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Review

Outlook on the Indian scenario of solar energy strategies: Policies and challenges

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ABSTRACT

India's abundant solar energy potential provides a clean and attainable replacement for the extremely harmful, polluting and rapidly depleting conventional sources of energy. Development of policies for the viable utilization of solar energy can help India emerge as a leader in the global arena. This paper presents a comprehensive study of different policies in place to help achieve that goal while addressing the various barriers associated with the generation of electricity using solar energy. A brief overview of the development and current scenario of the Indian PV market is also discussed in this work enlisting various corporations, both public and private, in the field of development of solar photovoltaics in the country.

1. Introduction

To measure the development of an economy, many economists make use of a unit called the energy demand of the economy. Current estimates predict that the demand for basic energy sources is set to increase three fold worldwide in the coming decades [1]. Reports published by the International Energy Agency estimates India's total energy scenario to increase can be attributed to a demographic expansion making India the most populated country by 2050 [2]. Another report published by Greenpeace highlights factors like population increase and exponential GDP development that affect the future energy demands of the country, increasing the demand over 200% by 2040–50 [3]. These reports project an increase in oil demand and natural gas consumption in the coming decades. To overcome this steep rise in energy demand, it is projected that the country's power system would need to quadruple in size. While the reports demonstrate the future rise in demand for energy, they also present projections for renewables by the year 2050. The Greenpeace report projects an increase in PV installations across the country, with PV accounting for 20%–40% of installed renewable energy technologies all over India [3,4].

In developing countries, like India, various factors influence the demand for sufficient resources like income generation, social development, serious health issues that arise due to the use of fuelwood, charcoal etc. There has been a trend historically showing the amount of greenhouse gas emissions being significantly more for the developed economies as compared to the developing economies. However, recent studies suggest that this trend is now taking an opposite turn [1,5]. To combat the problems of energy poverty and the harmful environmental effects of conventional sources of energy, there has been a tectonic shift from conventional sources of energy to the non-conventional sources, namely Hydropower, Bioenergy, Nuclear, Wind and Solar energy. There has also been an increase in the use of gaseous fuels in various sectors like transportation, industry and residential. Hydropower and natural gas are clean and ideal fuels for energy production but many problems dampen the use of these sources like lack of supply, delay in clearances, public agitations and certain harmful effects of large hydro dams on the environment [6].

Keeping up with the global trend, India has also shifted towards renewable sources of energy to meet its energy demands. In 1974, the electricity demand in India was being supplied with a total installed capacity of 16.7 GW, all of which was owned by the Central and State Governments [6,7]. Out of this capacity, more than half (51%) was being operated using coal as fuel, 42% with large hydro, and 4% with nuclear and 2% with gas, with renewables accounting for 0% [7]. The oil crisis in the 1970s′ was a welcome shock for the Government as it pushed the focus from coal to renewables. This coupled with the early 1990s’ financial crisis and engagement of the private sector in industrial development, brought about by the liberalization and industrialization of the Indian economy in 1991 triggered a growth of the renewable energy sector [8].

India, being a tropical country, has an abundance of solar energy. Its geography allows many regions to receive a vast amount of solar

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radiation throughout the year. Forecasting done throughout the country based on satellite and then authenticated by ground data shows that 500000 TWh of electrical energy is being received by India's lands, with most regions receiving 4–7 kWh/m^2/day [9]. The maximum global horizontal irradiance is received in the states of Rajasthan and Gujrat.

The technology for solar power plants can be broadly classified to.

1. Solar Photovoltaic (SPV) plants
2. Solar thermal Power plants.

Solar Photovoltaics technologies can be further classified into monocrystalline Si solar cells, multi-crystalline Si solar cells and thin film solar cells. Crystalline Si solar cells currently occupy 85–90% of the global PV market while thin film technologies occupy a minority section of the PV market, with most technologies becoming next to obsolete [10]. Each solar cell technology has its own merits and demerits but PV is the key to decarbonize the energy supply. This is of utmost importance in the Indian energy context considering India is currently the third largest emitter of CO_2 (after USA and China). Studies show that the CO_2 emitted by solar photovoltaics throughout lifetime of the plant is far less than the conventional power plants i.e. coal. This can also be attributed to the fact that most CO_2 equivalent emissions from solar power plants occurs during the manufacturing stage [11]. Fig. 1 clearly shows the comparison between the life cycle emissions of various sources of energy in tons of CO_2 equivalent per GWh.

The abundance of solar irradiance, the need for rural electrification, the benefits of solar energy and development of the solar market has led to the development of major policies over the years. Section 2 and 3 cover the development of the PV market in India followed by the major policy changes that have taken place in the country regarding solar energy. Section 4 describes the various challenges in the development of policies and deployment of technology. Section 5 gives various suggestions as to what immediate measures can be taken to remedy the situation.

2. Solar PV market in India

The Paris Agreement to decrease the GHG emissions has given a push to the development of new and efficient renewable energy technology. The first PV cells were expensive and gave a very low efficiency whereas the energy produced through coal was cheap and readily available. But over the years, an exponential decline has been observed by various studies in the prices of PV technologies. A study suggests that the price of solar panels has dropped by up to 80% since 2009 alone [12]. This decrease in cost along with the requirement to decarbonize the energy supply has led to an increase in PV installations. The costs of solar PV have also shown a downward trend from 2010 to 2015, illustrating a drop in prices from 0.285 USD/kWh to 0.126 USD/kWh [1,12]. A report published by the International Energy Agency in 2018 describes the low cost of PV tenders in countries around the world. The levelized cost of electricity were at a record low of 2.1 USDcents/kWh in Chile and Mexico while Europe saw the costs go down to 5 USDcents/kWh [13].

These factors have enabled the development of solar PV market in the country as well as worldwide.

2.1. Initial development

The development of the PV market in India can be broken down into three major changes that happened near the end of the 20th century, which is shown in Fig. 2 [14]:

Simultaneously, the technological aspect of PV technology that has improved significantly over the years, is the efficiency, ranging from 8 to 9% in the 1980's to almost 20% in the last few years. This can be seen as a tremendous achievement considering the efficiency of PV cells was 1% at the time of conception of the technology. Along with improvement in performance of PV cells, the costs per peak watt have also declined [15,16].

