Assessment of India's energy dynamics: Prospects of solar energy

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ABSTRACT

During the last decade, energy demand has increased manifold in India. To cope up with the rising energy demand, the Indian government has announced the National Solar Mission to generate 100 GW solar power by 2022. Large-scale solar power developers have been allotted around 60% of the National Solar Mission target. Therefore, it becomes pivotal to find the ground reality of solar power developers. To fulfill this objective, we selected the solar sources of the country and adopted a hybrid research methodology. The solar irradiation data were collected for one year in the four big cities of India, Mumbai, New Delhi, Chennai, and Bangalore during 2019 to evaluate the efficiency of photovoltaics (PVs). MATLAB and RETScreen were employed for data analysis and evaluating the efficiency of photovoltaics. We take this a step further by performing the Life Cycle Assessment analysis to scrutinize the different features of solar energy, including fuel consumption, price, average lifetime, maintenance and operation expenses, land requirements, and greenhouse gas emissions. The results reveal that all these cities have an enormous solar power potential, as they are located in an area where solar irradiations are consistently available all over the year (except for monsoon season). Moreover, solar energy is more durable, cost-saving, and easy to maintain. Furthermore, we identified the significant barriers over the whole solar energy spectrum by conducting semi-structured interviews with industry experts. These barriers are broadly classified into technological, policy, regulatory, financial, transparency, accountability, infrastructural, and trade policy categories. Finally, essential policy recommendations have been suggested for all stakeholders in order to fulfill the country's energy demand on its way to a future of sustainable development.

I. INTRODUCTION

Modern economies cannot survive without the consistent availability of energy. Sectors like agriculture, education, healthcare, transportation, and mining require a non-stop supply of energy for proper functioning. A country's success and economic growth are directly dependent on the appropriate use of energy (Ikram *et al.*, 2020a; Iqbal *et al.*, 2018, 40). Therefore, energy is considered as the primary element of a country's economy (Sahir and Qureshi, 2008). But it has always been a challenging task to find new and efficient ways of energy generation.

Due to recent industrialization and economic development, India has become the fourth largest consumer of electricity after China, the USA, and Russia (Global Energy Statistical Yearbook, 2019a). Statistics revealed that the demand for energy would increase further as China and India will be responsible for the most significant share of energy demand in Asia until 2050 (EIA, 2019). In the meantime, India ranked fifth in the world in terms of electricity generation (Global Energy Statistical Yearbook, 2019b). However, the current electricity generation system of the country is dependent on thermal energy sources (Irfan *et al.*, 2019a). Coal alone accounts for 57% of India's energy generation (Irfan *et al.*, 2019b). Massive dependence on conventional energy resources has led to severe environmental hazards, i.e., erratic weather patterns, health issues, and global warming (Balakrishnan *et al.*, 2019).

In terms of size, India is home to 80% South Asians. The country has become the sixth largest emitter of greenhouse gas (GHG) emissions worldwide and is responsible for 75% of the South Asian region's GHG emissions (Rehman *et al.*, 2020). It is projected that the emissions will grow further, as the energy structure of the country is primarily based on fossil fuels (Ikram *et al.*, 2020b). 76% of the households in rural India are energy poor and are dependent on wood and charcoal to fulfill their daily energy requirements, thus experiencing indoor air pollution. The report on the Global Burden of Disease reveled that indoor air pollution accounts for two million premature annual deaths in the country. It is expected that the per-capita mortality rate would grow by 21% until 2030 if the indoor air pollution continues to increase at the present level (Ikram *et al.*, 2019; Gordon *et al.*, 2018).

Increased fossil fuel prices, oil uncertainty, and GHG emissions have led policymakers to think about the future of conventional energy sources (Irfan *et al.*, 2019c). Governments are trying to shift the energy structure from conventional to renewable energy which can minimize climate change on one hand and reduce the pressure on imported oil bill on the other hand (Ahmed *et al.*, 2016). Countries all over the world are finding modern ways of energy generation by utilizing renewable energy sources (Irfan *et al.*, 2019d).

India is pioneered in the world to establish a separate ministry for non-conventional sources of energy. The Ministry of New and Renewable Energy (MNRE) was set up in 1980 with an aim to uplift renewable energy's share in the country. During the last two decades (2000–09 and 2010–19), the Indian government has shown great interest in the development of renewable energy, especially solar energy. The country has an estimated solar energy potential of 750 gigawatts (GW) (MNRE, 2016-17). MNRE has set a target to increase renewable energy's capacity up to 175 GW by 2022, out of which solar resources alone will contribute 100 GW. Due to technological advancements and active government support policies, the solar industry has experienced remarkable growth recently (Raina and Sinha, 2019). With the construction of new solar parks, the cumulative solar capacity in India has reached 35 GW, ranked fifth in the world (REN21, 2020).

Regardless of the tremendous progress of the solar industry, still, a large population cannot fulfill the daily energy needs. Bhattacharyya (2006) pointed out that 40% of Indian people do not have access to modern energy. Lenzen *et al.* (2006) compared the household energy needs among India, Brazil, Japan, Australia, and Denmark and found that there are considerable differences in the energy needs of these countries even at the same income level due to different population densities, lifestyles, technologies, and geographical conditions.

A. Research motivation

Some researchers have examined the development of solar energy in India from different perspectives. For instance, Sharma *et al.* (2012) discussed the strategies and perspectives of solar power in India. Ummadisingu and Soni (2011) addressed the concentrating solar power technology, while Sharma (2011) compared the development level of the Indian solar industry with the rest of the world. However, they did not emphasize on scrutinizing the competitive assessment of solar energy in the major Indian cities and the development of relevant implementation policies. Consequently, a comprehensive research is required to bridge this gap. We have selected the four cities of India, namely Mumbai, New Delhi, Chennai, and Bangalore. The primary reason for the selection of these cities is that these cities are big Indian cities with a massive population and numerous industrial zones. The energy demand has intensified due to domestic and industrial activities. Besides, the energy structure of these cities is primarily based on conventional electricity which is not only costly but also has posed several environmental issues. Another reason for selection is that these cities are located in an area where solar irradiations are consistently available all over the year. If harnessed effectively, solar energy can turn out to be a viable renewable energy choice for these cities. For this purpose, solar irradiation intensity was collected every month in these cities for a period of one year. The efficiency of photovoltaic (PV) was then measured by analyzing data in MATLAB and RETScreen.

In addition, there is a research gap of the Life Cycle Assessment (LCA) of solar technology in the Indian perspective, as the researchers did not investigate it thoroughly in the past. This is another motivation to conduct this research. Different features, i.e., price, life duration, fuel consumption, maintenance and operation expenses, land requirements, and intensity of GHG emissions were analyzed. Further motivation to write this paper is to explore the significant barriers which the Indian solar industry is currently facing. We conducted semi-structured interviews with industry experts and consulted published articles, energy reports, and official statistics.

B. Research contributions

This research makes the following contributions. First, to fill the literature gap, we analyzed the competitive assessment of solar energy in the big cities of India which has not been focused in the previous research. Second, we carried out the LCA analysis of solar energy to scrutinize the different features of solar energy, including fuel consumption, price, average lifetime, maintenance and operation expenses, land requirements, and greenhouse gas emissions. Third, we identified and prioritized the barriers that hamper the smooth progress of solar energy. Finally, essential policy measures were suggested to turn these barriers into opportunities and maximum deploy solar energy in the country. This research may not only enrich the existing literature by examining the competitive assessment of solar energy in India but could also assist the government and stakeholders by having an in-depth understanding of solar energy technology and to make procurement strategies accordingly.

The rest of the paper is organized as follows: Sec. II demonstrates the research methodology. Section III presents the energy dynamics of India. Section IV deals with the analysis and results. Section V identifies the significant barriers, hindering solar energy development. Section VI discusses the research findings accompanied by essential policy recommendations. Section VII provides the conclusions and section VIII discusses the limitations and future studies.

II. RESEARCH METHODOLOGY

A hybrid research methodology was adopted for data analysis. Solar irradiation data were gathered on monthly basis and plotted against the 1 kW PV in the four big cities (Mumbai, New Delhi, Chennai, and Bangalore) of India for a period of one year during 2019. Calculations were made after plotting the data against PV. Simulation results have been shown in terms of average monthly power generation in all four cities. Each month, the power generation by solar cells is presented in Figs. 5–8.

We performed the LCA analysis to analyze the different features of solar technology. LCA is a renowned methodological tool to examine the environmental impacts of a process, product, or activity along its entire life cycle. Analysts utilized this tool to estimate the future energy fluxes of an industry as a function of economic growth and regulatory perspectives. A basic feature of LCA is that every physical product ultimately turns into waste. Therefore, it is critical to reflect its environmental effects from "cradle to grave." This comprises not only the raw materials used in the production procedure, related emissions and wastes but also the final destiny of a product (Ayres, 1995).

