finding regarding economic viability shows that an off-grid solar photovoltaic system ensures the electricity at price of PKR 6.87/kWh while this is cheap source of energy as compared to traditional energy source (about 20.79 PKR / kWh). Furthermore, the system of off-grid solar photovoltaic could reduce, 119,000 metric tons of CO₂ per year simultaneously it ensure the all remote rural areas implement the off-grid solar energy system. The study provides a useful renewable roadmap for energy in South Asian countries and those presently captivating distant and off-grid regions.

Keywords Remote rural areas · Electrification · Off-grid solar system · Economic viability · CO₂ reduction · Sindh

1 Introduction

The World will face great energy shortage due to growing population and higher energy consumption. Simultaneously, the world community is facing the greater depletion of fossil fuel. Energy is the major element of economic growth and social wellbeing of any society. Approximately, 1.1 billion individuals are living a life without availability of clean and cheap electricity, while most individuals are from the pastoral regions of Sub-Saharan

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Africa and South Asia (Sánchez-Lozano et al. 2016; U.S. Energy Information Administration 2017). Similarly, Pakistan as many other South Asian economies has been fronting a severe power shortage from previous decades. Continuously increasing residents of Pakistan surviving in pastoral regions do not have access to sufficient energy. Pakistan is an emerging country having social and economic growth difficulties necessitating continuous energy stream. Presently, the overall energy importunity is concluded by 25,000 MW which is predicted to grow up to 40,000 MW through 2030 (Jun et al. 2014). However, the power stream in Pakistan is almost 17,000 MW, although capacity desired to fulfil demand is 25,000 MW which caused the power scarcity of 8000 MW. Therefore, energy shortage in populated area is assorted from 12–18 h per day (Soomro et al. 2019). Furthermore, 70% population of country's residents live in 50,000 rural areas and distribution lines. Approximately, 105 million individuals of Pakistan (around 58% people) consume biomass for household because of insufficient energy and gas stream (Perwez et al. 2015). Alternatively, the power sector faces several problems containing insufficient stream line shortages, collection rates, heating oil, and network. Devouring these problems, it would be actually expensive and difficult to attach rural areas with the state grid station. Presently, gas subsidizes 45% to Pakistan's power production, trade in oil underwrites 35%, coal 6%, hydro power 12%, and nuclear power at 2% (BP 2017). Consequently, reusable energy is actually ranked first in accumulation to increase the capability of the prevailing power grids (Barton and Infield 2004).

Sindh is one of the four provinces of Pakistan, bordering Baluchistan to the west and India to the east, currently utilizes wide range of fossil energy resources.

Yet many remote parts of Sindh province has no access to electricity for days (Sánchez-Lozano et al. 2014) especially for 48% residents of the rural areas (Zubair et al. 2019). Having low electricity requirements in these villages between 50 and 100 W per household, the demand in the rural areas is low compared to cities and towns. Moreover, the fossil fuel energy consumption adds an economical and less sustainable energy option in the remote rural areas which adds additional cost. In addition, no participation of private investment exists in rural Sindh regions because of the lack of infrastructure and low potential for rapid development. Based on these factors, off-grid solar power could be regarded as the best option for electricity production in Sindh province. Further, the availability of solar irradiance in the regions throughout the year is high (Siddiqi et al. 2018). Sindh contains an enormous solar capacity over 300 sunny days with an annual global horizontal irradiation of 1800–2200 kWh/m² (Ashfaq and Ianakiev 2018; Stöckler et al. 2016). Various studies are concerned with the association of energy, economic and environmental issues such as Anser et al. (2020), Mohsin et al. (2019c, 2020a), Iram et al. (2019), and Iqbal et al. (2019).

Several researchers have also suggested an off-grid solar energy system as a way forward to the energy needs in countryside village areas since it does not involve fuel transport cost and has relatively easy installation (Uyan 2013). It was also stated that the off-grid solar energy is a suitable and local environmental benefitted energy option in the village areas (Effat 2013) including quite operation and low CO₂ emissions; therefore, huge amount of finance is needed to install renewable energy projects (Sun et al. 2019b, 2020a, c, d). In another study (Alami Merrouni et al. 2018), authors observed that the deployment of PV systems improves people's living standards which enhances the socio-economic situation especially in the rural area (Al Garni and Awasthi 2017). Existing policies are ineffective to achieve complete electrification of rural regions of Sindh. In order to evaluate the solar energy potential and its economic viability, regional feasibility of specific research is needed. Currently, no such studies have been reported for the province of Sindh.

Therefore, in the study, first, we investigated solar power potential of different village areas of the province. Second, assessed the economic viability of the rural areas and approximates the CO₂ emissions to be reduced. Third, proposed a model that shows significant differences in terms of robustness of the results as compared to previous studies. Fourth, discussed the emission benefits of the solar systems. Fifth, not only conducted an empirical estimation of solar characteristics, but also presented a comparative study of proposed sites. Sixth, we recommended a policy for decision makers so that transition towards renewable energy resources can be done smoothly and ensure the climate change mitigation. Hence, this study would also help policymakers to propose effective rural electrification programs using PV systems for Sindh province, and also encourage the unwilling stakeholders to invest.

Remaining paper is constructed as follows: Section two explains the electricity background in Sindh province, and Sect. 3 describes methodology while section four contains data sources. Section five explains results and discussion, and Sect. 6 contains conclusion and policy implication.

2 Background

Sindh province is the second largest economy in Pakistan. Location of the province of Sindh is of strategic significance because of its long coastline. Karachi provides an economical and shortest route to the neighboring countries for cargo transfers. Due its prime location, the port attracts foreign investments, development projects and leading to economic growth in general (Gondal et al. 2018).

At present, 28 solar power projects of 956.8 MW total capacities are under development. Independent power producers (IPPs) have been awarded with upfront tariff by National Electric Power Regulatory Authority (NEPRA) for 472.48 MW. 7 projects of 72.58 MW are in the process of getting financial agreements (Shiva Kumar and Sudhakar 2015).

The US (NREL), US AID, Alternative Energy Development Board (AEDB) are associated with each other and they supported a comprehensive evaluation of Pakistan's solar power capacity. Their collaborative research findings show that the state has the capacity of 1500–3000 luminous (Muhammad et al. 2017). The availability of usual comprehensive padding ensures the 19 to 20 MJ/m²/day having the normal 8–8.5 sunlight hours/day. Also, the Baluchistan is plentifully ironic in solar power. These standards of insulation are measured as the upper standards at international level (Fig. 1).

The USAID report shows that Pakistan, contains extended bright days, which is profitable for construction of solar power plans (Mohsin et al. 2018a; Al Asbahi et al. 2019). The estimated solar power potential shows that 1600 GW power yearly that is added 40 times more than the present power generation volume (Bozkurt and Karakilcik 2015). The major portion of energy generation containing the sector wise contribution of 33.6% with gas, 32.1% from oil, hydropower 26.1, 5.7% from nuclear sources, renewable energy sources 2.2 and 0.2% coal (Kalhor et al. 2019). The Sindh province of Pakistan contains enough sources of wind, solar, and micro-hydro-projects which can be used to produce electricity. Conversely, the management of Sindh has not contributed an extensive effort to the increase of request for power. The renewable energy strategy was conscripted in 2006 but the policy was not successful because of government's and administrative lack of interest (Fig. 2).