2.2. Corporations involved in PV development

The 1980's saw the seed being sown in the field of PV development with the Government forming the Department of Non-Conventional Energy Sources (DNES) in 1985–86 as part of the 5 year national programme. The DNES was later given ministry status. The second company to include PV products in its portfolio was a public sector company, namely Bharat Heavy Electrical Ltd. (BHEL), which was originally in the business of equipment of power generation [14]. The DNES and BHEL held a monopoly over the market, with only one or two private sector companies entering the market of PV.

A major turning point in the field of PV was the establishment of TATA BP Solar Ltd, which was a joint venture of BP Solar, (UK) and

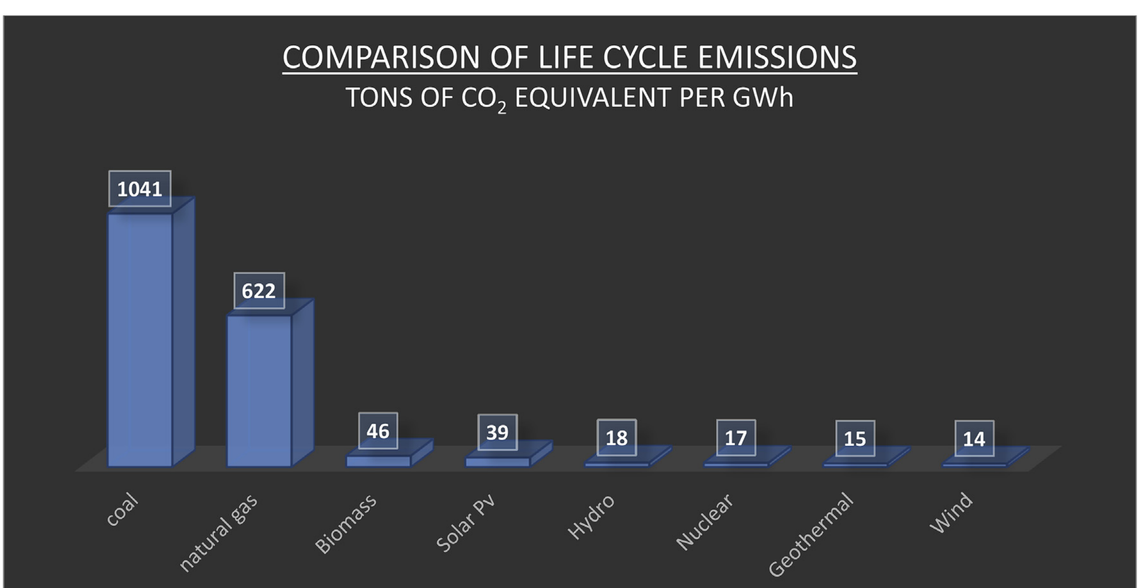

Fig. 1. Comparison of life cycle emissions [11].

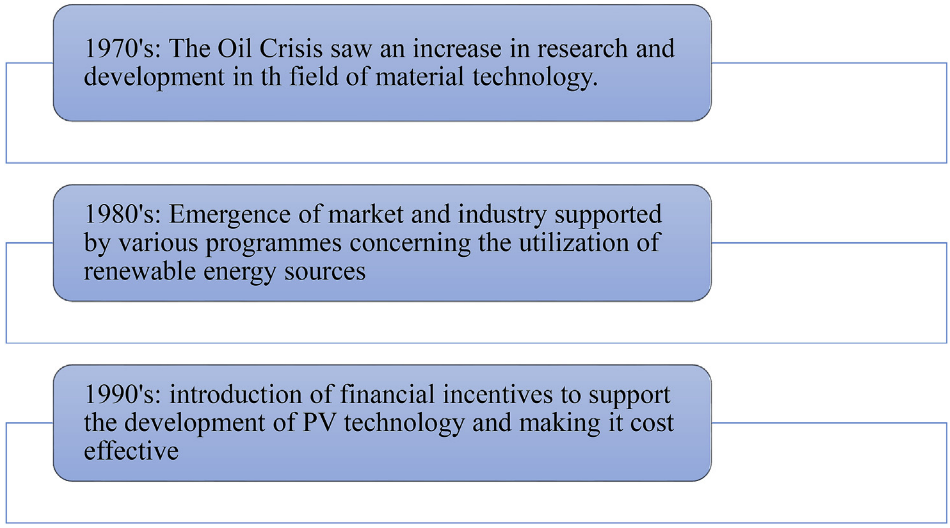

Fig. 2. Development of PV market in late 20th century in India.

Table 1
Corporations involved in PV installations state wise [34].

State	Names of Corporation
Rajasthan	Alex Spectrum Radiation Pvt Ltd., Maharashtra Seamless Ltd., Mahindra Solar One Pvt Ltd., SunEdison Energy India Pvt Ltd., Azure Power Pvt Ltd., DDE Renewable Energy Pvt Ltd.,
Tamil Nadu	CCCL Infrastructure Ltd.
Uttar Pradesh	EMC Ltd.
Orissa	Aftaab Solar Pvt Ltd
Andhra Pradesh	Saisudhir Energy Ltd., WELSPUN Solar AP Pvt Ltd.,

House of Tata. In 2001, TATA BP Solar was the major manufacturer of solar panels in India. The 21st century saw an overwhelmingly large number of private corporations venturing into the solar PV sector. A report published by the Ministry of New and Renewable Energy, outlining the targets and achievement of the National Solar Mission shows the various corporations involved in PV installations and development throughout various states of the country [34]. Table 1 highlights some of the corporations involved in respective states.