Many scholars have applied LCA in different aspects of energy settings, including land use and electricity generation of PV (Fthenakis and Kim, 2009), polymer solar cell modules (Espinosa *et al.*, 2011), solar module recycling process, and metal used in emerging PV technologies (Müller *et al.*, 2005). We considered different features of solar technology such as price, fuel consumption, average lifetime, maintenance and operation expenses, land requirements, and GHG emissions. The focus was on levelized cost of electricity (LCE) and the economic feasibility of solar technology. LCE has been used to determine the electricity cost generated by PV for household purposes in the current research. Besides, different parameters (PV area, power voltage, power current, the efficiency of PV, the power rating of PV, life duration of PV, the capital cost of PV, the efficiency of the battery, cost of the battery, and life duration of battery) were utilized to determine the economic viability of grid-connected PV system.

Finally, we conducted semi-structured interviews by approaching industry experts to identify the significant barriers in the way of solar energy penetration (see the Appendix). These experts belong to different government institutions like the Ministry of New and Renewable Energy (MNRE), Indian Renewable Energy Development Agency (IREDA), Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commissions (SERCs). 174 industry experts in total were interviewed.

A. Survey area

Mumbai was selected as the first city to start our research. This is the capital city of Maharashtra state and is the most populous city in India. Currently, it is inhabited by 20.4 million people (World Population Review, 2020). The city is famous for its deep natural harbor and is the commercial and financial capital of the country due to numerous industrial zones (United Nations, 2016). It is considered as the economic hub of India as it generates 6.16% of the total GDP. The average electricity supply is between 2500–3000 MW and demand is 3400 MW. Electricity shortfall is 10%–15% due to the enormous energy needs of domestic and commercial users and this shortfall even pronounced in the summer season (CSO, 2018). Figure 1 depicts the location of the survey area. In terms of population, New Delhi is the second-largest city of India and is inhabited by 16.3 million people. Delhi Transco Limited is responsible for the distribution of electricity in New Delhi (Rediff India, 2007). The available power supply is 353 3000 MWh, while demand is 353 5000 MWh in this city, resulting in a deficit of 2000 MWh (CEA, 2018).

Chennai has a broad industrial base of computers, hardware manufacturing, automobile, and healthcare products. During 2012, the Chennai achieved the second rank in the export of information technology products. The city is also called Detroit of India due to the presence of major automobile companies in the city. Therefore, the energy needs of the city have increased exponentially in recent years. Shut down of electricity for long periods of time has made the situation more critical. Bangalore is the capital of Karnataka state with a population of 8.5 million people, making it the third-most populous city of India. Besides, it is the second fastest-growing metropolis with an economic growth rate of 10.3% (Rediff India, 2006). The economic development of the city is being affected by the worst load shedding.

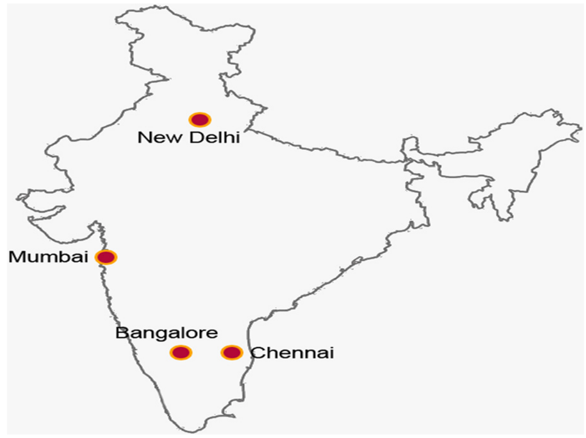

FIG. 1. Survey area.

III. ENERGY DYNAMICS OF INDIA

Since the last century, there has been an enormous demand for energy all over the world and India is no exception. Energy crisis, on one hand, is hampering the economic development of the country, and on the other hand, is affecting the quality of life of common people (Jewitt and Raman, 2017). The installed electricity capacity of India from different energy sources has been reported in Table I from a period of 2016–2019 (CEA, 2016a, 2016b, 2017, 2018, 2019; IRENA,

TABLE I. Installed electricity capacity by type in India (MW). Data source: CEA (2016a, 2016b, 2017, 2018, 2019); IRENA (2017, 2018, 2019, 2020). Data for coal, gas, diesel, and nuclear electricity are taken from the CER (2016a, 2016b, 2017, 2018, 2019), while the data for large hydro, PV, wind, biomass, municipal waste, and solid biofuels are taken from the International Renewable Energy Agency reports (2017, 2018, 2019, 2020).

Type	2016	2017	2018	2019
Coal	186 593	194 403	196 097	198 494
Gas	25 057	25 329	24 867	24 937
Diesel	919	838	838	510
Nuclear	5780	6780	6780	6780
Large hydro	41 566	49 382	50 066	50 225
PV	9658	19 047	26 869	34 831
Wind	28 875	32 878	35 288	37 505
Biomass	9185	9,533	10 253	10 228
Municipal waste	574	293	159	165
Solid biofuels	8998	9,240	10,240	10 046
Total	317 205	347 723	361 457	373 721

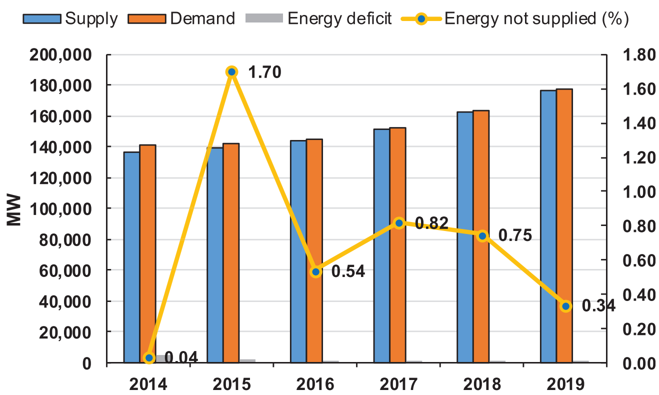

FIG. 2. Electricity demand-supply situation from 2014 to 2019. Data source: (CEA, 2016a, 2016b, 2017, 2018, 2019).

2017, 2018, 2019, 2020). Although the government is putting serious efforts to fulfill the energy needs of the country, still there is a massive gap between power demand and supply. During 2019, the gap was 614 megawatts (MW), indicating that the country has a shortfall of 23×10^9 kilowatt-hours (kWh). The power demand-supply gap has been depicted in Fig. 2 (CEA, 2016a, 2016b, 2017, 2018, 2019).

An enormous solar energy potential exists in India, as most Indian states receive 300 sunny days per year. Overall, 5000×10^{12} kWh solar energy is incident on Indian land in a year, while some areas get 4–7 kWh per square meter every day (Sharma *et al.*, 2012). India has made remarkable progress in solar energy installations and this is witnessed from the last decade, as the cumulative installed solar capacity was only 10 MW in 2008 which jumped to 35 060 MW at the end of 2019 (REN21, 2020). Similarly, annual installed capacity has grown from 6 MW to 77 05 MW during the same period (IRENA, 2020). Figure 3 shows the cumulative and annual installed solar energy capacity in India.

Figure 4 compares the capacity addition of solar energy during 2018–2019 among surveyed Indian states (CSO, 2019). It is evident from Fig. 4 that the state of Karnataka has the highest capacity addition of solar energy (16.55%), followed by Tamil Nadu (15.93%), Maharashtra (15.08%), and New Delhi (1.32%), respectively. Shakti Sthala Solar Park is one of the largest solar parks in India with an

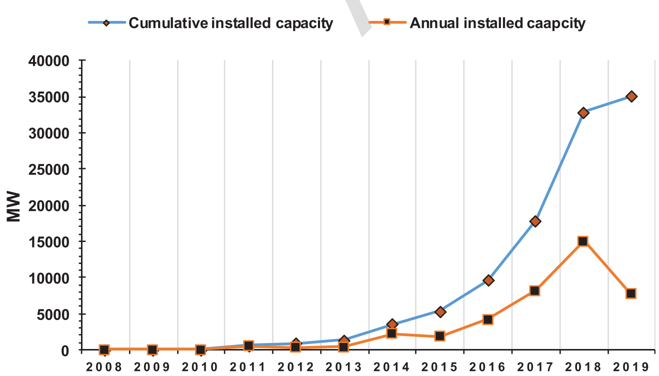

FIG. 3. Cumulative and annual installed solar energy capacity in India. Data source: IRENA (2020).