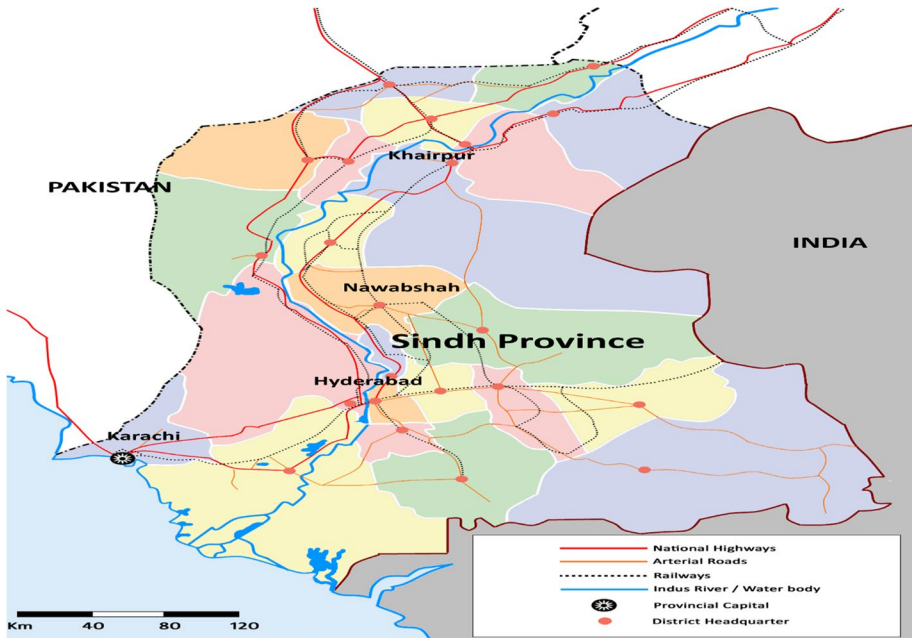


Fig. 1 Sindh province map (Source: Google map)

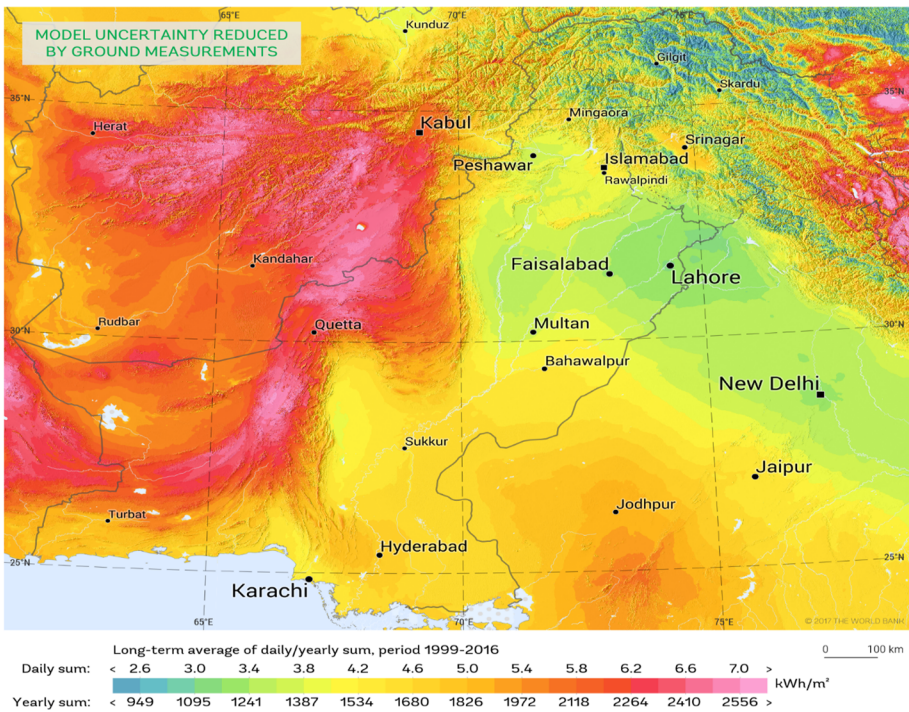


Fig. 2 Pakistan Direct Normal Irradiation Map (World Bank Group 2017)

Alternative energy development board (AEDB) intends to install solar photovoltaic systems in rural houses. This development is as a result of government's hope for socio-economic development and environmental conservation in rural areas solar energy framework. Figure 3 presents the key region in Pakistan's electricity sector (Government of Pakistan 2006). Against the backdrop of environmental degradation and rampant climate change, people across the globe are incessantly moving forward to find sustainable solutions to these problems. The green economy, in this regard, is treated as an effective source of achieving sustainability, as it emphasised on the preservation of economic resources, economic growth and environmental friendless (Huntington 2015). Focusing on the significance of the green economy, a deep analysis of the determinants of its growth is considered significant. In this connection, change in the public spending is considered as the key indicator for this study. The actual government spending lies between 20 and 45% of the GDP (Aly et al. 2017). Further López et al. (2011) conducted a panel data analysis taking 38 countries which claims that if the share of public spending on public wellbeing increases by 10%, the emission of sulfur dioxide and concentration of lead would be reduced by 4 and 7%, respectively.

National electric power regulatory authority (NEPRA) confesses that installation of ultra-voltaic structures is substantially low in remote areas of country. To overcome this issue, organizational coordination is essential for the success of solar photovoltaic program in villages and in remote areas (Aydin et al. 2013). At the start of 2006, there was no organizational setup for the planning and development of such projects. Later on, to fill up this gap, AEDB and PCRET was established but still re-developed organizations failed to plan and execute the innovations of solar photovoltaic electrification strategies and polices especially for remote areas of Pakistan. Cost of upfront of development and tariffs was the leading hurdles in this progress as photovoltaic panels during its financial budget 2014–15, and it was considered a huge setback on the progress of solar photovoltaic energy (Anwarzai and Nagasaka 2017). Although later on, government realized the importance of solar energy by reducing tariff on solar panels, yet many hurdles like high tariff (50%) on solar inverters and batteries are still prevailing. Currently, researcher of the leading institutes suggests that governments should install solar power projects especially in rural areas of the country (Mohsin et al. 2020b).

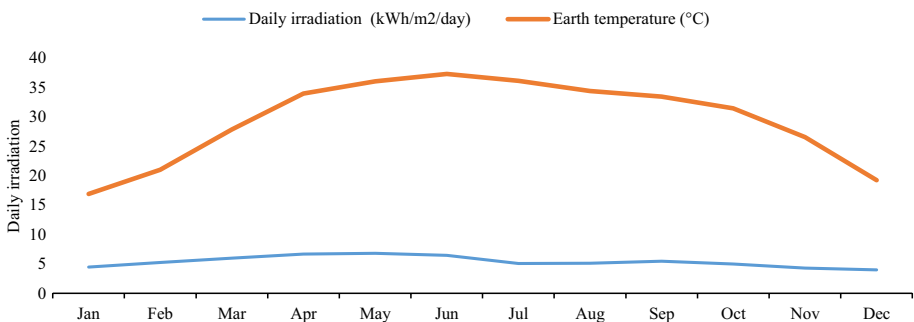


Fig. 3 Solar irradiance of Badin Region

3 Research framework

3.1 Capacity of solar irradiation

Generally, the solar systems technology can be divided into two categories: (i) solar thermal technology and (ii) photovoltaic technology (Su et al. 2017). Photovoltaic technology converts sunlight into electrical energy, a technology widely used globally. The photovoltaic modules are made of crystalline, organic materials, and quantum dots, whereas solar thermal technology converts radiation into thermal and electrical energy (Redlinger et al. 2015) using PV and thermal module. Therefore, maintaining the optimal angle of the solar panels is needed to increase the solar power output. Installation of solar trackers helps altering the angle of the solar boards along the path of sun's radiation, thereby improving the performance. However, these solar trackers are expensive and energy intensive (Liu et al. 2017). Therefore, it is more suitable to manually change the solar panel's title angle. Many methods have been used in order to calculate the solar irradiance (Charabi and Gastli 2011; Doljak and Stanojević 2017). In this study, we also calculate the tilt angle by considering a tilted surface I_G^T is described as:

$$I_G^T = I_B^T + I_D^T + I_R^T \quad (1)$$

where I_B^T is direct beam, I_D^T shows the diffuse irradiation, and I_R^T shows the solar panel reflected rays on a tilted surface. The fiscal spending regarding renewable and R&D impact the green economic growth positively. These positive impacts show that both the composition and technique effect are present in the estimated scenario. This coincides with the study of Shahbaz et al. (2018) which states that toxic emissions can be reduced to a great extent by increasing spending on public goods. Besides, from the estimation results it is observed that coefficient of fiscal spending on education is almost double the coefficient of fiscal spending on R&D. For example, G_B represents the ratio for the mean value of daily direct beam and then I_B^T can be transformed as,

$$I_B^T = I_B G_B \quad (2)$$

G_B is a geometric parameter (Liu and Jordan 1961) which is utilized for computing G_B . The growth of fossil fuels ensures that there is enough room to develop. To reduce the risk of politics and terrorism, multiple oil sources should be used to ensure a safe and reliable oil supply to enhance energy security. Oil-importing countries should rely on the USA, Canada and Russia instead of the Middle East and Africa by actively adjusting their trade strategies. In any case, this conceivable energy scheme is assessed and criticized due to over-compromised and dismissing these prating control among the measurements such as energy security, energy equity and environmental sustainability (La Viña et al. 2018; Sun et al. 2019a).

