Solar Energy Sector in India: Exploring Actors, Knowledge Production and Innovation

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Abstract:

This paper presents the current solar energy scenario in India and explores the ways in which various actors, agencies and policies shape the solar energy sector in the country from different perspectives on the system of innovation literature. To make the country as one of the leaders in terms of solar energy generation and to promote ecologically sustainable growth, addressing the nation's energy security challenge is one of the visions of *the National Solar Mission*. The paper explores the role played by the significant presence of productive R&D institutions, universities and supportive policy. The study also highlights the increase in research outcomes in context to the patents, research publications and R&D investment which has become an essential need post the announcement of the solar mission in the country.

Keywords:

Solar Energy; Sectoral System of Innovation; National Solar Mission; Innovation; India.

1. Introduction

Energy is an important sector for economic growth of a nation like India. The country's economy is one of the fastest growing economies in the world. Due to the rapidly growing population and growing economy, the consumption in the energy sector has increased rapidly. There is a wide gap between the country's energy production and the energy consumption (Krishna, C., Sagar, A.D. and Spratt, S., 2015). About 300 million people in the country lack access to basic energy service according to World Bank report 2014. On the other hand the country has a huge potential of solar energy. The government of India launched *the National Solar Mission* in November 2009 (officially took off in January 2010). It was a major initiative to promote ecologically sustainable growth while addressing India's energy security challenge. The goal is to make the nation as one of the leaders in solar energy production in the world by 2022. Under this mission, there are three phases such as phase-I (2010-2013), phase-II (2013-17) and phase-III

(2017-2022) with different target achievements. The mission also has other additional goals such as promoting R&D, public domain information, develop trained human resource for the solar industry and expand the scope and coverage of earlier incentives for industries to set up solar photo voltaic (PV) manufacturing in India. This mission has garnered a lot of attention for various reasons and the mission has inspired a full-fledged research on it.

Solar energy technologies and innovation promote the ecologically sustainable growth while addressing the country's energy security challenge (MNRE, 2013). It will constitute a major contribution by India to the global effort to meet the challenges of climate change. According to the Ministry of New and Renewable Energy (MNRE) solar energy has been an important component of the country's energy planning process and it is no longer an *"alternate energy"* but will increasingly become a key part of the solution to the nation's energy needs.[1] In June 2008, India has released National Action Plan on Climate Change (NAPCC) to promote development goals while addressing climate change mitigation and adaptation and to enhance ecological sustainability of the country's development path[2].

The mission is one of the eight national missions[3] under the NAPCC and it is one of the leading one because it fights the issues of climate change and it also tries to answer the questions of meeting India's energy demand and expanding development opportunities of different solar technologies throughout the country. In our study knowledge production refers to the research outcomes such as patents and research publications from the various R&D institutions, university, firms etc. and innovation stands here the ability to absorb, adapt and transform a given technology into specific operational, managerial skills that accelerates an innovative organizational culture, characteristics of internal promoting activities and capabilities of communication facilities of firms to others in both market or non-market relations. There are different key actors who constitute or shape Indian solar energy sector like business enterprises or private firms, R&D institutions, universities, financial institutions, government ministries, non-governmental organization etc.

[1]Ministry of New and Renewable Energy (MNRE), GoI. See. http://www.mnre.gov.in/

[2]Press Information Bureau, Government of India. See. http://pib.nic.in/release/rel_print_page1 .asp?relid=44098.

[3]The other seven national missions are National Mission for Enhanced Energy Efficiency, National Mission on Sustainable Habitat, National Water Mission, National Mission for Sustaining the Himalayan Ecosystem, National Mission for a Green India, National Mission for Sustainable Agriculture, and National Mission on Strategic Knowledge for Climate Change.

2. Objectives and Research Methodology

The main objective of the study is to map the energy scenario in the country in order to understand the significance of renewable energy with focus on solar energy. Others are

- to study the various policies enunciated by the government with special reference to first phase of *the National Solar Mission* and its impact on institution building; and
- to explore the dynamics of innovation by identifying various actors and institutions which determine the process of innovation in the solar energy sector.

Our study is based on both quantitative and qualitative data. The quantitative data primary means the number of scientific research publications related to solar energy and patents granted in various solar technologies. It is undertaken first by reviewing the available literature related to renewable energy, solar energy and a few articles based on the mission. The concept of innovation that is used in the study is drawn from innovation system perspectives of National Innovation Systems (Freeman, 1987 and 1995; Lundvall, 1992; Nelson, 1993; Edquist, 1997) and Sectoral Innovation Systems (Carlsson, 1995; Breschi and Malerba, 1997; Nelson and Mowery, 1999). The information and data related to solar policies and programmes, various solar PV and solar thermal technologies, research and development activities and other useful information about various institutions such as *Ministry of New and Renewable Energy* (MNRE), *Solar Energy Centre* (SEC), *Solar Energy Cooperation of India* (SECI), *Indian Renewable Energy Development Agencies* (IREDA), etc. were retrieved from their annual reports and websites of the above institutes.