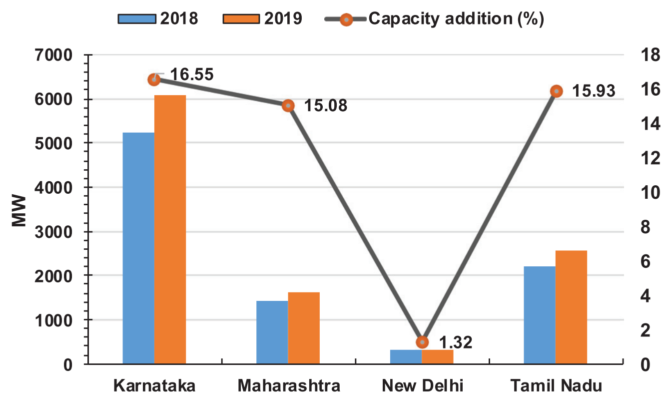

FIG. 4. State-wise solar energy capacity (MW) addition during 2018–2019. Data source: CSO (2019). The surveyed cities, i.e., Bangalore is located in the state of Karnataka, Mumbai is located in the state of Maharashtra, Chennai is located in the state of Tamil Nadu, while New Delhi is the national capital and union territory.

installed capacity of 2000 MW. Some major Indian solar parks with installed capacity have been presented in Table II (Adani, 2019; MNRE, 2016; Panwar *et al.*, 2011), while PV tariff rates among major Indian states have been reported in Table III.

IV. ANALYSIS AND RESULTS

A. Life cycle assessment (LCA) analysis of solar energy

1. Levelized cost of electricity (LCE)

LCE is an important metric to analyze the electricity cost generated by any source. The estimated LCE/kWh of stand-alone PV is calculated by the following equation (Baurzhan and Jenkins, 2016):

TABLE II. Major solar parks of India. Data source: Adani (2019), MNRE (2016), Panwar *et al.* (2011).

Developer	Capacity (MW)	State
Karnataka Solar Power Development Corporation Ltd	2000	Karnataka
Gujarat Power Corporation Ltd	615	Gujrat
M/s Sai Guru Mega Solar Park Pvt. Ltd	500	Maharashtra
Maharashtra State Electricity Generating Company Ltd.	500	Maharashtra
M/s Paramount Solar Power Pvt. Ltd.	500	Maharashtra
Adani Group	648	Tamil Nadu
Welspun Energy Ltd	151	Madhya Pradesh
Lanco Power	100	Rajasthan
KSK Energy	100	Rajasthan
Reliance Energy	100	Rajasthan
Godavari Power	50	Rajasthan
Corporate Ispat	50	Rajasthan
Megha Engineering Ltd	50	Andhra Pradesh
NTPC Ltd	50	Gujrat

TABLE III. PV tariff rates across different Indian states. Lakh = 1×10^5.

State	PV capital cost (lakh INR/MW)	PV feed-in-tariff (INR/kWh)
Gujrat	1000	For MW scale plants: 8.03 with accelerated depreciation 8.97 without accelerated depreciation For KW scale plants: 9.63 with accelerated depreciation 10.76 without accelerated depreciation
Karnataka	1550	14.5 (consists of small solar and rooftop PV plants)
Maharashtra	1000	LCE 9.5 with accelerated depreciation LCE 11.16 without accelerated depreciation
Orissa	1690	LCE 14.77 with accelerated depreciation LCE 17.80 without accelerated depreciation
Punjab	1000	LCE 9.35 with accelerated depreciation LCE 10.39 without accelerated depreciation
Tamil Nadu	1715	LCE 15.38 with accelerated depreciation LCE 18.78 without accelerated depreciation

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

Here, I_k stands for the investment cost, M_k denotes the maintenance cost, F_k stands for the fuel cost, year is denoted by k, the amount of generated electricity in kWh is denoted by E_k, d stands for the discounted rate, and n denotes the operational life duration of technology (Shah *et al.*, 2018). Regarding the cost perspective of solar technology, battery cost accounts for 18.3%, while PV module cost is 5.80% of the total installation cost. The estimated life duration of a typical PV system is 25 years. Yet, batteries need to be exchanged every five years because their average lifetime is 5 years (Irfan *et al.*, 2019c), specifying that batteries' cost alone is responsible for 91.6% during the whole lifecycle of a PV system. Other constituents of the PV system, including the circuit breaker, system controller, inverter, civil works, and charge regulator produce additional costs (CSO, 2019). Table IV shows the cost of all components used in a PV system. By using Eq. (1), it was calculated that the LCE of the PV system is INR 9.27/kWh.

By considering all aspects of solar energy, research results reveal that solar power generation is cheap in India, as the price to generate 1 kWh solar energy is only INR 9.27. The average lifetime of PV is 25–30 years. Additionally, PV does not require maintenance and operation expenses (Table V). The land required for the generation of PV electricity (1 kWh) is 0.02 m^2. Moreover, PV does not emit CO_2 and other hazardous gases during power generation (Aden *et al.*, 2010). The research findings are consistent with the previous studies of Olsen *et al.* (2013) and Aden *et al.* (2010).

2. Economic feasibility of the PV system

The net present cost (NPC) is a crucial cost parameter to scrutinize the economic feasibility of the PV system and is described as "the value of all the cost acquired by a PV system over its entire lifecycle minus the value of profits gained during the lifecycle of a PV project." NPC is denoted by the following equation (Salisu *et al.*, 2019):

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

Here, $C_{a.tot}$ is the annual total cost, CRF denotes the capital recovery factor, i presents the interest rate, and $Rproj$ indicates the project lifecycle (N). CRF is calculated by using Eq. (3) as

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

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

Here, i_o denotes the nominal interest rate, whereas f indicates the inflation rate. The high inflation rate reduces the real purchasing power and thus made it less affordable to buy PV. Therefore, if there is

TABLE IV. Costs of different components used in a PV system.

No.	Parts	Amount	Price (INR)	Life duration (years)	% Share of the price
1	Battery	1	15 000	5	18.3
2	PV panel	1	4750	20	5.80
3	Circuit breaker	1	270	20	0.32
4	System controller	1	480	20	0.58
5	Inverter	1	230	20	0.28
6	Civil work	…	850	20	1.03
7	Charge regulator	1	250	20	0.30
8	Battery replacement	4	60 000	20	73.3

TABLE V. Parameters used for the LCA of solar technology in India. Price, maintenance, and operation expenses are in Indian rupees, kWh: Kilowatt-hour, and yr: Year.

Parameters	Solar panel
Price	9.27 per kWh
Life duration	25–30 Years
Consumption of fuel	Nil
Maintenance and operation expenses	Nil
Land use	0.02 m^2/y/kWh
Carbon dioxide	Nil
Sulfur oxide	Nil
Nitrogen oxide	Nil

a higher inflation rate, then there will be less development of the solar industry. The electricity generation potential of PV in kWh is computed by using Eq. (5) (Okoye and Oranekwu-Okoye, 2018).

$$S_{pv} = P_{pv}.E_{pv}.S_t.\mathrm{PR}. \tag{5}$$

Here, S_{pv} is the electricity generation potential of PV. P_{pv} presents the panel area, E_{pv} denotes the efficiency, S_t shows the annual solar irradiations, and PR denotes the performance ratio utilized to regulate losses. E_{pv} is calculated by the following equation (Okoye *et al.*, 2016):

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

In this equation, the efficiency of PV is denoted by S_e, the temperature of PV is denoted by λ_t, the ambient temperature is denoted by A_t, the referenced temperature of PV is denoted by R_t, and the PV cell's nominal operating temperature and ambient nominal operating temperature are denoted by N_t and $E_{a.n}$, respectively. Besides, solar irradiation is represented by S_R, and solar irradiation for the nominal operating temperature of the PV cell test is denoted by S_N. Temperature is an important element while computing the economic feasibility of the PV system, as the optimum temperature yields the best tilt angles which in turn save the LCE of the PV system (Aziz *et al.*, 2020). Equation (7) shows the total electricity generated and demanded from PV.

$$\textit{Electricity difference} = \sum_{i=1}^{365}(E_{pv_i} - E_{d_i}). \tag{7}$$

Here, i denotes the day of the year, while E_{pv_i} and E_{d_i} represent the total electricity generated and demanded, respectively. Equation (8) depicts the required annual electricity to be saved in a battery E_b and is given as

$$E_b = \left(\sum SE - \sum DE\right).b_e. \tag{8}$$

Here, the surplus electricity is shown by SE, the deficit of electricity is denoted by DE, and the battery's efficiency is denoted by b_e. On the other hand, the battery's daily storage capacity B_d is calculated as

$$B_d = \frac{E_b}{365}. \tag{9}$$

Based on Eqs. (2)–(9), we determined the economic feasibility of the grid-connected PV system for household purposes. It was revealed that the area of the solar panel is 1.2 m^2, while the maximum voltage and current are 29.5 V and 7.65 A, respectively. Abdullah *et al.* (2017) reported that one household can easily be electrified with a PV system having a production capacity of 200 W. Thus, a 200-watt PV with a conversion efficiency of 16% and 140 Ah/12 V battery is suitable for the electricity requirements of one home. Table VI provides the simulation of the parameters.