$$G_B = \frac{\cos(L_1 - T_1) \cdot \cos Dsh \cdot \sin i_{ss} + i_{ss} \cdot \sin(L_1 - T_1) \cdot \sin Dsh}{\cos L_1 \cdot \cos Dsh \cdot \sin i_{ss} + i_{ss} \cdot \sin L_1 Dsh} \quad (3)$$

where L_1 is the latitude, T_1 is the tilt angle, i_{ss} and Dsh shows the declining angles? Meanwhile, the impact of fiscal spending in the form of R&D on solar progress shows that green development is influenced by state's spending on Research and Development. Meanwhile, Paramesh et al. (2018) studied how the use of fiscal instruments influenced the Asian countries in their evolution to green economic phase. They stated that Asian countries are slow

in accepting the fiscal tools to materialize this green economic transition. They suggested for country specific determination of fiscal tools for reaching the green economic objective. From the available literature, it has been observed that there are some studies conducted on the nexus of public expenditure and the reduction in environmental pollution and it can be defined as,

$$I_D^T = I_D \frac{(\cos(\lambda) + 1)}{2} \tag{4}$$

The range of albedo factor ω can be computed as:

$$I_R^T = \omega(I_B + I_D) \frac{(-\cos(\lambda) + 1)}{2} \tag{5}$$

3.2 The economic feasibility of solar PV

3.2.1 Solar energy system size and its storage

PV cells usually consist of two layers of a semi-conducting material that converts radiation into electricity. This happens when radiation hits the cell, an electric field across the layers is created, causing electricity (DC current) to flow. Subsequently the inverter converts DC to AC for domestic usage. The electricity generated by a solar photovoltaic system is a function of solar irradiance in the region, whereas several other criteria, for example efficiency, optimal tilt, and maintenance of solar PV, should be well-measured (Anwarzai and Nagasaka 2017; Sliz-Szkliniarz 2013). In addition, it is important to solar power output in an inclined solar photovoltaic system. We collected solar irradiance data from NASA database. The capacity of solar system to generate energy and S_{pv} (kWh) is calculated by means of Eq. (6) (Okoye and Oranekwu-Okoye 2018).

$$S_{pv} = a_{pv} \cdot b_{pv} \cdot c_t \cdot PR \tag{6}$$

where a_{pv} shows the rectangle area, b_{pv} represents the efficiency, c_t shows the annual solar irradiation attained, and PR shows the losses. b_{pv} is calculated as (Okoye et al. 2016):

$$b_{pv} = b_r [1 - \lambda_r] T_A - T_R + (T_N - T_{a-N}) \frac{I_T}{I_N} \tag{7}$$

where b_r shows the efficiency of solar panels, solar panels temperature can be shown by λ_r , T_A shows an ambient temperature and T_R represents the solar panels referenced temperature, T_N characterized the minimal operating temperature and T_{a-N} recognize the ambient minimal operating temperature, I_N shows the solar radiation.

The solar PV front end's entire power generation and required is offered as,

$$\text{Electricity difference} = \sum_{i=1}^{365} (S_{pv} - S_d) \tag{8}$$

Solar energy can be used and causes the electricity surplus situation such as, $S_{pv} > S_d$ however, when the electricity demand is more than the supply of electricity then $S_d > S_{pv}$ battery annual requirement K_b is therefore:

$$K_b = \left(\sum SE - \sum SE \right) \cdot e_b \tag{9}$$

where SE shows the surplus electricity, SE represents shortfall electricity and e_b shows the battery efficiency and instantaneously, the storage capacity of battery C_b is considered as:

$$K_b = \frac{S_b}{365} \tag{10}$$

3.2.2 Solar power potential

We used an urban resource flow modeling tool developed by (Pattanasethanon et al. 2007) to measure the total solar radiation incident. They used weather model to measure the sky radiance distribution from diffused horizontal irradiance and the global horizontal irradiance. The model also calculates the solar incident from the sky and the sun. The radiation absorption and inter reflection has been simulated by radiosity-based algorithm (Santbergen et al. 2017). The average solar radiation incident Q_R (W/m^2) is calculated using Eq. (11); the irradiance Q_i (W/m^2) is measured on hourly basis at discrete points (indicated as ‘j’) at any given site, while the total surface area A (m^2) measures the total area incident solar radiation (Lou et al. 2016; Alonso-Montesinos et al. 2015).

$$Q_R = \sum (Q_{i,j}A_j)/A \tag{11}$$

and

$$P_{gen} = \eta_{gen} \times A_c \times E_s \tag{12}$$

The efficiency of the PV generator is denoted by η_{gen} and AC is the receiving area of PV panels and universal solar radiation is E_s . The productivity of PV producer is the purpose of ambient situation, and possessions of the PV cell are calculated using Eq. (13);

$$\eta_{gen} = \eta_{mod} \times \eta_{dc/ac} \times P_f \times N_{mod} \tag{13}$$

The PV module efficiency is η_{mod} ; electrical efficiency is denoted by dc/ac, η_{mod} shows the number of PV modules, and P_f is the full module factor. In Eq. (4), the photovoltaic module efficiency can be assessed through the following equation,

$$\eta_{mod} = \eta_{ref} \{ 1 - \beta(T_c - T_{ref}) \} \times \eta_{dc/ac} \tag{14}$$

where β is a magnitude of PV module efficiency as a function of temperature, and the efficiency reference of PV generator is denoted by η_{ref} , Cell temperature is T_c , $\eta_{dc/ac}$ is the converter the efficiency converter $\eta_{dc/ac}$ which is equals to 0.95 and P_f is the full module factor equals to 0.9. The temperature cell can be calculated by the following equation (Habte et al. 2016):

$$T_c = T_{amb} \times E_s \times P_f \frac{NOCT - 20}{800} \tag{15}$$

The total electric power produced by PV is estimated through the following equation.

$$P_{tot}(t) = P_{pvs}(t) + P_{Ws}(t) \tag{16}$$

The electricity produced by PV and wind generators are $P_{vs}(t)$ and $P_{ws}(t)$, respectively, after passing through the inverter. The optimum and significance temperature is 25° to generate electricity from the solar source (Xiao et al. 2014).

3.2.3 Levelized cost

Levelized electricity costs (LCOE) are the vital metrics used to measure the electricity costs generated through various sources and technologies. It gives priority to many selections' contingent on total productivity. In the present study, we compare the electricity produced by remote solar ultra-voltaic structures and traditional on-grid systems to measure the total electricity costs of both systems. Both alternative technologies with an estimated low electricity cost in a kWh unit is calculated using a simple LCOE formula (National Renewable Energy Laboratory 2018):

$$LCOE = \frac{\sum_{\alpha=1}^n \frac{I_\alpha + M_\alpha + F_\alpha}{(1+d)^\alpha}}{\sum_{\alpha=1}^n \frac{e_\alpha}{(1+d)^\alpha}} \tag{17}$$

where, I_α shows the investment cost, M_i displays the repairs cost, F_i characterizes the fuel cost, α displays the year a , e_i shows the amount of power formed in kWh, d represents promotional rate, and n determined the duration of employed. The cost (LCC) of solar power is calculated using Eq. (18). It considers the cost of installation (IC), annual capital cost (CC), the annual maintenance cost (MC), (Sun et al. 2020b), (Mohsin et al. 2018b, 2019a) and the replacement (RC) cost of the components.

$$LCC = IC + CC + MC + RC \tag{18}$$

where as the initial capital cost is calculated as;

$$CC_{PV} = CC_{PV} A_{PV} \left(\frac{i_r(i_r + 1)^{L_s}}{i_r(i_r + 1)^{L_s} - 1} \right) \tag{19}$$

where C_{PV} , A_{PV} , L_s and i_r are unit cost of the PV panels, area of PV array, interest rate and the life span of the project, respectively. The maintenance annual cost is determined by,

$$MC_{PV} = A_{PV} C_{MNT - PV} \tag{20}$$

MC_{PV} are annual maintenance cost of PV panel.

3.3 CO₂ emissions reduction from solar PV

In the pastoral regions, the administration should connect solar ultra-voltaic structures so that they can also help to remove the consumption of fossil fuel that can have greater amount of carbon which have a negative impact on the environment and human health. Solar energy produce no CO₂ emissions (Jabeen et al. 2014). The quantity of alleviated CO₂ releases and petroleum retained or saved F_k is dignified using Eq. (21),

$$F_k = S_{pv} \times F_R \tag{21}$$

where F_R indicates the fuel needed for a carbon based fuel producer to produce energy of 1 kWh. As the amount of CO_2 decreased is measured in kilogram (kg) and the CO_2 emissions saved EM_k is calculated using Eq. (22),

$$\text{EM}_k = S_{\text{pv}} \times (C_d - C_{\text{pv}}) \quad (22)$$

where C_d shows the carbon produced in kg required for a diesel producer in order to produce 1 kWh of electricity, and C_{pv} shows the carbon having the units of kg needed of solar PV system to generate 1 kWh of electricity.