2.3. Future prospects of PV market in India

Owing to the growing demand for non-conventional sources to meet the daily basic needs of energy, solar PV market has taken a leap from where it was in the later part of the 20th century to where it is now. The domestic manufacturing market has grown courtesy of the Make in India Policy of the Government. This has led to several private sector corporations jumping in to the solar PV market. Table 2summarizes the list of top corporations involved in solar PV development:

3. Policy development in India

The research and development in the field of solar photovoltaics began in the 1980's with the main objectives being the research on solar cell materials as well as the development of solar photovoltaic module manufacturing sector [20]. To boost the field of solar photovoltaics and other renewable energy sources, the Ministry of Non-Conventional Energy Sources, which later was renamed as the Ministry of New and Renewable Energy (MNRE), was formed. The MNRE was the first of its kind Ministry to be established in the world with the sole purpose of drafting and implementing various policies for the development of renewable energy in the country [21]. Research indicates that India was the 3rd largest consumer of solar energy in 1995. In 2002, major solar energy was employed in the telecommunication sector, street lighting applications, solar powered pumps and other applications.

3.1. Requirement of solar policy in India

As previously stated, the energy sector was majorly operated by the use of coal as fuel source while renewables accounted for 0% of the entire energy sector. Several authors attribute the development of any industry to vitality, supply and accessibility. The electrical capacity in the country was 1350 MW in the year 1947, which has increased more than 100 times to a staggering 160000 MW in 2018. It has further been projected that the next 7 years will see a demand of 90000 MW to meet the basic electrical needs. At the same time the IEA (International Energy Agency) projected India to be the 2nd largest contributor in global energy demand by 2035 [10,22]. Studies indicate that although development of new technology leads directly to greater productivity and improved lifestyle, it simultaneously brings about socioeconomic changes in the society that may be opposed by the people [23]. The key elements in the Indian Energy strategy are awareness, grid parity and cost competitiveness and cost effectiveness. In order to achieve these, a sound and steady policy is required. Subsidizing the renewable energy production is a step in that direction but research indicates that subsidized renewable energy production is still 50% more expensive than conventional means of generation [24]. To achieve all the aforementioned targets policies in the direction of development of solar energy is a need of the hour.

As it has been mentioned in many published works, India has an abundance of solar resource as a result of India's geography and location. This abundance of solar resource gives a lot of flexibility to policy makers for the development of solar energy in the country. The year round abundance of solar energy makes it a viable source to meet the energy demands of the country.

3.2. Major policies in India

To promote R&D in the photovoltaics sector, the Government of India had set up the Commission for Additional Sources of Energy in the Department of Science and Technology. It was later merged with the department of Non-Conventional Energy Sources in 1992 [21]. Despite the establishment of these organizations, the renewable energy installed capacity was limited to only 29% of total installed capacity in 2002. Lack of exploitation of the available non-conventional resources led to the formation of many policies that later shaped the development of the solar PV industry. These policies were introduced as part of 5

Table 2
List of major corporations involved in PV development [17–19].

Tata Power Solar Systems Ltd	• Subsidiary of Tata Power • India's leading solar company. • Manufactures solar cells, modules and other solar products.
EMMVEE	• One of the most diverse solar companies in the country. • Founded in 1992 • Offers solar PV as well as solar thermal products.
Kotak Urja Pvt. Ltd.	• Founded in 1997 in Bangalore • A subsidiary of Kotak Group
Icomm Tele Ltd.	• Boasts of a presence in the international market • Offers solar solutions in the field of telecom, power and defence.
Mosar Baer Solar Ltd.	• Also has a global presence • Produces crystalline and thin film modules for different PV systems. • Assisted the ANERT program in Kerala to install solar panels on rooftops.
Indosolar Ltd.	• Founded in 2008 with the aim of developing world class manufacturing techniques.
Enertech Group	• Began in 1990. • Leading solar UPS manufacturers in India. • UPS is equipped with in-built multi power point tracker.
Delta India	• Delta India is the first to cross the milestone of over 1 GW rooftop installations.
Toshiba Mitsubishi-Electric Industrial Systems Corporation	• Formed in 2003. • Company supplies Solar Inverters in 1000 V and 1500 V capacities in industries across India.

year plans (10th and 11th) from 2002 to 2012. These plans targeted an addition in the installed capacity of 25 GW by 2012. Later on many other policies were formulated that have been discussed in the next section. These policies have helped increase the installed capacity of renewable energy with solar accounting for 19% of total installed renewables. A positive trend in the installation and development of solar energy has induced lucrative investments from the Government with INR 3000 crores (equivalent to 30 billions) being solely set aside for the development of solar energy in the fiscal year 2016–17 as well as increased the solar photovoltaic targets to 100 GW by the year 2022 [4,18,19,25]. Private investments have also played a major part in the development of solar energy. The major policy changes that were introduced to boost the renewable energy sector and solar energy sector are briefly discussed.

3.2.1. *Electricity Act 2003*

The Electricity Act of 2003 was enacted to transform the power sector in the country and to consolidate laws relating to generation, transmission and distribution of energy throughout the country [26]. It was introduced with the aim to promote the development of the electric industry, supply of electricity to all areas especially rural as well as to rationalize the tariff. This act authorized the Central Government to introduce polices regarding electricity generation in consultation with the State Governments [27]. The Tariff Policy came into existence because of the implementation of the Electricity Act. It suggested a policy that permitted the development of stand-alone systems. The Electricity Act also aimed to privatize the generation, distribution and transmission sectors. In accordance with the act, Feed in Tariff (FIT) and Renewable Purchase Obligation (RPO) were introduced.