B. Simulation results

We employed MATLAB (version R2019a) and RETScreen (version 6.0) for the data analysis and simulation of outcomes. MATLAB is a widely adopted software to perform extensive data analysis and visualization. The software is robust, efficient, and develops computational codes easily. Compared to conventional computer languages, it tests and implements complex algorithms without any difficulty. It has strong built-in routines that perform complicated computations. Besides, it has user-friendly graphic commands that instantly execute the visualization of results (Houcque, 2005). Similarly, RETScreen has the ability to categorize, evaluate, and optimize the financial and technical feasibility of potential solar power projects. It also calculates and validates the real performance of facilities and recognizes further energy production prospects, providing more valid conclusions (Owolabi *et al.*, 2019). Based on these advantages, we have utilized MATLAB and RETScreen for data analysis purposes.

To confirm the accurate locations for maximum solar intensity at the surveyed areas, we accessed the solar radiation map of India (NREL, 2016). Simulation outcomes are presented in terms of average monthly power generation (AMPG). The analysis of AMPG from PV in Mumbai city has been illustrated in Fig. 5. The simulation results show that a 1 kW PV in Mumbai produces a maximum of 0.23 kW power in the month of June and a minimum of 0.19 kW power in the month of August. Overall, solar energy is a good energy choice, as the city receives plentiful sunlight throughout the year except for the monsoon season (July and August). Figure 6 presents the AMPG analysis from PV in New Delhi. It is evident from Fig. 6 that a 1 kW PV generates a maximum of 0.23 kW power in April, May, September, and October, while a minimum of 0.16 kW power in July. One major

TABLE VI. Parameters utilized in the research.

Parameters	Unit	Value
Panel area	m^2	1.2
Power voltage: maximum	V	29.5
Power current: maximum	A	7.65
Efficiency of the solar panel	%	16
Power rating of the solar panel	WP	200
Life duration of the solar panel	Year	25
PV capital cost	INR/WP	105
Efficiency of the battery	%	85
Cost of the battery	INR/Ah	95
Battery life duration	Year	5
Nominal interest rate	%	6
Inflation rate	%	12

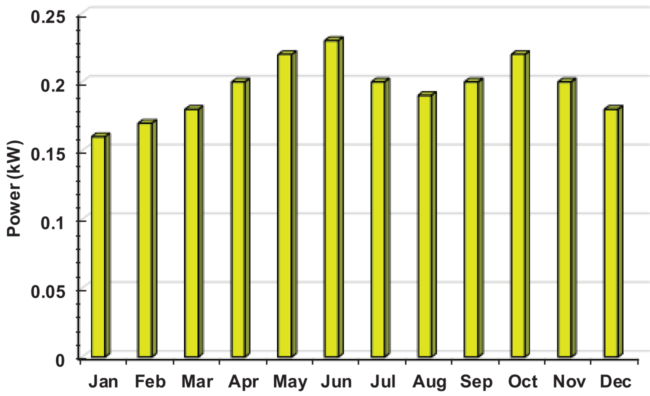

FIG. 5. Power generation of the solar cell in Mumbai.

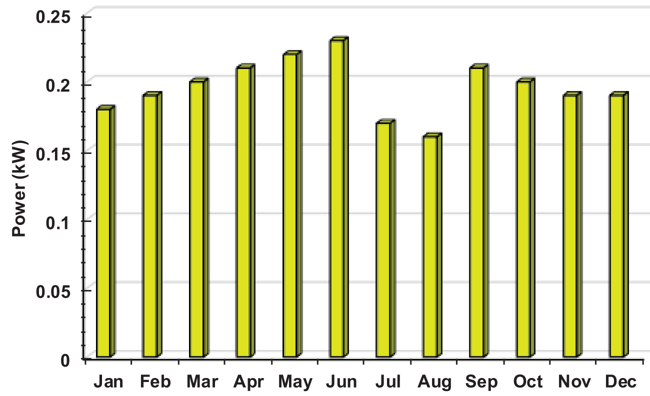

FIG. 7. Power generation of the solar cell in Chennai.

reason is that during July and August, the power generation capacity of PV considerably reduced due to heavy rains in the city, but for the rest of the year, solar power is a perfect energy option for New Delhi.

Similarly, the outcomes of the simulation reveal that PV provides a good power output in Chennai city too and is suitable nearly all over the year, but the power generation slightly reduced in July and August due to the start of monsoon rains. The AMPG analysis discloses that a maximum of 0.23 kW power is produced in the month of June, while a minimum of 0.16 kW power is produced in the month of August as illustrated in Fig. 7. Figure 8 demonstrates the analysis of AMPG from PV in Bangalore city. According to the simulation results, a 1 kW PV in Bangalore generates a maximum of 0.26 kW power during May and a minimum of 0.16 kW power during August and September. Generally, PV manages to fulfill the energy requirements of the city in hot summers. However, the city receives less solar irradiations during the months of July, August, and September due to the monsoon season.

V. EXISTING BARRIERS TO SOLAR ENERGY

Though there is potential for enormous solar energy in India, there exist certain barriers that are hindering its further development. Interviewees were asked about the barriers in the way of solar energy penetration (Appendix). These barriers are broadly classified into technological, policy, regulatory, financial, transparency, accountability, infrastructural categories, and trade policy barriers.

A. Technological barriers

High risks are always associated with solar technology, as this is not a mature technology in the Indian subcontinent. 54% of the interviewers exposed that the lack of R&D and limited production facilities for establishing mega-scaled solar power projects are the primary technological barriers. During the last decade, India has tried to upsurge the R&D and production facilities of solar technology. However, unawareness, lack of financial assistance, and ineffective policies have emasculated these efforts. Nearly all developed countries are expanding the solar power industry by establishing extensive production facilities and promoting R&D. According to MNRE, the cell and module production capacity in India is only 1212 MW and 5620 MW, respectively (MNRE, 2019), while countries like the USA, Germany, China, and Malaysia have already accomplished multi-gigawatt productions.

Besides, the average size of the module production unit and solar cell per annum is just 69 MWand 86 MW, compared to the module manufacturing capacity of a Chinese manufacturer (Trina Solar) which has exceeded 6 GW, more than all the 81 module manufacturers

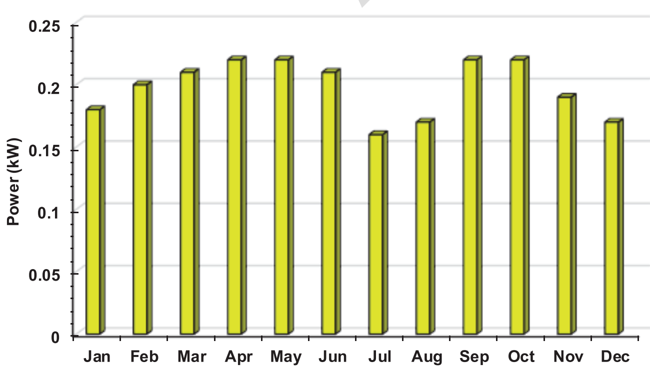

FIG. 6. Power generation of the solar cell in New Delhi.

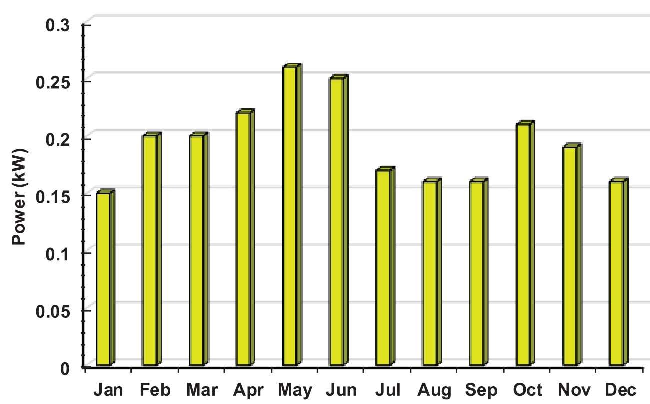

FIG. 8. Power generation of the solar cell in Bangalore.