3.4 Data

Data have been taken from different sources such as Pakistan Metrological Department Reports of Pakistan (Government of Pakistan 2006) and (World Bank data base for solar irradiation PV power of Pakistan). We used climatological data on the duration of sunshine, average minimum and maximum temperatures, and extraterrestrial radiation from different weather stations in Pakistan (Baloch et al. 2019) and from Global Solar Atlas. Data (collect form Pakistan Solar Radiation Measurement Data from energydata.com and Metrological department of Pakistan) was used to compute the solar power capacity and characteristics of the selected sites by using the proposed methodology. Mathematical analysis has been done using MATLAB and Microsoft Excel software sheet. The subsequent parameters estimations of solar irradiance have been evaluated through numerical assessment techniques.

4 Results and discussion

Research shows that temperatures in South Asia could reach unbearable levels by the end of the twenty-first century, and it is not possible to control the negative consequences of climate change without human intervention (Cagli et al. 2019; Malik and Umar 2019) such as the adoption of renewable and wind energy in the national energy mix (Mohsin et al., 2019a, b, c). In addition, ground source heat pumps, air source heat pumps and water source heat are increasingly used in Pakistan (Mohsin et al. 2018). The area of Nawabshah contains the maximum yearly solar irradiation having the amount of (5.49 kWh/m²) after that the region of Kambar contains the (5.48 kWh/m²), the region of Panoaqil contains the amount of (5.45 kWh/m²), area of Mirpurkhas has the quantity of (5.41 kWh/m²), whereas the region of Badin contains the solar irradiation up to (5.39 kWh/m²).

The amount of spending on renewable van increases the energy security. If a country's per capita GDP grows at a stable population level, this may be the result of technological progress, which will produce more results while maintaining the same population level, and ultimately affect the growth of the green economy. Global analysis of GDP per capita can help provide comparable insights into global economic prosperity and economic development. Both GDP and population are factors in the per capita equation. This means that the country with the highest GDP per capita may or may not be the highest.

4.1 Solar irradiation obtained at the optimal tilt angle

By using Eqs. (1)–(5), solar irradiation received from 0° to 90° tilted panels is shown in Figs. 3, 4, 5, 6 and 7 for each rural region. In Panoaqil, the solar energy production could be increased through 9.87 percent at the best tilt angle of 28.9°. Similarly, the area of Badin 9.98% at 29.1°, the area of Nawabshah 10.11% at 29.3°, Mirpurkhas 11.66% at 30.6° and 10.43% in Kambar at 29.5°.

It can be seen that the trend of solar irradiation increases in the month of May June July august and September, while October to March it shows the decreasing trend of solar

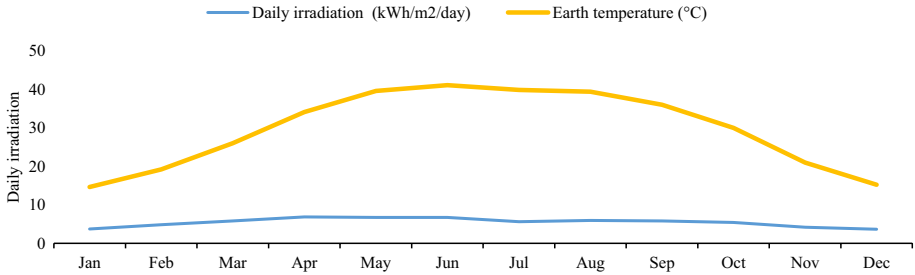


Fig. 4 Solar irradiation of Kambar

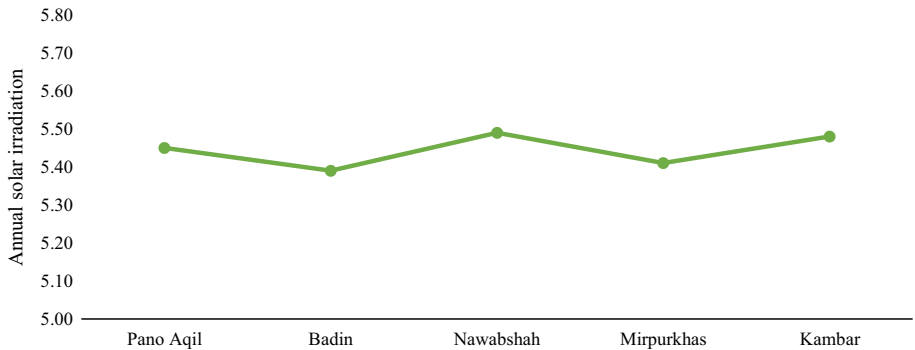


Fig. 5 Per year solar irradiane in rural regions of Sindh

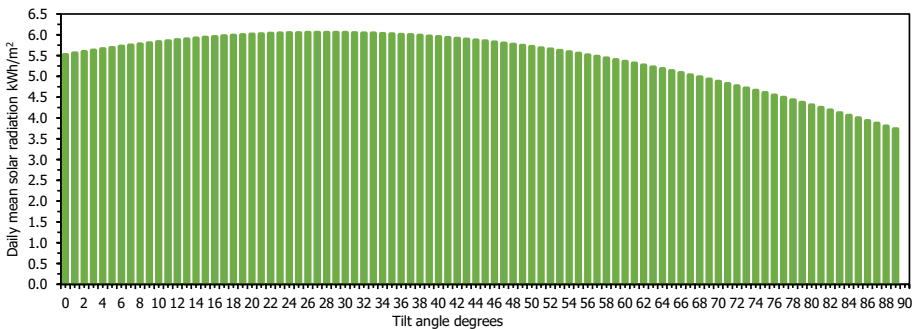


Fig. 6 Tilt angle at 0 to 90 degree in Badin region

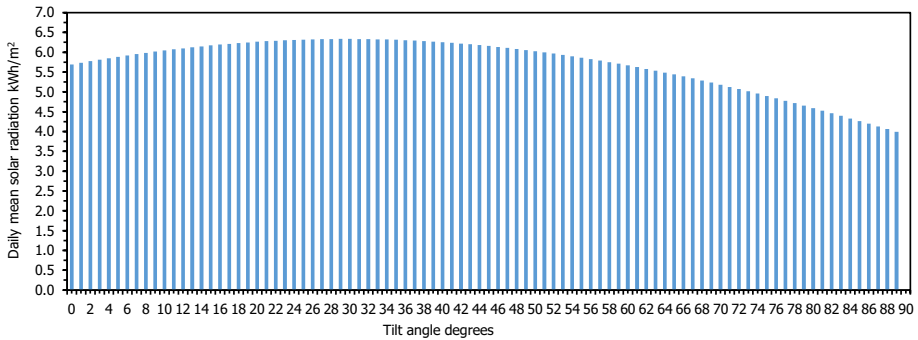


Fig. 7 Tilt angle at 0 to 90 degree in Nawabshah region

irradiance. The solar statistics for $1 \times 1 \text{ km}^2$ area show that the solar irradiance is limited to top 5% with terrain roughness variation permissible capable of 25%. The average value of the top 5 percentile yielded to be $6.4 \text{ kWh} = \text{m}^2 = \text{day}$, whereas the minimum available raster data show resolution of 250 m^2 of available area of interest. The country obtains solar energy having the mean value of $5\text{--}7 \text{ kW h/m}^2/\text{day}$ and about $1800\text{--}2200 \text{ kW h/m}^2$ per year radiation. In the simulation, their range is $2\text{--}4\%$. Overall incident angle correction factor: The values they derived in the model ranged from 2 to 3.5%. Pollution loss factor: The impact on system performance due to dust accumulation on the PV panel is called pollution loss. The range is between 2 and 6%. Photovoltaic module degradation: reducing the power output of the module is called degradation. With the passage of time, this decrease occurred gradually, and degradation rate is considered to be 0.5% per year.

4.2 Economic feasibility of PV solar

The off-grid solar energy is planned for electricity generation in the direction of cater village areas of Sindh province households in Pakistan. Results shows that the parameters considered for simulation adapted from the literature (Ullah et al. 2017). Based on Eqs. (6)–(10), this determined PV module area which has been founded that is 1.2 m^2 ; however, the highest voltage and current are 26.3 V and 7.61 A, respectively. The battery of 140 Ah/12 V is suitable for a solar panel of 200 W in order to satisfying the load of one household in remote areas of Sindh villages. Furthermore, the solar panel's conversion efficiency is 16%. Maximum electricity can be generated in rural areas of Sindh province in the month of April to June, though, because of monsoon season, whereas the small deterioration has been noted during the months of summer in the village areas of Sindh province in Pakistan. The Levelized cost of energy (LCOE) for planned solar sites are PKR 6.87/kWh. Conversely, power production price through the traditional energy sources varies from PKR 20.79/kWh to PKR 21.12/kWh, while the findings are consistent with the study done by (Ullah et al. 2017) (Table 1).