3.2.2. *Tariff policy (2006)*

The Tariff Policy of 2006 was brought into effect in continuation with the National Energy Policy of 2005. This policy was to include provisions regarding renewable energy and cogeneration. The Tariff Policy was developed keeping in mind the framework established by the Electricity Act of 2003 [28]. The tariff policy has evolved over the years in consultation with the state governments and the Central Electricity Authority. Fig. 3 lists down the main objectives of this policy as [29]:

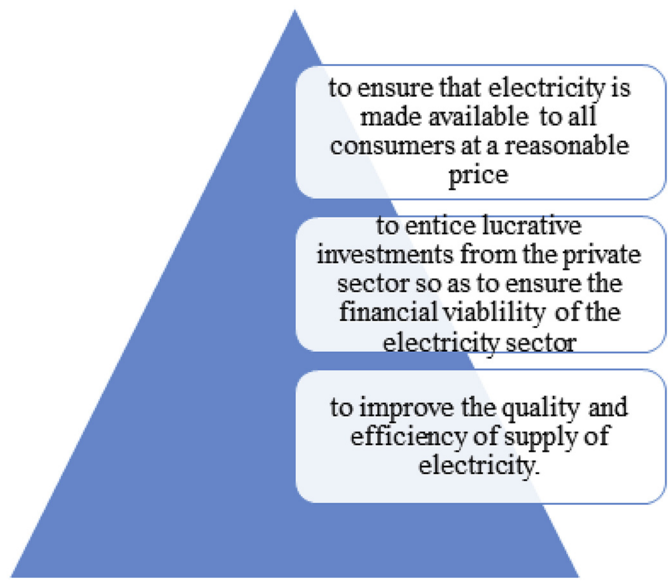

Fig. 3. Main objectives of Tariff Policy 2006.

The aim of this particular policy was to give special tariff to renewable energy generation. The Central Government notification suggests that guidelines have been issued for tariff based bidding process to procure electricity generation and distribution licences. Through this, the Central Government aims to introduce competitiveness in the process of price determination. The Central Government believes that this competition will lead to significant benefits to consumers by bringing about reduction in capital costs and a significant increase in efficiency. The tariff policy was further amended on 31st March 2008, 20th January 2011, 8th July 2011 and the last amendment being notified on 28th January 2016. This amendment added certain objectives to the original Tariff Policy as more focus was given to renewables and Hydro power to facilitate adequate and uninterrupted supply of electricity to consumers [30].

3.2.3. *Integrated energy policy 2006*

The Integrated Energy Policy was developed by an expert committee of the Planning Commission under the directive of the Deputy Chair of the Planning Commission and the then Prime Minister of India Manmohan Singh [31]. This policy was brought into effect in August of 2006 addressing all aspects of energy in the country including energy security, access and availability, affordability and effects on the environment. Recognizing the adverse effects and the inadequacy of supply coupled with projected increase in demand for conventional sources of energy, the policy proposed the following in relation to solar energy [31,32]:

I. It required power regulators to seek alternate incentive structures that encourage utilities to integrate solar and other renewable energy sources like wind, small hydro, and so on into their systems.
II. Requiring power regulators to mandate feed in laws for solar energy as provided under the Electricity Act 2003.

A general goal of this policy can be summarized to provide safe and convenient energy at lower cost in an efficient and economically viable and environmentally sustainable way.

3.2.4. National Action Plan on climate change

Recognizing that climate change is challenge that needed immediate attention, India, in collaboration with the United Nations Framework Convention on Climate Change, introduced the National Action Plan for Climate Change (NAPCC) in 2008. The aims of the NAPCC was primarily to address the urgent and critical concerns of the country as well as to promote the development objectives without compromising the environment. One of the most successful plans of NAPCC was the National Solar Mission which aimed to increase the share of solar energy in the total energy mix of the country. The National Solar Mission also aimed to launch major R&D programmes in order to create more affordable and convenient solar systems with provisions for long term storage options [33]. Many research works have recognized the numerous schemes that have been introduced under the National Solar Mission that have assisted in electrifying remote areas which earlier had next to zero access to electricity. Under these schemes Dharnai has become the first village to achieve 100% installed solar capacity with 100 kW lighting around 450 homes [9]. Along with that, aggressive R&D has also been initiated empowering the domestic manufacturing sector and creation of intra-state transmission lines in states like Gujrat, Himachal Pradesh, Karnataka, Madhya Pradesh, Rajasthan and Maharashtra [21]. Section 3.2.6 covers briefly the objectives and installation targets under the National Solar Mission.

3.2.5. Generation based incentives for solar (2009)

The generation based incentives scheme for generation of energy using solar energy was introduced in 2009 to boost electricity generation using solar photovoltaics. This scheme targeted mainly the small grid solar projects below 33 kV and aimed to lower the gap between base tariff of INR 5.5 and the tariff demanded by the Central Electricity Regulatory Commission [20]. This was presented as an incentive to attract private investments in the field of electricity generation using solar photovoltaics.

3.2.6. Jawaharlal Nehru National Solar Mission (2010)

The Jawaharlal Nehru National Solar Mission is a major initiative by the Central Government with active participation of the states to promote ecologically sustained growth while addressing the challenges of energy security and energy poverty. Before JNNSM, the solar capacity of the country was a mere 17.8 MW [34]. The mission was announced in 2010 with it being implemented in January 2011. The mission outlined specific targets of 20000 MW grid connected and 2000 MW of off grid solar power capacity, including both solar photovoltaics and solar thermal energy [20,34]. The main objective of JNNSM is to establish India as a global leader in solar energy. The mission adopted a three phase approach spanning a period of 10 years with targets set for each phase based on the success of the previous phase and any improvement in technology for use of solar energy. Fig. 4 depicts the phase wise targets of JNNSM [34–37]:

Several authors published reviews of JNNSM to ascertain whether the targets mentioned under the above phases could be accomplished. Shrimali et al. identified JNNSM as one of India's key policy in the field of solar energy. They suggest that while the policy may be bold in its goal and approach, yet it holds the capability to transform billions of lives in the country [38]. Harriss-White et al. believe that though the technologies to accomplish the goals are available, the policy may be obstructed by the structure of energy subsidies, risk aversion of banks and the failure in coordination of market-state institution [39].