TABLE VII. Comparison of government support for solar energy.

Country	Availability of loans	Support for R&D	Government subsidies	Subsidized utilities	Support for the acquisition of land
China	Yes	Yes	Yes	Yes	Yes
India	…	…	Yes	…	…
Malaysia	Yes	…	…	Yes	Yes
Taiwan	Yes	Yes	Yes	Yes	Yes
USA	Yes	Yes	Yes	-	Yes

of India. A comparison of government support for solar energy among different countries has been reported in Table VII. Moser Baer, the oldest solar enterprise in India has faced severe losses over the years, specifying the failures of the Indian solar industry. Currently, 15 local enterprises are manufacturing cell equipment and 48 are making module equipment. Out of the 15 cell manufacturing enterprises, 6 have totally idled production (Rathore *et al.*, 2018). Consequently, there is a high dependence on foreign technology to meet the present needs of the Indian solar power industry.

Currently, different types of technologies are in use for PV panels throughout the world. However, two of them have been most widely adopted. These are (i) crystalline silicon and (ii) thin film. Crystalline silicon further consists of (i) monocrystalline silicon and (ii) polycrystalline (or multi crystalline) silicon. Whereas, thin film comprises (i) amorphous silicon, (ii) cadmium telluride (CdTe), and (iii) copper indium gallium selenide (CIGS). Table VIII provides a cost comparison of these technologies across different countries (Woodhouse *et al.*, 2019; PV-magazine, 2020; Alibaba, 2020; Indiamart, 2020a; Indiamart, 2020b).

B. Policy and regulatory barriers

The government of India has released several policy documents in the form of preferential tariff and fiscal policies to support the solar industry. These include feed-in tariffs (FITs), renewable purchase obligations, accelerated depreciation, lifting of import duties, and tax incentives (Mahesh and Jasmin, 2013). FIT is considered an important policy measure to increase the penetration of solar energy worldwide (Shahmohammadi *et al.*, 2015). The government of India announced Renewable Energy Certificates (RECs) policy in 2010. The policy states that solar energy developers will receive FIT and a subsidy of INR 0.50/kWh (Shrimali *et al.*, 2013).

Tax incentives were given in 1990 to provide investors a friendly tax structure. Investors now can enjoy tax holidays, depreciation allowance, and monetary benefits. One of the major tax incentives is that investors can depreciate 100% of their capital equipment during the first year of the start of the project. Other incentive includes soft loans, wheeling, and capital subsidy (Singh *et al.*, 2004). Several State Electricity Regulatory Commissions (SERCs) have stipulated FIT and renewable portfolio obligation (RPO) in the respective states. However, an FIT regulated by a cost-plus approach under a rate of return framework discourages the maximum usage of solar energy and does not include incentives for cost minimization in the country. These regulatory frameworks are not the same in every state. The economic efficiency has been neglected due to the predominant way of fixing an RPO with the cost-based FIT (Singh, 2009). Table IX compares the solar FIT across different Indian states (Bose and Sarkar, 2019).

TABLE VIII. Cost comparison of PV technologies across different countries. All values are in US dollars per watt.

PV technology	USA	China	India	European Union
Monocrystalline silicon	0.014	0.009	0.49	0.2
Polycrystalline silicon	0.156	0.097	0.37	0.2
Amorphous silicon	0.8	1.15	0.79	0.32

Interviewees were asked about different policy parameters, i.e., maximum and minimum project capacity, the role of national agencies, and shortlisting of projects. They exposed that the country lacks a comprehensive national solar power policy. Experts specifically stated that the most significant issue which all solar enterprises are facing is that there is no legal enforcement of RPO at the national level. There is a difference in the RPO framework in different states. Interviewees have the opinion that it is very important to have a common RPO for all states. For instance, renewable energy legislation has been implemented in more than half of the American states. Thirty states including Washington, D.C., New Jersey, California, Connecticut, Massachusetts, New Hampshire, and Puerto Rico passed more than 100 renewable energy bills during the 2018 legislative session. The national renewable policy landscape for 2018, particularly emphasizes on renewable portfolio standards, net-metering, permitting, and interconnection for renewable energy, energy storage, tax incentives, and consumer protection (NCSL, 2019). The new Waxman- Markey climate change bill states that there should be a national RPO of 20% in the country. India also needs the implementation of these types of policies for the smooth development of the solar industry. The American president, Donald Trump, has attempted to restore much of the USA' energy system, supporting coal against renewable energy, less funding

TABLE IX. Comparison of solar FIT in different Indian states for the period of 2013–14–2018–19. All values are in INR/kWh.

State	2013–14	2014–15	2015–16	2016–17	2017–18	2018–19
Gujrat	9.64	8.97	6.77	6.30	5.86	5.86
Karnataka	8.40	8.40	6.51	6.51	4.36	3.05
Rajasthan	N/A	7.50	6.74	5.40	3.93	3.93
Maharashtra	8.98	7.95	7.08	6.04	5.13	2.72
Madhya Pradesh	10.44	10.44	10.44	5.45	5.45	5.45
Tamil Nadu	N/A	7.01	7.01	5.10	4.50	3.11

for climate change research and preferring nuclear energy (The Guardian, 2018). The most visible action of Trump's current administration is having plans to pull the United States out of the Paris climate agreement COP21. In addition, the administration has decided to cut the budget of renewable energy by three-quarters, and cancel Obama's "Clean Power Plan" and climate change policies (Shugerman, 2018).

Another problem in India is the unbalanced level of RPO. SERCs should carefully determine the RPO level, as a high RPO target help distribution companies to buy more solar electricity, while a low RPO target restricts them to buy solar electricity from solar power utilities (Nampoothiri, 2013). Limited government subsidy is another major problem. 11% of the industry experts exposed that the allocation of subsidies is always a very lengthy and time-consuming process. Another significant problem is the wrong selection criteria of deciding developers for the *Jawaharlal Nehru National Solar Mission*. Interviewees think that the criteria should be changed from minimum-maximum capacity to financial status and track record of the developers. Table X compares RPO among different Indian states (Bose and Sarkar, 2019).

C. Financial barriers

Different business models have been introduced by the Indian government including gross metering, net-metering, and green financing to design suitable billing methods. Under the gross metering model, all the energy produced from the Roof Top PV (RTPV) system is first fed to the grid and later it is imported from the grid during consumption. On the other hand, net-metering is one of the most widely adopted approaches, allowing residents to cut their electricity bills by using self-generated electricity from the RTPV system. At the same time, it allows them to sell extra electricity to the grid and utilities. PV system has been extensively employed in net-metering for domestic use in India. Residents while using net-metering do not need storage systems, as the extra electricity is stored by the grid itself. In addition, it is inexpensive and has low maintenance costs since the consumers do not need batteries and generators by adopting net-metering (Arunkumar and Murugavel, 2014). Nearly all states have announced their targets to offer net-metering and FIT provisions (Goel, 2016).

Despite numerous benefits, net-metering also has challenges. For instance, many states are cautious to offer a healthy environment for RTPV because distribution companies (discoms) are hesitant to sacrifice exceptional buyers who pay high prices. Due to this reason, the net-metering policy is inconsistent. RTPV consumers are facing massive challenges due to these inconsistencies. Every state has different criteria of the metering category, size of the system, approval period, and the type of connection. Therefore, the policy is hampering the development of RPTV. Another major challenge is the size of the system, as many states have an upper limit of system size (normally 1 MW) for an RTPV project (Bajaj, 2018).

TABLE X. Comparison of RPO across major Indian states.

State	2014–15	2015–16	2016–17	2017–18	2018–19
Gujrat	1.25%	1.50%	1.75%	1.75%	4.25%
Karnataka	0.25%	0.25%	0.75%	2.75%	6.00%
Rajasthan	1.50%	2.00%	2.50%	4.75%	6.75%
Maharashtra	0.50%	0.50%	1.00%	2.00%	2.75%
Madhya Pradesh	1.00%	1.00%	1.25%	1.50%	1.75%
Tamil Nadu	0.05%	0.50%	2.50%	5.00%	Not announced

Green financing is a systematic approach comprising a variety of stakeholders to merge the financial sector in the transformation procedure toward a carbon-free environment and from the perspective of adaptation to climate change. Away from devising the policy measures for green financing, green elements require to be accompanied into laws and regulations such as financial, taxation, and credit policies. To realize climate goals in emerging countries like India, massive green financing is required in clean energy technologies. According to the International Energy Agency, $\$1 \times 10^{12}$ of annual investment is needed to achieve the Paris targets by 2050. Green banks have been evolved as solutions to develop green infrastructure markets in India. For instance, the IndusInd Bank has started green projects in different cities and installed solar-powered ATMs which have resulted in the conservation of energy as well as a reduction in CO_2 emissions.