Every system has an age limit, because as time goes by, the system begins to degrade and its efficiency decreases, and after a sufficiently long-time interval, all components need to be replaced or the entire system needs to be re-developed. Generally, the lifetime of a photovoltaic system is regarded as 25 years, because photovoltaic materials will deteriorate over time and efficiency will decrease accordingly. Other changes in power generation may be caused by differences in sunshine hours or major system

Table 1 Per household load Requirement

Appliance	Used item	Working time	Watts score	Load (W h)
Ceiling fan	1	12	12	144
Pedestal fan	1	8	12	96
LED light	3	5	12	180
Charging slot	2	2	5	20
Total watts per day				440

failures. In addition, their future operation does not require expensive fuel. Solar energy resources can be obtained for free and ensure energy security. It is estimated that the cumulative energy produced during the projected life of the power plant is 31,08,450 MWh. The calculated LCOE (0.0795 \$/kWh) seems appropriate. LCOE is considered to be a powerful indicator for the price of electricity sold to customers. Customers can afford tariffs and investors are satisfied. The Sindh Electric Power Company has also initiated a number of small projects with good solar energy potential, ranging from 10 to 50 MW (Table 2).

The total daily solar energy incident shortwave reaches the ground surface at a wide area considering the seasonal variations in day length, the sun altitude above the horizon, and absorption of other atmospheric ingredient clouds. It includes ultraviolet radiation and visible light. The sea-level solar radiation range is 900–1000 w/m². The flat surface insolation depends on the location of the sites and its average is ranging from 450–650 W/m²/day. The production of solar power potential is predicted to be more than 1,00,000 MW. The estimated solar power potential is greater than 40 times from existing power generation capacity. The province of Baluchistan is rich in term of solar irradiation potential having an average 8.5 h/day sunlight per which yields 20 MJ/m² of solar insolation (Table 3).

Table 4 shows that the Kallar Kahar daily average highest incident shortwave solar energy is 7.9 kWh during June 7. The Jamshoro daily average highest incident shortwave solar energy is 7.6 kWh during May 25. The peak per square peak solar power incident shortwave has been observed at 0.67 kWh at around 12:30 pm. The Nooriabad daily average highest incident shortwave solar energy is 8.1 kWh during June 10. The peak per square peak solar power incident shortwave is 0.60 kWh at around 12:00 pm. The Ketī Bandar daily average highest incident shortwave solar energy is 7.2 kWh during the month of May 19. The Jiwani daily average highest incident shortwave solar energy is 7.6 kWh during the month of May 19. The highest solar power potential has been observed in May because summer in Pakistan is extremely hot. So, all other sites show a higher solar power potential in terms of electricity generation. The Gaddani daily average highest incident shortwave solar energy is 7.4 kWh during May 24. The peak per square peak solar power incident shortwave is 0.94 kWh at around 12:30 PM.

Also, the results reveal that the Gawadar site's daily average highest incident shortwave solar energy has been observed 7.5 kWh during May the month of 19. Actually, the results show considerable differences at each site. The Hushab daily average highest incident shortwave solar energy is 6.9 kWh during May 31. The Hushab daily average highest incident shortwave solar energy is 8 kWh during June 7. Results reveal that all of the sites have enough sunshine and a suitable temperature to generate solar power so all of the sites are internationally considered suitable and commercially viable for solar power project installation.

Table 2 Solar Variable in QA Solar Park *Source:* (Khosla et al. 2020)

Input variables	Season wise available solar hours	Clarity index	Efficiency of panels (%)	Efficiency of inverter (%)	Available number of PV modules	Availability of trans-former in days	GHI (kWh/m ²)
Range of values	350–1340	0.88–1	8–15	80–95	3,91,900–3,92,100	358–365	325–970

Table 3 Parameters used in the study

Parameter	Unit	Value
Panel area	m ²	1.2
Max current	A	7.61
Energy voltage max	V	26.3
Energy rating of PV	WP	200
Ambient temperature	°C	20
Temperature of panel	°C	25
Efficiency of panel reverence	%	16
NOM Solar radiation	W/m ²	800
Life of PV panel	Year	25
Capital cost of panel	PKR/WP	110
Efficiency of battery	%	85
Cost of battery	PKR/Ah	120
Cost of O/M	% of total cost	4
Discount rate	%	9
Battery duration	Year	5

Table 4 Viability of wind and solar power potential

Sites	Q_R (kWh)	Temperature (°C)	Solar power
Kallar Kahar	7.9	41	✓
Jamshoro	7.7	44	✓
Keti Bandar	7.2	37	✓
Nooriabad	8.1	47	✓
Gaddani	7.4	33	✓
Gawadar	7.5	48	✓
Hoshab	6.9	43	✓
Jiwani	7.6	37	✓
Jand	8	44	✓

Figures 8 and 9 show NREL CSR solar model output and NREL sunny solar model output, respectively. Local emissions impacts consideration, pollutant emission from specific resource and socio-economic characteristics are crucial for the development of successful completion of renewable power park as the instantaneous impact on the environment which is a concern of local inhabitants and the local policy makers.

4.3 Discussion

It has been noted that each domestic unit uses biomass for heating in winter for several months per year especially in cold rural areas of the country (Mohsin et al. 2019c; Iqbal et al. 2019).

In rural areas of the country biomass used for heating is the important element for the environmental degradation and it also increases the economic cost of the rural households (Al Asbahi et al. 2019). After the implementation of renewable energy policies, oil and

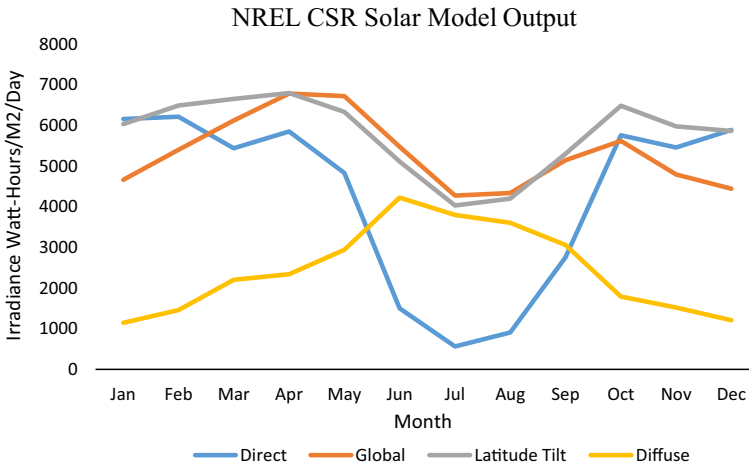


Fig. 8 NREL CSR solar model output

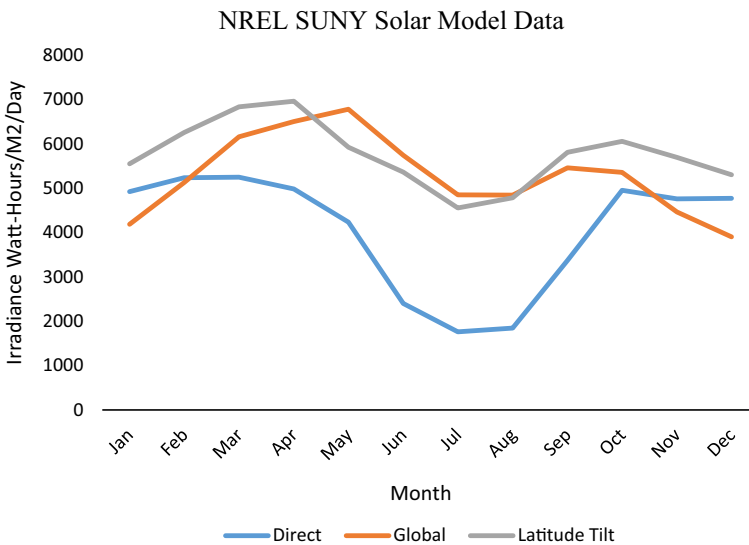


Fig. 9 NREL sunny solar model output

gas are the dominant element which needed to be remove from the national energy mix (Farooq and Kumar 2013; Sun et al. 2019a). The economic cost of energy consumption has increased considerably because of the high price of imported oil. By using Eq. (13), according to household, the planned solar energy system possibly will lessen CO₂ emission about 97.50 kg/year (Pakistan Bureau of Statistics 2017) lacking the sufficient supply of energy. If 100% solar energy system electrified to rural villages, then around 1,19,000 CO₂ metric tons alleviated yearly.