Different schemes and policies have been introduced under the JNNSM to accomplish the targets set for solar power addition. The MNRE, under the tutelage of the Government of India, has initiated the concept of solar cities. These solar cities aim at about 10% deduction in the projected demand for the presently used conventional sources of energy. Over 50 cities have been identified for conversion into solar cities with a funding of INR 5 million per city varying on the basis of population and initiatives [40]. In addition to solar cities, development of solar parks has also been initiated wherein solar parks will be developed in regions with a solar capacity of over 500 MW supported by appropriate funding by the Government to develop the necessary infrastructure [41]. As per the latest data published by the MNRE, solar parks with a capacity of 26.5 GW have been approved all over India in 22 states [42]. The government has also implemented the scheme of awarding concessional customs duty certificates as a financial incentive to developers for developing grid connected solar power plants [43]. This scheme offers developers concessions on duty that is levied on imports and exports. There have also been increased efforts to develop grid connected solar PV plants on canal banks and tops. With this scheme, the MNRE intends to set up PV plants of capacity 1–10 MW to an aggregate capacity addition of 100 MW to help achieve the targets under phase II of JNNSM [44]. Under this scheme, eight canal top and canal bank projects have been approved in eight states. A funding of INR 30 million/MW for canal top SPV projects and 15 million/MW for canal bank SPV projects have been approved for each project [45].

3.3. Policy instruments/incentives: generation based and financial

A number of published works validate numerous policy instruments and incentives that have been employed by the Government under various policies to improve the solar energy generation capacity in the country. Timilsina et al. enlist certain key instruments namely feed-in-tariff, investment tax credits, subsidies, favourable financing etc. [46]. Rohankar et al. reiterate the various financial incentives under various policies of the Government like long term power purchase agreements, renewable purchase obligations, renewable energy certificates etc. [47]. The following tables (Tables 3 and 4) categorizes different policy instruments that the Government has employed to promote the development of solar power in the country.

A number of capacity building instruments have also been assigned in certain policies like tax holidays, increasing the amount of foreign investment to 100%, viability gap funding to reduce the upfront costs of installations.

3.4. International solar alliance

The International Solar Alliance (ISA) is a joint venture of 121 solar rich countries with the vision to provide a dedicated platform for the cooperation among the countries to promote global development of solar energy generation [48]. The ISA was spearheaded by Prime Minister of India Shri Narendra Modi and the President of France Emmanuel Macron in 2015. The ISA aims to provide a platform where the global community, including bilateral and unilateral organizations, corporations and industrial entities can come together to achieve their common goal of increased development and use of solar energy. The ISA is headquartered in the city of Gurugram in the state of Haryana, India at the National Institute of Solar Energy (NISE), which is an organization devoted to the research and development of solar energy. In the Indian perspective, the targets set under the ISA are to achieve an installed capacity of 175 GW by 2022, out of which solar accounts for 100 GW. Globally, the ISA aims to deploy 1000 GW of solar energy generation with an investment of $1000 trillion [49].

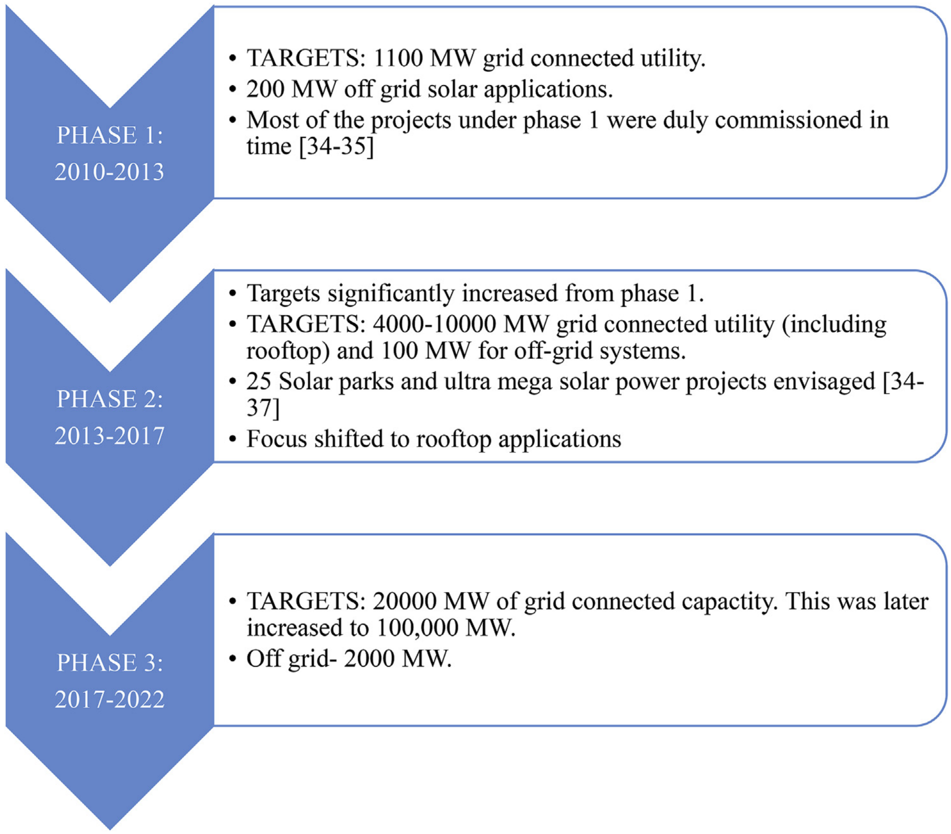

Fig. 4. Phase wise targets of JNNSM.

3.5. Organizations involved in solar energy development

Various public sector as well as educational organizations have been established in India by the Government to focus on research and development activities on solar energy. The following section discusses the public sector organizations as well as several educational institutes set up within the country that take part in promotion and development of solar energy.