Similarly, the Bank of Maharashtra encouraged the espousal of solar energy including solar home systems, solar water pumps, and the equipment which used PV cells as energy input to promote clean energy. However, green financing has been obstructed by numerous challenges including limited capital and lack of awareness among SMEs, regulatory gaps to determine, evaluate and scrutinize green business approaches and financing, and market distortions and shortcomings (Soundarrajan and Vivek, 2016). Table XI compares the RPTV policy initiatives among major Indian states.

Unlike conventional energy, solar technology does not have a proven track record. Therefore, it is tough for new solar energy projects to get monetary help from banks and financial institutions. Debt financing is a significant barrier for solar power developers. CERC estimated that the per MW capital cost for PV projects is INR 691 lakhs (CERC, 2015), specifying that a high upfront capital is required for solar energy projects. There are structural challenges as well which are restricting the investment in the solar power industry. Banks have reduced investment exposure toward renewable energy due to massive capital already extended for conventional energy sources (FICC, 2019). Therefore, the renewable energy sector is confronting with the capital crunch. Projects have become uneconomical, as the loan interest rate is more than 10% for renewable energy programs (IREDA, 2017), whereas other sectors, i.e., real state and infrastructure have been enjoying a much lower interest rate. Compared with USA and Europe, the cost of renewable energy projects increases by 24%–32% in India due to complex terms of debt (Shrimali *et al.*, 2013).

Another important barrier is the lack of non-recourse financing for solar energy projects. At present, it is almost non-existent in the country. The financial risk of developers increases manifold, as the majority of them are working with limited resource funding in India. Financial closure time is another issue. Initially, the "Jawaharlal Nehru National Solar Mission" delineated three months' time period of financial closure. Later, it was made even more strict by announcing that if developers do not finance projects within this specified time, they would be invoked with the performance guarantee of US $100 000 per MW (BTI, 2016).

D. Transparency and accountability barriers

A country cannot achieve sustainable growth without good governance. There are numerous reasons for corruption in India, including the absence of transparent laws and regulations, unrestricted

TABLE XI. Comparison of RTPV policies among major Indian states.

State	Policy guidelines	Target segment
Gujrat	Gross metering without depreciation at INR 10.7 per kWh	Residential, government
	Gross metering with accelerated depreciation at INR 9.6 per kWh	
	Project developers receive FIT for 25 years and households will receive lease rental	Industrial, commercial Buildings
Karnataka	Gross and net-metering without subsidy at INR 9.56 per kWh	All customers
	Gross and net-metering with subsidy at INR7.20 per kWh	
Rajasthan	Net-metering without accelerated depreciation at INR 7.50 per kWh	All customers
	Net-metering with depreciation at INR 6.63 per kWh	
Tamil Nadu	For a period of one year, net-metering is available for self-use and energy banking	50 MW for households
	For the first 2 years, generation-based incentives will be provided at INR 2 per kWh, for the next 2 years at INR 1 kWh, and for the successive 2 years at 0.5 kWh	300 MW for city and countryside lighting and institutional buildings

powers of bureaucracy, high taxes, enormous government departments, and the monopoly of government organizations. Spending money in government programs and schemes is the primary corruption source in India. Coal allocation scam or "Coalgate" is a classic example of such corruption. The incident took place in 2012 when the government allocated 194 coal blocks to private enterprises without the formal bidding process (Miklian and Carney, 2013). 30% of the industry experts exposed that from the announcement of the project until the end of the project, they are forced to pay bribes to higher authorities. They also exposed that there is a lack of transparency in the acquisition of land and issuing contracts to the developers. The Indian government announced the "National Clean Energy Fund" in 2010 to uplift the growth of renewable energy. Even questions have raised on the transparency of this fund, as it is being utilized on the projects of other departments and ministries instead of R&D of the renewable energy sector.

Another notorious case of opaque transparency has been spotted in the state of Rajasthan where the Rajasthan Renewable Energy Corporation Limited approved commissioning certificates of a 5 MW solar energy project to seven subsidiary companies of LANCO (a private company). Later, it comes to know that the certificates were granted even before the completion of the project (BTI, 2016). Experts have the opinion that doing in foreign countries is easy as compared to India and they give priority to invest in foreign countries. They believe that 55% of the total time of a solar energy project is utilized in getting approvals, assessments, and subsidies, as the existence of several government institutions, i.e., the Central Electricity Regulatory Commission, the State Electricity Regulatory Commissions, and the Ministry of New and Renewable Energy, makes legal procedures a difficult task (Rathore *et al.*, 2018). However, there is considerable space for improvement to give developers a favorable environment for solar energy generation and the foremost important step is to simplify the approval system by reducing the dependence on multiple institutions. Developers become demotivated by too many bureaucratic formalities. Therefore, these formalities should be lessened on an urgent basis.

E. Infrastructural barriers

The acquisition of land is an essential part of setting solar energy projects. Industry experts mentioned that acquisition of land is the most significant barrier under infrastructural barriers category and the process differs in every state. Almost six to twelve months are required for land acquisition and in some cases, even one year is not enough. A clearance from several government departments including the National Green Tribunal, the forest department, and the Ministry of Rural Development is needed for this purpose. Therefore, land acquisition is a very cumbersome process for solar projects in India. There are several cases where projects postponed or even shifted to other localities due to the complications in land acquisition. For instance, in the state of Andhra Pradesh, a 205 MW solar power project at the Ananthapuramu solar park was deferred in 2018 due to problems in land acquisition. A similar case has been seen in Jodhpur, when a 300 MW solar power project of Hero Future Energies got delayed for six months. The company acquired land in January 2019 instead of June 2018 and even then, not all of it. Moreover, Pavagada Park has been established on 13,000 acres of land in the north of Bengaluru. The land for this solar park was leased from farmers. In 2019, it was reported that farmers have mortgaged some of their land (The Economic Times, 2019).

The Right to Fair Compensation and Transparency in Land Acquisition, Rehabilitation and Resettlement (LARR) Act 2013, governs the acquisition of land in the country (Goswami, 2016). Resettlement and Rehabilitation Policy 2007 encloses that developers will be responsible to give resettlement compensation to the dislocated communities, adding extra financial burden on the developers. The problems do not settle here, developers still need the approvals from (i) land usage establishments, (ii) pollution control board, (iii) ministry of environment, (iv) district Magistrate, Panchayats, (v) and no objection certificate (NOC) from the energy department before setting up a solar power project. Problems exist after the acquisition of land as well. In some cases, the allotted land is in remote regions and connected with poor roads. There is a great difficulty in transporting solar panels to the respective areas. Even solar panels break during transportation which delays the regular operation of solar projects.

Natural disasters like landslides, floods, and earthquakes frequently occur in India (NDMA, 2016). Sometimes, the allotted land is prone to these disasters, causing an extra financial burden on the project developers. Experts revealed that the other significant infrastructural barriers are transmission & distribution (T&D) losses and commercial & technical losses. T&D losses were more than 18% during 2017 in India, as compared to 6% in USA and China in the same year, respectively (World Bank, 2017). According to experts, the old grid structure, high pilferage, insufficient investment in the distribution network, and improper load management are the primary reasons for T&D losses. Commercial & technical losses were 25% during 2016 in India (CEA, 2016b). Experts told that poor billing management and power theft are the main reasons for commercial & technical losses.

F. Trade policy barriers

India planned to install 100 GW solar energy in the country until 2022. To achieve this target, the government has already started the construction of solar farms by working closely with domestic and foreign partners. However, the modules and solar cells made by indigenous firms are expensive, have low operational and manufacturing capacity, and do not meet the desired quality standards. The total operational and manufacturing capacity of solar cells and modules was only 1.67 GW and 3.16 GW and 5.50 GW and 8.39 GW, respectively, at the end of 2017 (BTI, 2017), which do not meet the current requirements of the industry to realize the target of installing 100 GW solar energy. Besides, the crystalline silicon PV modules' production capacity is mainly concerted in China and relatively cheap. Therefore, about 80% of the solar cells and modules used in Indian solar power projects are imported from Chinese firms (ISE, 2018).

In addition to cost concerns and inconsistency between demand-supply, local manufactures need to deliver massive module capacities in a short time period, use the latest technology, and have a high efficiency which is possible only from Chinese, American, and Malaysian manufacturers due to their state of the art technology and economic feasibility. During the fiscal year (FY) 2020, India's imports of solar power equipment, whether or not assembled in module or panel stood at US $1525 million from China. During FY 2017, 2018, and 2019, India imported US $2817 million, US $3418 million, and US $1694 million worth solar equipment from China, respectively. A substantial increase in imports has been noticed since the last few years, as imports of cells and modules bound to 9700 MW during the FY 2017–18, compared to the imports of only 1275 MW in the FY 2014–15 (Bose and Sarkar, 2019).