Currently, the biomass in rural areas is scorched in old-style incineration cooktops, whereas it resulted in low quality fuel utilization energy efficiency, so the solar power is

the suitable option for rural electrification in the country especially in the Sindh region. The energy efficiency of thermal source of a bulk biomass energy through burning stove is more expensive and it has less environmental effect than electricity (Morgans et al. 2018). The global share of renewable energy is expected to exceed 12.4% (one-eight) by 2023, where the most growth will be seen in the electricity sector with almost 30% increase from 2017 to 2023. Furthermore, renewable energy is expected to generate more than 70% of electricity worldwide (Gareta et al. 2006). The key sources of this renewable energy generation are solar PV, hydropower, wind and bioenergy. At present, the worldwide share of these renewable energy sources is hydropower (16%), wind (6%), solar PV (4%) and bioenergy (3%) and (International Energy Agency 2018). This may also be a good solution for the reduction in carbon emission and climate change issues. Climate change associated with global warming has had a serious impact on the globe, especially in developing countries. World's temperature, for example, has risen significantly in recent decades (Kung et al. 2019). There is a dire need to focus on this issue. The adverse effects of global warming are increasing in the forms of floods, draughts, heat waves, rising sea levels, low agricultural yields associated health and deprivation effects.

5 Conclusion and policy recommendations

The off-grid solar PV system can be adapted to the module area of solar PV of 1.2 m²; however, the solar panel is 200 W, with the total daily solar energy incident, the sun altitude above the horizon, and absorption and ultraviolet radiation and visible light, while the production of solar power potential in Sindh province is rich in term of solar irradiation. Kallar Kahar Jamshoro daily average highest incident shortwave solar energy is 7.6 kWh during May. The Jiwani daily average highest incident shortwave solar energy is 7.6 kWh during the month of May 19. Generally, the results show considerable differences at each site, for example, the sites have enough sunshine and a suitable temperature to produce solar power to commercially viable for solar power project installation. A 20-kWh fossil fuel producer generated the power of 4 kWh/l, while the planned solar energy system possibly will lessen CO₂ emission about 97.50 kg/year and 4,185,828 families in countryside areas in Sindh lacking sufficient supply of energy. Levelized cost of energy (LCOE) for planned solar sites are PKR 6.87/kWh. The traditional energy sources vary from PKR 20.79 to 21.12/kWh. Based on this study which includes economic feasibility analysis, we propose the solar photovoltaic system as a solution to the electricity needs. Off-grid solar photovoltaic system is found to have high potential because of its low operating and maintenance costs, easy installation, transportability and less harm to the environment. The five regions' solar irradiance has been evaluated. Moreover, off-grid solar photovoltaic could mitigate about 119,000 metric tons of CO₂ per year in all rural regions. Since solar PV-based electricity generation could be the most efficient and reliable option for the Sindh province both the federal and provincial governments can play a crucial role in its facilitation. Similarly, the findings of the study could be synonymous to the rural regions of other South Asian countries. Hence, the succeeding policy suggestions can be used to construct solar PV in remote rural areas of South Asian countries and Sindh in particular.

1. Off-grid rural electrification initiated by taking all stakeholders into account. The government should initiate hybrid solar and wind projects especially there should be roof top solar geezer in the northern areas and in the Baluchistan.

2. A supportive policy must be planned for stakeholders who could easily invest in rural regions. There should be a risk-free return scheme from the government so that the public should invest in the solar panel. There should be public private investment partnership schemes in the solar power market.
3. The accessibility of green funds and micro-financing of renewable energy projects might support rural societies to connect the solar energy system with national energy system of the country.
4. The straight and production cost of solar energy system must be reduced by adding the subsidy for rural household. There should be special installation of solar because for changing cloud conditions, the realization of dual angles can be better adjusted. On cloudy and rainy days, the lower panel will collect solar radiation more efficiently, on sunny days, the taller panel will collect solar radiation more efficiently, and on days with variable cloudiness, such as a sky full of clear cumulus clouds. Two angles may be better to handle height changes or complex solar irradiance fields.
5. There should be a tax on fossil fuel energy consumers and government should introduce subsidy schemes of solar power in the country in order to promote the policy of renewable energy. The government should initiate the 100% renewable energy scheme in the country to ensure reliable and green energy.
6. The quality control principles should be considered for solar energy system. The cross-border trade of solar energy across the region such as India Afghanistan Iran China and Nepal should be introduced.
7. Precedence should be given to the homegrown rural societies to create the awareness about renewable energy system.

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Availability of data and materials The data that support the findings of this study are openly available on request.

Compliance with ethical standards

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Ethical approval The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. We declared that we do not have human participants, human data, or human tissue.

Informed consent We do not have any individual person's data in any form.

References

- Al Asbahi, A. A. M. H., Gang, F. Z., Iqbal, W., Abass, Q., Mohsin, M., & Iram, R. (2019). Novel approach of principal component analysis method to assess the national energy performance via energy trilemma index. *Energy Reports*, 5, 704–713. <https://doi.org/10.1016/j.egy.2019.06.009>
- Alami Merrouni, A., Elwali Elalauoui, F., Mezrhab, A., Mezrhab, A., & Ghennioui, A. (2018). Large scale PV sites selection by combining GIS and analytical hierarchy process. Case study: Eastern Morocco. *Renewable Energy*, 119, 863–873. <https://doi.org/10.1016/j.renene.2017.10.044>
- Al Garni, H. Z., & Awasthi, A. (2017). Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia. *Applied Energy*, 206, 1225–1240. <https://doi.org/10.1016/j.apenergy.2017.10.024>
- Alonso-Montesinos, J., Batlles, F. J., & Portillo, C. (2015). Solar irradiance forecasting at one-minute intervals for different sky conditions using sky camera images. *Energy Conversion and Management*, 105, 1166–1177. <https://doi.org/10.1016/j.enconman.2015.09.001>
- Aly, A., Jensen, S. S., & Pedersen, A. B. (2017). Solar power potential of Tanzania: Identifying CSP and PV hot spots through a GIS multicriteria decision making analysis. *Renewable Energy*, 113, 159–175. <https://doi.org/10.1016/j.renene.2017.05.077>
- Anser, M. K., Mohsin, M., Abbas, Q., & Chaudhry, I. S. (2020). Assessing the integration of solar power projects: SWOT-based AHP–F-TOPSIS case study of Turkey. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-020-09092-6>
- Anwarzai, M. A., & Nagasaka, K. (2017). Utility-scale implementable potential of wind and solar energies for Afghanistan using GIS multi-criteria decision analysis. *Renewable and Sustainable Energy Reviews*, 71, 150–160. <https://doi.org/10.1016/j.rser.2016.12.048>
- Ashfaq, A., & Ianakiev, A. (2018). Features of fully integrated renewable energy atlas for Pakistan; wind, solar and cooling. *Renewable and Sustainable Energy Reviews*, 97, 14–27. <https://doi.org/10.1016/j.rser.2018.08.011>
- Aydin, N. Y., Kentel, E., & Sebnem Duzgun, H. (2013). GIS-based site selection methodology for hybrid renewable energy systems: A case study from western Turkey. *Energy Conversion and Management*, 70, 90–106. <https://doi.org/10.1016/j.enconman.2013.02.004>
- Baloch, M. H., Wang, J., Kaloi, G. S., Memon, A. A., Larik, A. S., & Sharma, P. (2019). Techno-economic analysis of power generation from a potential wind corridor of Pakistan: An overview. *Environmental Progress and Sustainable Energy*, 38(2), 706–720. <https://doi.org/10.1002/ep.13005>
- Barton, J. P., & Infield, D. G. (2004). Energy storage and its use with intermittent renewable energy. *IEEE Transactions on Energy Conversion*, 19(2), 441–448. <https://doi.org/10.1109/TEC.2003.822305>
- Bozkurt, I., & Karakilcik, M. (2015). The effect of sunny area ratios on the thermal performance of solar ponds. *Energy Conversion and Management*, 91, 323–332. <https://doi.org/10.1016/j.enconman.2014.12.023>
- Cagli, E. C., Taskin, D., & Evrim Mandaci, P. (2019). The short- and long-run efficiency of energy, precious metals, and base metals markets: Evidence from the exponential smooth transition autoregressive models. *Energy Economics*, 84, 104540. <https://doi.org/10.1016/j.eneco.2019.104540>
- Charabi, Y., & Gastli, A. (2011). PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renewable Energy*, 36, 2554–2561. <https://doi.org/10.1016/j.renene.2010.10.037>
- Doljak, D., & Stanojević, G. (2017). Evaluation of natural conditions for site selection of ground-mounted photovoltaic power plants in Serbia. *Energy*, 127, 291–300. <https://doi.org/10.1016/j.energy.2017.03.140>
- Effat, H. A. (2013). Selection of potential sites for solar energy farms in Ismailia governorate, Egypt using SRTM and multicriteria analysis. *Cloud Publications International Journal of Advanced Remote Sensing and GIS*, 2(1), 205–220.
- Farooq, M. K., & Kumar, S. (2013). An assessment of renewable energy potential for electricity generation in Pakistan. *Renewable and Sustainable Energy Reviews*, 20, 240–254. <https://doi.org/10.1016/j.rser.2012.09.042>
- Gareta, R., Romeo, L. M., & Gil, A. (2006). Forecasting of electricity prices with neural networks. *Energy Conversion and Management*, 47(13–14), 1770–1778. <https://doi.org/10.1016/j.enconman.2005.10.010>
- Gondal, I. A., Masood, S. A., & Khan, R. (2018). Green hydrogen production potential for developing a hydrogen economy in Pakistan. *International Journal of Hydrogen Energy*, 43(12), 6011–6039. <https://doi.org/10.1016/j.ijhydene.2018.01.113>
- Government of Pakistan. (2006). *Policy for development of renewable energy for power generation*. Alternative Energy Development Board, December, 2006 Minister for Water and Power, Pakistan.