3.5.1. Public sector organizations

Fig. 5 highlights the public sector organizations devoted to the development of solar energy capacity in India [50,51]:

3.5.2. Educational institutes

Along with the above mentioned public sector organizations established for the development of solar energy systems, a number of centres for research in the field of solar energy and other renewable energy systems have been set up in various educational institutes throughout the country. Along with assisting the ministry with research in the field of renewable energy, these centres also build the skill force in the country by imparting knowledge about the renewable energy systems. Some of the institutes involved in the field of renewable energy are mentioned in Table 5:

4. Major challenges to development and deployment of solar energy

The abundance of solar resource is not the only factor involved in the development of solar energy generation capacity of the country. Several factors prove to be an obstacle in installing solar PV plants and operating them at their full capacity. The following section briefly discusses the various challenges that need to be overcome in order to achieve the capacity addition targets. They can be subcategorized as under:

4.1. Technological barriers

Although the solar photovoltaic technology has taken enormous leaps when it comes to technology, it still hasn't proven to be enough. Research suggests that the low conversion efficiency of solar photovoltaic technology compared to conventional systems remains to be the biggest technological challenge in development of solar energy systems [6]. Another barrier is that PV plants are rarely able to provide an immediate response to load demand. This problem does not arise in conventional power plants and thus makes them more effective [62]. Although the use of storage mechanisms like battery banks helps deal with this challenge but autonomy can only be provided for so many days without increasing cost and size of plant. As it has been mentioned in earlier sections, a different variety of solar PV technologies are

Table 3
Generation based Policy Instruments [46,47].

Feed-in-tariff	FIT is a benchmark tariff issued by the Central Electricity Regulatory Commission for purchase of solar energy and other renewable energy.
Renewable Energy Credits	This scheme was introduced in the NAPCC by the MNRE. This scheme provides a predetermined quota for solar. It was introduced with the aim of enhancing the demand for solar energy based electricity.
Renewable Purchase Obligation	This policy instrument mandates State and private distributors to purchase solar generated electricity.

Table 4
Finance based Policy Instruments [46,47].

Tax Benefits	Under this scheme, the Central Government provides tax benefits for solar power projects. Under this scheme, the project developers are exempted from paying taxes on earnings by selling the power produced from solar energy for a period of 10 years.
Power Purchase Agreement	As part of the National Solar Mission in NAPCC, developers are permitted to sign a long term power purchase agreement with special tariff for a period of 10–25 years. This incentive intends to cover the high capital cost of solar power installations.
Concessional custom and excise duty	This incentive was introduced to exempt the developers from customs and excise charges on the export of certain parts of solar plants to avoid the developer pulling out of the project thus leading to incomplete projects.

available in the market. But the efficiencies of each of these technologies looks considerably low in comparison to conventional power plants. Several studies also depict various other technological barriers in the development of solar energy generation like the intermittent nature of solar radiation which hampers the ability of the PV system to meet the consumers demand, difference in the standard conditions and real time conditions also effect the performance. Component failure often leads to inability of solar PV system to generate electricity until the component is replaced [63]. Operation in high temperature and mismatch in output from individual panels in a PV array often leads to the creation of hotspots which reduce the efficiency of the solar PV plant. These hotspots in the long run cause severe deterioration of the PV panel thus increasing the cost of maintenance and repair. To avoid the formation of hotspots, quality check is a must for PV module developers. Standards must be set for the manufacturer to improve the quality and lifetime of the PV modules.

4.2. Economic barriers

High initial investment cost of the PV technologies often leads to discouragement among developers who refrain from investing in solar PV technologies [62]. Absence of a proper financing mechanism poses a challenge in the development of PV installations. Research indicates that the investment required for PV installations is relatively for developing countries due to a variety of factors [63]. These factors also cause a hindrance in solar PV development in the country. Dobrotkova et al. studied the cost viability of solar PV prices in developing countries. They concluded that even though low cost of PV installations is possible, it requires the support of a variety of factors like high capacity factors, low cost of auxiliary equipment, low risk investments etc. [64]. Their research suggests that there are concerns among experts over the process of auction based PV procurement as they believe that auctions may lead to unviable prices that may lead to poor quality of projects. The interdependency of markets and prices often leads to developers backing out of projects due to unforeseeable risks. Nowadays, although various tax exemptions have been implemented on solar PV technologies, tax still remains a hurdle in low cost solar PV development [63,64]. The cost of energy produced using PV technology is measured using levelized cost of energy. The economics of solar PV generation take into consideration the factors like cost of PV panels, battery sizing, peak ratings of load, power factor required etc. These are to be borne by the consumer. These factors often increase the investment costs for installations and thus discourage consumer interest in the technology [65].

4.3. Environmental barriers

Many studies indicate that while solar energy is cleaner than conventional energy sources, it still brings with it many environmental impacts that can cause harm to the environment as the years pass. Shahsavari et al. state that major environmental impact due to the PV technology happens during the process of manufacturing of PV panels. This happens due to the use of toxic compounds in the production lines [1]. Another study indicates that Cadmium telluride and copper indium selenide thin film technologies may harm the environment due to the presence of selenium [66]. While crystalline silicon panels' composition mostly comprises of non-hazardous waste, the mass of thin film and cadmium telluride etc. consist of hazardous material that may need proper treatment [67]. The use of PV panels and batteries adds to the e-waste from the PV plant over its lifetime. The recycling of e-waste remains a big challenge in combating the impact of PV technology of the environment.

4.4. Social barriers

Making full use of the advantages offered by solar PV technology still hasn't been possible majorly due to lack of social awareness about the technology. This is a hurdle in the development of solar PV systems especially in developing countries. Lack of understanding of the technology has proven to be an obstacle in the acceptance of solar PV as an