In compliance with the government plans to achieve 100 GW solar energy capacity, MNRE intends to invite bids for 30 GW in this and the next FY. The idea is to support Made in India and encourage local manufacturers to compete with Chinese and other counterparts. Consequently, the government has imposed customs duty on imported solar power equipment. For instance, safeguard duty was imposed on the import of parts of PV systems from China and Malaysia for a period of two years to protect local players. As a first step, a safeguard duty of 25% was imposed on the import of solar power equipment from a period of 30 July 2018–29 July 2019 which reduced to 20% during the next six months and in the current FY, it has been further reduced to 15%, increasing the cost of developers (Behuria, 2020). On the other hand, all solar projects will be affected severely by this trade policy, as the local manufacturers do not have the capability to realize the target of installing 100 GW solar energy. Currently, India can only manufacture PV and related equipment to attain 15% of the annual installation target (Bloomberg, 2018).

The international solar society realizes a huge solar power market in India. However, the growth of the Indian solar power industry is lethargic even when the country has abundant solar resources, low cost of indigenous solar equipment, and the availability of land for establishing large solar farms. The primary reason is the absence of a single comprehensive policy structure. India is being confronted with immense pressure at the International level to reduce GHG emissions. Consequently, the *Jawaharlal Nehru National Solar Mission* has been announced by the Indian government to install 100 GW solar power by 2022 and overcome GHG emissions. To successfully attain the target, the government needs to formulate a common policy for the solar industry at the federal level, single-window clearance system, develop infrastructure, and provide easy and long-term financing. Figure 9 established a framework, depicting the relationship between barriers, policy measures, and economic feasibility of the PV system.

VI. DISCUSSIONS AND POLICY RECOMMENDATIONS

Findings reveal that solar energy is a suitable energy choice in the survey region. Overall, PV generates enough electricity in all four cities. The simulation results reveal that a 1 kW PV produces a

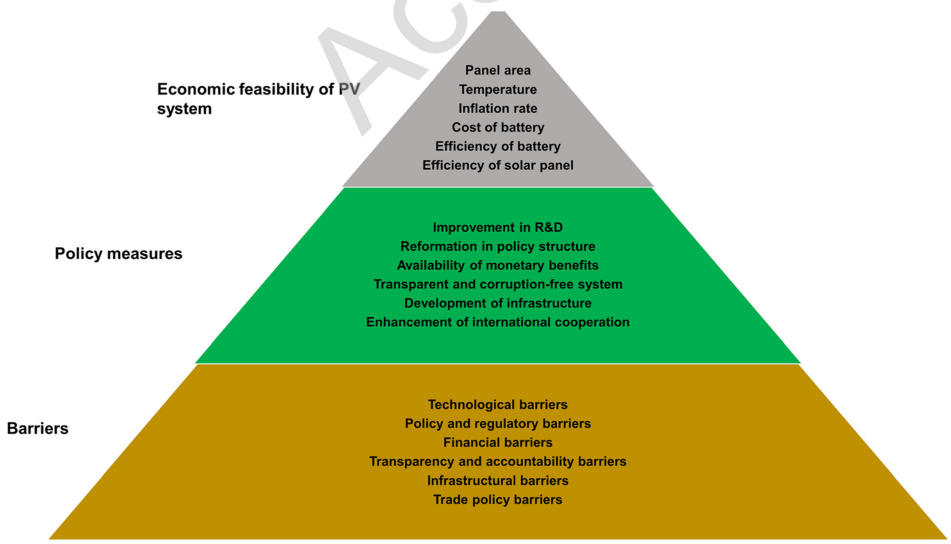

FIG. 9. Framework depicting the relationship between barriers, policies, and economic feasibility of the PV system.

maximum of 0.26 kW and a minimum of 0.15 kW power per day in the survey area. On average, we can generate 0.20 kW power every day which not only assists in reducing electricity shortfall time, but will also lower the burden on the energy structure of the country. Therefore, solar energy will serve as a future prompt substitute for conventional thermal energy.

Meanwhile, the vital elements of the solar industry, i.e., investment and financial mechanism, modern technology, solar power development policies, and infrastructure have been undervalued during their development path. Consequently, a large gap exists between the actual and expected performance of the solar industry's value chain. Energy crises have severely affected the Indian economy. The adequate supply of energy is crucial for the all-round balanced economic development of a country and provides a dynamic input for all sectors of life (Kumar, 2017). There is always a close relationship among per-capita energy consumption, per-capita income, per-capita gross domestic product (GDP), and standard of living. Higher per-capita energy consumption is associated with the rapid pace of economic development (Rehman *et al.*, 2019). Conversely, India has a lower per-capita energy consumption, lower per-capita income, and lower per-capita GDP, compared with developed countries, which is negatively affecting its socio-economic development. The progress of the Indian economy is impossible without the proper generation and consumption of energy. The country is facing several obstructions in realizing the maximum potential of its power sector and the major barrier is fuel unavailability to the industrial sector. The dependence on coal has increased, as the Coal India Ltd (CIL) has restricted the supply of coal to 65% of the actual coal needs by coal-based thermal power plants. The inadequate fuel supply has resulted in an increase in energy production costs. In addition, the financial performance of state discoms has led to decreasing operation efficiencies and outstanding debts and the situation becomes even worse if the country still follows the policy of relying on conventional power sources. Research findings present four major reasons that warrant the importance of developing the solar power industry in India.

First, the electricity generation structure of India is heavily dependent on fossil fuels which not only have adverse impacts on the environment but are also very expensive and put a huge burden on the national budget. The feeble Indian economy cannot bear such a burden. Consequently, the future fossil fuel supply of the country is uncertain. Second, the former policy of depending on fossil fuels for energy production completely failed as it did not produce the expected outcomes of handling energy shortfall problems of the country. Third, India has been listed among the top climate-vulnerable countries (DTE, 2019). Incessant reliance on fossil fuels could leash the country into an undesirable situation of climate change. Finally, India is sanctified with abundant solar energy resources. If properly exploited, the country can tackle all energy crises within a short period of time.

The investment in solar power is increasing tremendously all over the world and it has earned global recognition due to falling costs and technological advancements. According to the vision and policies of PM Modi's government, the capacity of renewable energy will be upscaled to 175 GW, out of which solar energy alone will fulfill 100 GW until 2022 to meet the electricity needs of the country (MNRE, 2016-17). To achieve this target, the Indian government has sanctioned a subsidy of INR 5000 crore for the solar sector.

Various additional subsidy programs have also been launched. For instance, the central government provides a subsidy of 30% for the installation of grid-connected rooftop PV systems in all states, while hilly states (Himachal Pradesh, Uttarakhand, and Jammu-Kashmir) will receive a subsidy of up to 70%. Besides, the farmers will get a subsidy of 90% on the installation of a solar water pumping system (MNRE, 2020). Similarly, the government announced "grid-connected PV power plants along the banks of canals" scheme to feed the central grid. According to this scheme, MNRE will provide a subsidy of INR 3 crore/MW or 30% of the total project cost. All states having canal networks are eligible for the subsidy program. The government has also introduced subsidy programs to facilitate users, far away from the national grid. These include a subsidy of INR 102/W for the installation of home lights, INR 142.5/W for streetlights, INR 30 000/Horsepower (HP) for installing solar pumps up to 3 Horsepower (HP) capacity, and INR 19,000/HP for solar pumps having a capacity between 3 HP and 5 HP (SECI, 2014–15).

Based on research findings, the following policy recommendations have been advised for the Indian government to gradually uplift solar energy's share in the country. The policy framework has been illustrated in Fig. 10.

A. Improve R&D

R&D is a vital value-adding element of solar power development. Local production facilities should be improved by continuous R&D activities in order to reduce operating costs and dependence on foreign countries. To speed up, enough funds should be available for this purpose.