- Habte, A., Sengupta, M., Andreas, A., Wilcox, S., & Stoffel, T. (2016). Intercomparison of 51 radiometers for determining global horizontal irradiance and direct normal irradiance measurements. *Solar Energy*, *133*, 372–393. <https://doi.org/10.1016/j.solener.2016.03.065>
- Huntington, H. G. (2015). Crude oil trade and current account deficits. *Energy Economics*, *50*, 70–79. <https://doi.org/10.1016/j.eneco.2015.03.030>
- <https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html>
- International Energy Agency. (2018). Renewables 2018—Market analysis and forecast from 2018 to 2023. IEA. <https://www.iea.org/reports/renewables-2018>.
- Iqbal, W., Yumei, H., Abbas, Q., Hafeez, M., Mohsin, M., Fatima, A., et al. (2019). Assessment of wind energy potential for the production of renewable hydrogen in Sindh Province of Pakistan. *Processes*, *7*, 196. <https://doi.org/10.3390/pr7040196>
- Iram, R., Zhang, J., Erdogan, S., Abbas, Q., & Mohsin, M. (2019). Economics of energy and environmental efficiency: Evidence from OECD countries. *Environmental Science and Pollution Research*, *27*, 3858–3870. <https://doi.org/10.1007/s11356-019-07020-x>
- Jabeen, M., Umar, M., Zahid, M., Rehman, M. U., Batool, R., & Zaman, K. (2014). Socio-economic prospects of solar technology utilization in Abbottabad, Pakistan. *Renewable and Sustainable Energy Reviews*, *39*, 1164–1172.
- Jun, D., Tian-Tian, F., Yi-Sheng, Y., & Yu, M. (2014). Macro-site selection of wind/solar hybrid power station based on ELECTRE-II. *Renewable and Sustainable Energy Reviews*, *50*, 76–84. <https://doi.org/10.1016/j.rser.2014.04.005>
- Kalhor, S. A., Shahid, M., Ali, S. M. U., Ahmed, T., & Ara, D. (2019). Wind and solar energy resources potential across coastal mega cities, of Pakistan. *International Journal of Recent Technology and Engineering*, *8*(2 Special Issue 8), 1895–1902. <https://doi.org/10.35940/ijrte.B1196.0882S819>
- Khosra, A. A., Rashid, T. U., Usman, M., & Khalil, M. S. (2020). Performance analysis based on probabilistic modelling of Quaid-e-Azam Solar Park (QASP) Pakistan. *Energy Strategy Reviews*, *29*, 100479. <https://doi.org/10.1016/j.esr.2020.100479>
- Kung, C. C., Zhang, N., Choi, Y., Xiong, K., & Yu, J. (2019). Corrigendum to “Effectiveness of crop residuals in ethanol and pyrolysis-based electricity production: A stochastic analysis under uncertain climate impacts” [Energy Policy 125 (2019) 267–276] (S0301421518306712) (10.1016/j.enpol.2018.10.016). *Energy Policy*. <https://doi.org/10.1016/j.enpol.2019.03.021>
- La Viña, A. G., Tan, J. M., Guanzone, T. I. M., Caleda, M. J., & Ang, L. (2018). Navigating a trilemma: Energy security, equity, and sustainability in the Philippines’ low-carbon transition. *Energy Research and Social Science*, *35*, 37–47. <https://doi.org/10.1016/j.erss.2017.10.039>
- Liu, B., & Jordan, R. (1961). Daily insolation on surfaces tilted towards equator. *ASHRAE J.; (United States)*, *10*, 5047843.
- Liu, J., Xu, F., & Lin, S. (2017). Site selection of photovoltaic power plants in a value chain based on grey cumulative prospect theory for sustainability: A case study in Northwest China. *Journal of Cleaner Production*, *148*, 386–397. <https://doi.org/10.1016/j.jclepro.2017.02.012>
- López, R., Galinato, G. I., & Islam, A. (2011). Fiscal spending and the environment: Theory and empirics. *Journal of Environmental Economics and Management*, *62*, 180–198. <https://doi.org/10.1016/j.jeem.2011.03.001>
- Lou, S., Li, D. H. W., Lam, J. C., & Chan, W. W. H. (2016). Prediction of diffuse solar irradiance using machine learning and multivariable regression. *Applied Energy*, *181*, 367–374. <https://doi.org/10.1016/j.apenergy.2016.08.093>
- Malik, F., & Umar, Z. (2019). Dynamic connectedness of oil price shocks and exchange rates. *Energy Economics*, *84*, 104501. <https://doi.org/10.1016/j.eneco.2019.104501>
- Mohsin, M., Abbas, Q., Zhang, J., Ikram, M., & Iqbal, N. (2019). Integrated effect of energy consumption, economic development, and population growth on CO2 based environmental degradation: A case of transport sector. *Environmental Science and Pollution Research*, *26*, 32824–32835. <https://doi.org/10.1007/s11356-019-06372-8>
- Mohsin, M., Nurunnabi, M., Zhang, J., Sun, H., Iqbal, N., Iram, R., & Abbas, Q. (2020). The evaluation of efficiency and value addition of IFRS endorsement towards earnings timeliness disclosure. *International Journal of Finance and Economics*. <https://doi.org/10.1002/ijfe.1878>
- Mohsin, M., Rasheed, A. K., & Saidur, R. (2018). Economic viability and production capacity of wind generated renewable hydrogen. *International Journal of Hydrogen Energy*, *43*, 2621–2630. <https://doi.org/10.1016/j.ijhydene.2017.12.113>
- Mohsin, M., Rasheed, A. K., Sun, H., Zhang, J., Iram, R., Iqbal, N., & Abbas, Q. (2019). Developing low carbon economies: An aggregated composite index based on carbon emissions. *Sustainable Energy Technologies and Assessments*, *35*, 365–374. <https://doi.org/10.1016/j.seta.2019.08.003>