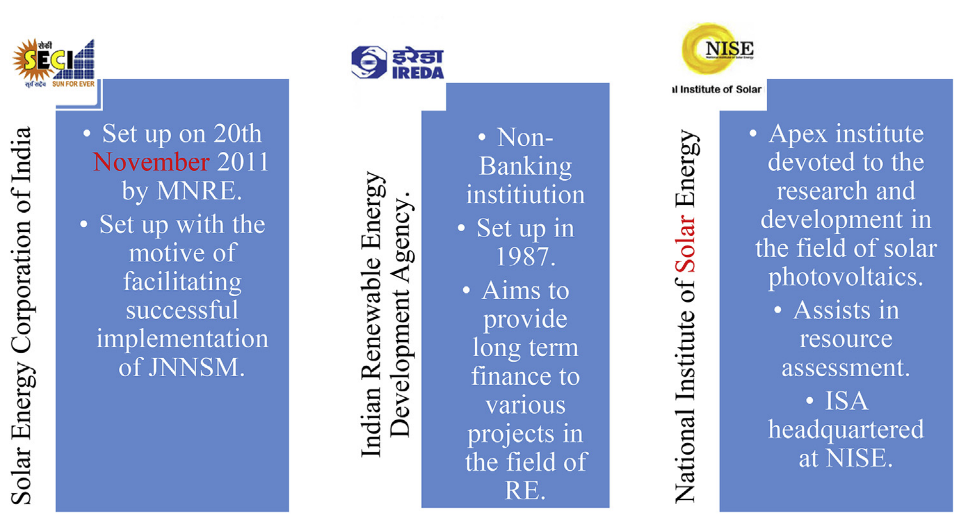

Fig. 5. Public sector organizations in solar energy.

Table 5
List of educational centres in India focussed on development of Renewable Energy Technology [34,52,53,54,55,56,57,58,59,60,61]

IIT Mumbai	• Set up in 2009–10 • Focussed on research and education in the field of Photovoltaics.
IIT Delhi	• Set up in 1978 • Centre for Energy Studies.
IIT Rajasthan	• Set up in 2011–2012 • Focussed on research and education in the field of solar thermal technology
IISc Bangalore	• Centre of Excellence established with the focus on development of decentralized solar thermal power applications.
NIT Hamirpur, Himachal Pradesh	• Centre for Energy and Environmental engineering established in2009. • Actively engaged in different environmental engineering research areas and promotion of renewable energy sources. • Energy Park established under Himurja.
NIT Tiruchirapalli	• Centre for Energy and Environmental Science and Technology established in 1995. • Major research areas include solar energy, bioenergy wind energy and energy efficient building design.
NIT Jaipur, Rajasthan	• Vision is to foster renewable energy technologies, to provide higher education and training programmes in the area of renewable energy.
NIT Bhopal, Madhya Pradesh.	• Department of Energy established in 2004 with the objectives of providing quality education and contribute to research and development in the field of energy and environment.
Anna University	• Centre for New & Renewable Sources of Energy established in the year 1984 and later it was renamed as Institute for Energy Studies (IES) in the year 1999. • Major objective is to promote sustainable development and reduce carbon footprint.
TERI University	• Department of Energy and Environment set up with the mission to address the challenges relating to energy needs and environmental management. • Undertake research in fields of renewable energy, climate science, etc.
Jadavpur Universty	• School of Energy Studies founded in 1984 to initiate activities in energy research. • The major thrust areas of the research activities are concentrated in the field of Renewable Energy, Integrated Energy Systems, and Energy Conservation. • School also has international collaborations with University of Newcastle, UK University of Ulster, Northern Ireland, UK.
BITS Pilani	• Centre for Renewable Energy and Environment Development started with the objectives to conceive, develop and employ renewable energy application projects. • Centre collaborating with MNRE, IREDA, Institute of Flensburg Germany to further the development of alternate energy.

option by the local consumers. Inadequacy of land also is a problem as large areas of lands are required for the construction of large capacity solar PV power plants [1,68].

4.5. Auxiliary barriers

Many studies enlist a number of challenges in the development in of solar PV systems in the country. These challenges may be of small magnitude but their effects can be felt on a bigger scale. Dust deposition and inadequate cleaning of solar panels often causes decrease in the efficiency of the panel as dust obstructs the incoming insolation from the sun [69]. Also uncertainties and unavailability of weather data leads to improper design of the system for any given loads [1]. This may cause reduction in the lifetime of the system leading to less or no return on investment for the developer. Authors suggest that lack of legal framework for independent power producers coupled with restrictions on siting and construction also obstruct the PV development in the country [68]. Another study indicates that lack of storage technologies, shortage of certain materials is another obstacle that must be dealt with to improve the status of PV installations in the country [62,70]. Market failure due to external factors often hinders the solar PV development. Factors may be the high financial risks due to future uncertainties of return on investment in scheduled time period, underinvestment in solar PV technology etc. [71].

5. Discussion and suggestions

With the abundance of solar energy in India, over the next few years, with policy support and improvement in technology, solar energy technologies for electricity generation are well placed to meet the increasing demand for energy. Several published works, while addressing the issues with solar energy generation, do not refute the capability of solar energy to address the issue of energy security and combat energy poverty in developing countries. Solar photovoltaics is one of the technologies which utilizes the abundant solar energy available to generate electricity. As has been discussed in section 1 of this manuscript, several reports published by international energy agencies highlights the rise in energy demands, both worldwide as well as in India, in the coming decades. In order to meet these high demands, mobilizing cost efficient investments is required for Indian policy makers at both national and state level with effective cooperation between various levels of Government. Achieving a 100% renewable based system should also be a target for policy makers in the coming years. Studies show that achieving a 100% renewable based power system can be attainable and more cost effective as compared to fossil fuel based systems [72].

Over the course of the past two decades, several policies have been brought into effect to accelerate the development of solar energy development in the country and thus decrease the dependence on conventional sources of energy for the energy needs of the country. India, being a country with more population in the rural sector than the urban, has had policies developed in terms of electrification of the rural areas and providing resources adequately to these villages. A recent influx of policies focussing on overall development of rural areas has helped make substantial gains in the 100% rural electrification target of the Government. While Government reports show almost 100% rural electrification in the country, independent reports and published works state that these numbers are not exact and many villages are still in the dark. Of all the policies, none have focussed on solar energy development as compared to the JNNSM. Set for a period of 10 years with targets like never before, this policy for solar energy development has been the most successful in increasing the solar energy installations in the country. Under JNNSM, the total installed capacity of solar energy generation in the country has reached almost 26 GW as of October 2018. A variety of schemes have been implemented under the JNNSM with the aim of exploiting the full potential of solar energy available in India and push the installations in the direction of the 100 GW target. Along with introducing state wise schemes under JNNSM, the government has also taken steps at the central level to help achieve that target. The central public sector undertakings and the Defence Ministry have been issued directives to implement grid connected solar PV plants on defence and government establishments. This move encourages private developers and residential customers to implement solar PV plants thereby adding to the capacity of solar energy generation.