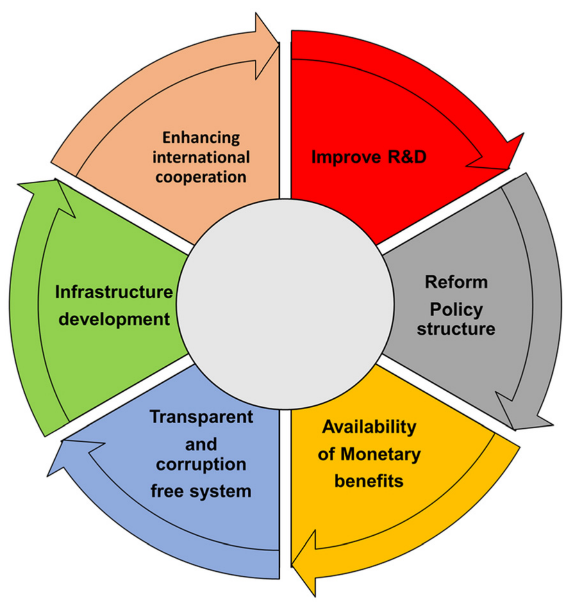

FIG. 10. Policy framework for the development of the solar industry.

B. Reform policy structure

Quick solar energy development requires an active and robust policy structure. The government should formulate a comprehensive and consistent policy at the national level for solar energy. RPO should be enforced at the state level and federal level. The PV market indicates that big installations are becoming more and more competitive due to technological innovations (Tisheva, 2018). However, small projects need support. Therefore, subsidies should be provided to small project developers and prosumers promptly. The criteria for selecting developers for the *National Solar Mission* program should be based on financial status and track record basis instead of minimum and maximum capacity.

C. Availability of monetary benefits

Solar power projects are capital intensive and require high upfront costs. Therefore, the government should provide easy and long-term financing to small developers until the initial upfront costs shall recover. Besides, cheap panels should be provided to individuals, prosumers, and energy communities. The issue of debt finance should be resolved. Banks and other financial institutions should be advised to allocate special loan quotas for solar energy projects. Additionally, the interest rate for renewable projects should be reduced to motivate domestics and foreign developers to invest in solar power programs.

D. Transparent and corruption-free system

For sustainable development, the system should be transparent and free from corruption. Regulations should be made in such a way that every government scheme has proper checks and balances, the powers of bureaucracy should be reduced, and an effective tax structure should be adopted, documenting that developers and prosumers should be offered a 10-year tax holiday for developing solar projects and have the opportunity to avail 40% accelerated depreciation.

E. Infrastructure development

The infrastructure of the Indian solar energy sector needs significant improvements. The acquisition of land is time-consuming and requires clearance from several government departments. Besides, there is a lack of transparency in the acquisition of land. Therefore, the process of land acquisition should be simplified. This can be achieved by reducing dependence on so many government departments, cutting bureaucratic requirements, and adopting transparent means of land acquisition. Proper roads should be provided for the secure transportation of PVs and related stuff to target areas. The old and inefficient T&D network should be improved to alleviate T&D losses. In addition, an appropriate billing management system should be implemented.

F. Enhancing international cooperation

As the local modules and solar cells are of low quality and very expensive. Therefore, collaboration with foreign institutions and countries who are competent in solar power technologies is crucial to realize the government's policy targets of installing 100 GW solar power at the end of 2022.

VII. CONCLUSIONS

Energy is the backbone of socio-economic development of a country. Fossil fuels are the primary energy sources of India, as coal alone fulfills 57% of the country's energy requirements. At the same time, the prices of fossil fuels have increased tremendously. Due to recent economic development and ever-increasing population, the demand for energy has amplified, resulting in a shortfall of electricity (Irfan *et al.*, 2019e). At the end of 2019, there was a shortfall of 614 MW in the country (CEA, 2019). This, in turn, has severely affected all the domestic and industrial sectors. To overcome energy shortage problems, policymakers and governments all over the world are in search of finding alternate means of energy generation. In this study, we realized the viable renewable energy choice for India and selected the solar sources of the country. Solar irradiation data were collected every month in the four major cities of India, i.e., Mumbai, New Delhi, Chennai, and Bangalore for a period of one year. MATLAB and RETScreen were employed for data analysis and evaluating the efficiency of PV. Research findings reveal that solar energy is a suitable energy choice, as these cities are situated in an area where solar irradiations are consistently available all over the year (except for the monsoon season). We also performed the LCA analysis and examined the different features of solar energy. The analysis reveals that PV power generation is cheap in the country, as the cost required to generate 1 kWh solar electricity is INR 9.27. Besides, PV has a good average lifetime of 25–30 years. PVs do not require maintenance and operation expenses and only need 0.02 m^2 land to produce 1 kWh electricity. PV does not emit CO_2 and other poisonous gases during power generation. The climatic conditions and topography of these cities are perfect for the maximum penetration of solar energy. People also have become aware of the benefits associated with solar energy, but there also exist some barriers in the way of solar energy, which were identified in this research by conducting semi-structured interviews with industry experts. These barriers can be broadly classified into technological, policy, regulatory, financial, transparency, accountability, infrastructural, and trade policy categories. Finally, essential policy recommendations have been offered to upsurge the share of solar energy in the total energy mix of the country.

VIII. LIMITATIONS AND FUTURE STUDIES

This study also has some limitations. The selected study sample was relatively small. We only selected four big cities of India. Therefore, other cities and particularly rural areas were overlooked. Future studies shall expand the survey to other regions of the country. Furthermore, only solar energy was considered in the survey area as every renewable energy technology has different effects, benefits, and costs. Thus, subsequent researchers may focus on examining the concrete development of other renewable sources including wind, biomass, hydro, and geothermal energy.

The current research, as outlined, has been based on hybrid methodology. The inputs for this research include solar irradiation data, life-cycle analysis, and the responses acquired from the interviewees. Along these lines, the study is the collection of this hybrid methodology, which has been demonstrated, and the derived outcomes are argumentative. A comparative account of economic feasibility for four big cities would have been more meaningful. However, it is not possible for the present research due to two reasons. First, this would lead to conduct a new survey, involving all the features of the paper, whereas, in the present situation, the data gathered through conducting interviews is merely a segment of the study. Hence, the data presented in this study has little to do in this situation. Second, this is a completely separate aspect which would be encompassed in a future study.

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APPENDIX: THE SEMI-STRUCTURED INTERVIEW

List of major interview questions and how industry experts answered (Table XII).

TABLE XII. List of major interview questions and how industry experts answered.

Construct	Items	Percentage (%)
Technological barriers	Lack of R&D and limited production facilities.	54.3
	Unreliable local technology.	15.2
	The inefficiency of indigenous solar cells and modules.	13
	Thermal loss from heat storage in solar thermal parabolic trough systems.	10.9
	The country is dependent on foreign technology for essential parts and equipment.	6.5
Policy and regulatory barriers		
	Lack of a comprehensive national solar power policy.	20.7
	Lack of legal enforcement of Renewable Purchase Obligation (RPO).	18.5
	Unbalanced RPO level.	15.2
	Limited government subsidies to support the solar energy sector.	12
	Wrong selection criteria of deciding developers for the National Solar Mission.	10.9
	Limited Feed-in Tariff for solar power projects.	8.7
	Some government policies are unclear and confusing.	6.5
	Environmental regulations have not properly implemented in the country.	4.3
	Less priority has been given to renewables as compared to conventional energy sources in the current policy framework.	3.3
Financial barriers		
	Bank loans are limited and debt financing is a major issue for solar energy developers.	21.7
	The high-interest rate for solar energy projects.	18.5
	Lack of non-recourse financing for solar energy projects.	17.4
	Strict financial closure time.	16.3
	Solar power projects have low economies of scale.	9.8
	The construction of solar energy parks is capital intensive.	6.5
	Minimal share of foreign investment in solar energy projects.	5.4
	There is hesitation from investors due to the risk associated with the performance of solar energy projects.	4.3
Transparency and accountability barriers		
	Developers are forced to pay bribes directly or indirectly.	30.4
	Lack of transparency in the acquisition of land.	22.8
	Lack of transparency in issuing contracts to the developers.	18.5
	Lack of transparency in handling the National Clean Energy Fund.	15.2
	Lack of transparency in getting approvals and government subsidies.	13
Infrastructural barriers		
	The acquisition of land is very lengthy and time-consuming.	27.2
	Poor roads and old railway structures.	22.8
	Transmission & distribution (T&D) losses.	28.5
	Commercial & technical losses.	16.3
	The grid structure is old fashioned and only supports traditional electricity.	15.2

TABLE XII. (*Continued.*)

Construct	Items	Percentage (%)
Open-ended questions		
	What is the average cost needed to produce 1 kWh solar energy?	
	What is the average lifetime of PV?	
	Do solar parks consume fuel for regular functioning?	
	What is the per hour maintenance and operation expenses for PV parks?	
	How much amount of carbon dioxide, sulfur oxide, and nitrogen oxide is emitted during the regular operation of solar parks?	

DATA AVAILABILITY

The data that support the findings of this study are available within the article and its supplementary material.

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