- Mohsin, M., Taghizadeh-Hesary, F., Panthamit, N., Anwar, S., Abbas, Q., & Vo, X. V. (2020). Developing low carbon finance index: Evidence from developed and developing economies. *Finance Research Letters*. <https://doi.org/10.1016/j.frl.2020.101520>
- Mohsin, M., Zhang, J., Saidur, R., Sun, H., & Sait, S. M. (2019). Economic assessment and ranking of wind power potential using fuzzy-TOPSIS approach. *Environmental Science and Pollution Research*, 26, 22494–22511. <https://doi.org/10.1007/s11356-019-05564-6>
- Mohsin, M., Zhou, P., Iqbal, N., & Shah, S. A. A. (2018). Assessing oil supply security of South Asia. *Energy*, 155, 438–447. <https://doi.org/10.1016/j.energy.2018.04.116>
- Morgans, C. L., Meijaard, E., Santika, T., Law, E., Budiharta, S., Ancrenaz, M., & Wilson, K. A. (2018). Evaluating the effectiveness of palm oil certification in delivering multiple sustainability objectives. *Environmental Research Letters*, 13(6), 064032. <https://doi.org/10.1088/1748-9326/aac6f4>
- Muhammad, F., Waleed Raza, M., Khan, F., Khan, S., & Ahmad, A. (2017). Socio economic prospects and challenges of solar potential in Pakistan. *International Journal of Scientific & Engineering Research*, 8(11), 1268–1273.
- National Renewable Energy Laboratory. (2018). Simple levelized cost of energy (LCOE) calculator documentation. National Renewable Energy Laboratory, (March 1995), 1–2.
- Okoye, C. O., & Oranekwu-Okoye, B. C. (2018). Economic feasibility of solar PV system for rural electrification in Sub-Sahara Africa. *Renewable and Sustainable Energy Reviews*, 82, 2537–2547. <https://doi.org/10.1016/j.rser.2017.09.054>
- Okoye, C. O., Taylan, O., & Baker, D. K. (2016). Solar energy potentials in strategically located cities in Nigeria: Review, resource assessment and PV system design. *Renewable and Sustainable Energy Reviews*, 55, 550–566. <https://doi.org/10.1016/j.rser.2015.10.154>
- Pakistan Bureau of Statistics. (2017). Pakistan Bureau of Statistics | 6th Population and Housing Census. *Pakistan Bureau of Statistics*. <https://doi.org/10.1117/1.JRS.11.015015>
- Paramesh, V., Arunachalam, V., Nikkah, A., Das, B., & Ghnimi, S. (2018). Optimization of energy consumption and environmental impacts of arecanut production through coupled data envelopment analysis and life cycle assessment. *Journal of Cleaner Production*, 203, 674–684. <https://doi.org/10.1016/j.jclepro.2018.08.263>
- Pattanasethanon, S., Lertsatitthanakorn, C., Atthajariyakul, S., & Soponronnarit, S. (2007). All sky modeling daylight availability and illuminance/irradiance on horizontal plane for Mahasarakham. *Thailand. Energy Conversion and Management*, 48(5), 1601–1614. <https://doi.org/10.1016/j.enconman.2006.11.012>
- Perwez, U., Sohail, A., Hassan, S. F., & Zia, U. (2015). The long-term forecast of Pakistan's electricity supply and demand: An application of long range energy alternatives planning. *Energy*, 93(Part 2), 2423–2435. <https://doi.org/10.1016/j.energy.2015.10.103>
- Redlinger, M., Eggert, R., & Woodhouse, M. (2015). Evaluating the availability of gallium, indium, and tellurium from recycled photovoltaic modules. *Solar Energy Materials and Solar Cells*, 138, 58–71. <https://doi.org/10.1016/j.solmat.2015.02.027>
- Sánchez-Lozano, J. M., García-Cascales, M. S., & Lamata, M. T. (2016). Comparative TOPSIS-ELECTRE TRI methods for optimal sites for photovoltaic solar farms. Case study in Spain. *Journal of Cleaner Production*, 127, 387–398. <https://doi.org/10.1016/j.jclepro.2016.04.005>
- Sánchez-Lozano, J. M., Henggeler Antunes, C., García-Cascales, M. S., & Dias, L. C. (2014). GIS-based photovoltaic solar farms site selection using ELECTRE-TRI: Evaluating the case for Torre Pachecom, Murcia, Southeast of Spain. *Renewable Energy*, 66, 478–494. <https://doi.org/10.1016/j.renene.2013.12.038>
- Santbergen, R., Muthukumar, V. A., Valckenborg, R. M. E., van de Wall, W. J. A., Smets, A. H. M., & Zeman, M. (2017). Calculation of irradiance distribution on PV modules by combining sky and sensitivity maps. *Solar Energy*, 150, 49–54. <https://doi.org/10.1016/j.solener.2017.04.036>
- Shahbaz, M., Naeem, M., Ahad, M., & Tahir, I. (2018). Is natural resource abundance a stimulus for financial development in the USA? *Resources Policy*, 55, 223–232. <https://doi.org/10.1016/j.resourpol.2017.12.006>
- Shiva Kumar, B., & Sudhakar, K. (2015). Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India. *Energy Reports*, 1, 184–192. <https://doi.org/10.1016/j.egy.2015.10.001>
- Siddiqi, M. M., Azmat, R., & Naseer, M. N. (2018). An assessment of renewable energy potential for electricity generation and meeting water shortfall in Pakistan. *International Journal of Innovative Science and Research Technology*, 3(9), 84–89.
- Sliz-Szkliniarz, B. (2013). Assessment of the renewable energy-mix and land use trade-off at a regional level: A case study for the Kujawsko-Pomorskie Voivodship. *Land Use Policy*, 35, 257–270. <https://doi.org/10.1016/j.landusepol.2013.05.018>

- Soomro, M. I., Mengal, A., Memon, Y. A., Khan, M. W. A., Shafiq, Q. N., & Mirjat, N. H. (2019). Performance and economic analysis of concentrated solar power generation for Pakistan. *Processes*, 7(9), 575. <https://doi.org/10.3390/pr7090575>
- Stöckler, S., Schillings, C., & Kraas, B. (2016). Solar resource assessment study for Pakistan. *Renewable and Sustainable Energy Reviews*, 58, 1184–1188. <https://doi.org/10.1016/j.rser.2015.12.298>
- Su, D., Jia, Y., Alva, G., Liu, L., & Fang, G. (2017). Comparative analyses on dynamic performances of photovoltaic–thermal solar collectors integrated with phase change materials. *Energy Conversion and Management*, 131, 79–89. <https://doi.org/10.1016/j.enconman.2016.11.002>
- Sun, H., Edziah, B. K., Sun, C., & Kporsu, A. K. (2019). Institutional quality, green innovation and energy efficiency. *Energy Policy*, 135, 111002. <https://doi.org/10.1016/j.enpol.2019.111002>
- Sun, H., Mohsin, M., Alharthi, M., & Abbas, Q. (2020). Measuring environmental sustainability performance of South Asia. *Journal of Cleaner Production*, 251, 119519. <https://doi.org/10.1016/j.jclepro.2019.119519>
- Sun, H., Pofoura, A. K., Adjei Mensah, I., Li, L., & Mohsin, M. (2020). The role of environmental entrepreneurship for sustainable development: Evidence from 35 countries in Sub-Saharan Africa. *Science of the Total Environment*. <https://doi.org/10.1016/j.scitotenv.2020.140132>
- Sun, H. P., Tariq, G., Haris, M., & Mohsin, M. (2019). Evaluating the environmental effects of economic openness: Evidence from SAARC countries. *Environmental Science and Pollution Research*, 26, 24542–24551. <https://doi.org/10.1007/s11356-019-05750-6>
- Sun, L., Cao, X., Alharthi, M., Zhang, J., Taghizadeh-Hesary, F., & Mohsin, M. (2020). Carbon emission transfer strategies in supply chain with lag time of emission reduction technologies and low-carbon preference of consumers. *Journal of Cleaner Production*. <https://doi.org/10.1016/j.jclepro.2020.121664>
- Sun, L., Qin, L., Taghizadeh-Hesary, F., Zhang, J., Mohsin, M., & Chaudhry, I. S. (2020). Analyzing carbon emission transfer network structure among provinces in China: new evidence from social network analysis. *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-020-08911-0>
- World Bank Group 2017. *World Bank. End Poverty*. <http://pubdocs.worldbank.org/en/908481507403754670/Annual-Report-2017-WBG.pdf> (2017).
- U.S. Energy Information Administration. (2017). EIA—International Energy Outlook 2017. International Energy Outlook. [https://www.eia.gov/forecasts/ieo/pdf/0484\(2016\).pdf](https://www.eia.gov/forecasts/ieo/pdf/0484(2016).pdf).
- Ullah, H., Kamal, I., Ali, A., & Arshad, N. (2017). Investor focused placement and sizing of photovoltaic grid-connected systems in Pakistan. *Renewable Energy*, 121, 460–473.
- Uyan, M. (2013). GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region Konya/Turkey. *Renewable and Sustainable Energy Reviews*, 28, 11–17. <https://doi.org/10.1016/j.rser.2013.07.042>
- Xiao, C., Yu, X., Yang, D., & Que, D. (2014). Impact of solar irradiance intensity and temperature on the performance of compensated crystalline silicon solar cells. *Solar Energy Materials and Solar Cells*, 128, 427–434. <https://doi.org/10.1016/j.solmat.2014.06.018>
- Zubair, M., Awan, A. B., Praveen, R. P., & Abdulbaseer, M. (2019). Solar energy export prospects of the kingdom of Saudi Arabia. *Journal of Renewable and Sustainable Energy*, 11(4), 045902. <https://doi.org/10.1063/1.5098016>

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