Along with large scale electricity generation and localised generation using rooftop PV plants, floating PV plants are also being considered as a way to address certain issues pertaining to PV electricity generation [73]. With large water bodies surrounding India, and a number of rivers flowing within the Indian borders, floating PV can and should be utilized to increase the PV installed capacity in the country. Floating PV not only helps overcome the land unavailability, it also provides an easy solution for the temperature rise problem in PV with the flow of water acting as a natural coolant hence providing a higher energy output. Floating PV plants can be installed on dams which would help in increasing the energy generating capacity of that hydro power plant [74]. The natural flow of water over the floating PV plants can help clean the panels of any dust which would have otherwise caused shading of the panel reducing its conversion efficiency. While the abundance of water bodies around the country can help facilitate solar PV installations, the lack of water in regions where mostly the PV plants are located causes a major problem as regular cleaning and maintenance is not possible. Another problem that poses a barrier to solar deployment in the country is the imposition of safeguard duties on imports of parts and materials for PV plants. Though the aim of these duties is to protect the local developer, the current incapability of the domestic manufacturing sector makes these duties on imports an addition to the already high capital costs. This has discouraged the developers to venture into the solar energy market. Table 6 summarizes the various problems associated with utilizing solar energy. Certain measures that can be taken to overcome the problems are also suggested.

All the above mentioned suggestions can help overcome the many barriers solar energy development faces in India. India's geographical location gives it an advantage where solar energy can be abundantly exploited for a major part of the year. States like New Delhi, Maharashtra, Gujrat, and Rajasthan with sufficient solar radiation falling throughout the year can develop policies that provide a helping hand in achieving the targets for 2022.

Rooftop generation is by far the most promising solution for achieving the 100 GW target of solar energy generation under JNNSM. Rooftop generation provides a solution for the land issues addressed in the previous section, adds to the solar thermal generation in the country and provides consumers an opportunity to become self-sufficient, monetary benefits aside. Only with the implementation of strict policies for rooftop generation and adhering to those policies can solar energy rise as the best alternative to replace conventional fuels as the primary source of energy. Along with policies, the government needs to address the issue of financial aid for MSME's (Micro, Small and Medium Enterprises) to overcome key financial barriers and remover any hindrance in solar PV installations. While addressing the issues with solar power generation, the opportunities that arise with solar energy also need to be mentioned. Apart from combating the rising concerns of climate change, solar energy also addresses the issue of energy security. The secured supply of energy is a factor that can threaten the development of any country. Solar energy can be an answer to energy security and fasten the process of development in underdeveloped and developing countries.

6. Conclusion

The authors of this work have tried to comprehensively study and understand the policies in place for the development of solar energy in India and the barriers that need to be addressed for successful policy development and deployment. Solar energy is a promising approach to meeting the forthcoming energy demands and addressing the concerns for climate change.

- Although solar energy development has started picking the pace, rooftop generation still remains to an area were significant strides have not taken place.
- The suggestions discussed in previous section may help overcome that hurdle and provide an alternative for large scale installation issues like land availability, long range transmission, large auxiliaries etc.
- Technological advances also are required to help meet the targets of solar PV installations. With aggressive R&D, the correct policy implementation and proper financial schemes to address the issue of funding for PV installations, solar energy generation can accelerate the development process in India.
- Many educational programmes initiated by the government have increased the research being undertaken in the field of renewable energy.
- Setting up of separate centres and schools with the purpose of undertaking research projects in the field of solar energy has been a welcome step in the direction of enhancing the use of these energy sources.
- Over thirty centres have been set up under various scholarship programmes in India. A large research base all over the country gives the government the luxury to implement and encourage research and development of solar energy.

JNNSM has been the most efficient policy that has been brought forward by the policy makers with the purpose of enhancing installed capacity of solar energy generation. A culmination of several schemes

Table 6
Problems associated with solar power generation and Suggestions.

Problems	Suggestions
Conversion Efficiency	• Use of concentrated solar photovoltaics can help overcome this challenge. CSPV plants have a higher conversion efficiency than traditional PV power plants. • Regular maintenance can help address the issue of dust accumulation that cause low efficiency as dust reduces the area for absorption of solar radiation.
Land Requirements	• 1 MW uses over 10000 square metre of land. Rooftop generation helps overcome the issue of excess land requirement. • Another way to deal with land issues is utilizing building integrated photovoltaics (BIPV). BIPV makes use of thin film solar PV cells which are more flexible than traditional solar PV technologies. Although, BIPV comes with a disadvantage of its own as it is expensive than regular PV plant. • With a large portion of the country surrounded by water bodies, floating PV plants are an alternate to land power plants.
Policies for Rooftop Generation	• Stringent Rooftop policies are the need of the hour. • Need to create awareness among residential consumers and provide clear and credible information about various factors regarding rooftop generation like market for PV, availability, service and maintenance, net metering benefits. • Rooftop generation has many advantages like no land requirements, reduction of transmission costs as it directly supplies electricity to household.
Funding for Solar PV installations	• Banks need to be more flexible in regard of loans for PV installations for small and medium enterprises and residential consumers. • Limiting stages of approvals required to obtain net metering benefits. • Government should introduce use of a credit guarantee mechanism which provides a third party credit risk mitigation to lenders which will cover the risk for the lender and help the borrowing party pay back in case of a default. • Removing duties on imports of panels to bring about a reduction in the high capital costs of PV plants.

around the country has enabled its success. However more effort needs to be put in to achieve the required targets. Rooftop solar remains a promising area for implementation of solar energy programmes and initiatives that may push limits in terms of solar energy capacity and simultaneously lead India to being a green energy nation. A tropical geography, a large market base, attractive policy incentives and a plethora of educational and research facilities make India a prime contender to be a leader in the global energy market.

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