For understanding the research publications and patents analysis we use bibliometric analysis and databases available on USPTO (United States Patent and Trademark Office) and IPO (Indian Patent Office). Since bibliometric is a set of online database tools for analyzing publication data. According to Norton, it defines as the measure of texts and information which is associated with a publication includes author, affiliation, citations from other publications, co-citations with other publications, reader usage, and associated keywords (Norton, 2001). With the help of analyzing the data available in the Scopus[4] database the number of research publications related to

[4] Scopus is one of the largest online abstract and citation database of peer reviewed literature with smart tools that tract, analysis and visualize research which is covering more than 20,5000 titles from nearly 5,000 publishers. see http://www.info.sciverse.com/scopus/.

solar energy sector in different universities and R&D institutions in the country are calculated and analyzed accordingly. The information gathered from the libraries of Indian Institute of Technology IIT, Delhi and The Energy Resources Institutes (TERI) and others have also been incorporated. Some informal interviews were also undertaken to discuss various policy issues with professionals at the energy ministry.

3. Building Theoretical Framework and Literature Review

This paper has been undertaken to explore the ways in which various actors, agencies and policies influenced the solar energy sector under the theoretical framework of innovation literature. The concept of system of innovation was developed in parallel at different places in Europe and US in 1980s. As Schumpeter (1939) defines innovation is the key driver to economic change and regional development of a nation as the setting up of a new production function that covers the case of a new commodity, as well as those of a new form of organization (Schumpeter, 1939). He further mentions that invention, innovation and successful diffusion of new technologies are the major drivers of modern economies. Schumpeterian concept of innovation also draws attention to the introduction of new product, process innovation that is new to an industry, the opening of new market, development of new sources of supply for raw materials or other inputs, changes in industrial organizations (Schumpeter, 1939).

Further as Edquist (2001) argues, innovation is the new creation of economic significance which is normally carried out by firms or sometimes by individuals. The product or idea can be brand new, but more often new combinations of existing elements. He further describes that the category of innovation is extremely complex and heterogeneous. Similarly, Fagerberg et. al., (2005) also stresses that innovation is crucial for long term economic growth and it tends to cluster in certain industries/ sectors, which consequently grow more rapidly, implying structural changes in production and demand and, eventually, organizational and institutional change. Innovation is therefore acknowledged as the fundamental driving force for advanced economy nowadays.

We are further drawing our attention towards system of innovation from Metcalf (1995) who perceives that institutions which jointly and individually contribute to the development and diffusion of new technology also provides the framework that governments use in forming and implement policies to influence the innovation process (Metcalfe, 1995). In Edquist (1997) system of innovation is defined as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations" Edquist (1997, p.14). It has become increasingly common to regard the emergence of innovations as a complex process characterized by complicated feedback mechanisms and interactive relations involving science, technology, learning, institutions, production, public policy and market demand during 1990s (Edquist, 1997). The development of innovations are seen as characterized as processes of interactive learning, i.e., there is often an exchange of knowledge between organizations involved in innovation processes (Lundvall, 1992). Various kinds of knowledge and information are exchanged between organisations and such exchange often takes the form of collaboration that is not mediated by a market. From the different perspectives of innovation, hence it could be further studied in a national, regional and sectoral context such as National Innovation System (NIS), Regional Innovation System (RIS) and Sectoral System of Innovation (SSI). The SSI perspective has been developed and also increased in importance over time by Carlsson (1995), Breschi and Malerba (1997), (Cooke et al., 1997) Nelson and Mowery (1999) and so on.

The concept of sectoral system of innovation (SSI) is very popular today. Based on this framework there are many studies look at the dynamism of sectoral system in many sectors. For instance, Turpin and Krishna (2007) contend the dynamics underlying the three promising sectors in India such as ICT software, biotechnology and pharmaceutical sectors through the lenses of the SSI perspective. Krishna (2007) discusses the three main building blocks of the framework such as sectoral boundaries, key elements of the SSI perspectives and transformation of the sectoral system through the co-evolution of its constituent elements. He argues that the pharmaceutical sector is one of the most innovative sector among them.

In Malerba and Mani's book *"Sectoral System of Innovation and Production in developing countries"* Mani, S. (2009) also analyses the SSI perspectives in both pharmaceutical and telecommunication sectors. The pharmaceutical innovation system has three strong pillars such as 1) a very proactive government policy regime especially with respect to intellectual property rights 2) strong government research institutes, and 3) private sector enterprises which have invested in the innovation (Mani, S. 2009). He explores the boundaries of the innovation system in terms of the specific agencies of the government dealing with telecommunications development, the policy framework, the equipment suppliers, the service providers and the regulatory agency and also tracking the knowledge and technological domain among the various actors within the system. The author also explores three indicators for determining the innovative performance such as trade balance, R&D expenditure and number of US patents granted in both sectors. Finally, the author discerns that the pharmaceutical industry has much better performance in all the indicators compare to the telecommunication industry (Malerba, F. and Mani, S. 2009).

The SSI will help to draw our attention to the dynamics of innovation by identifying various actors and institutions which interact and determine the process of innovation in the solar energy sector. As we know that it is composed of various agents, institutions, types and structure of interactions among firms and non-firms organizations in a sector. Malerba (1997, 2002) defines the SSI as, "it is composed by the set of heterogeneous agents carrying out market and non-market interactions for the generation, adoption and use of (new and established) technologies and for the creation, production and use of (new and established) products that pertain to a sector (sectoral products)". Malerba mentions the basic elements of a sectoral system as products, agents, knowledge and learning processes, basic technologies, inputs and demand with links, interactions and institutions. In his approach, it have a knowledge base, technologies, input and (potential or existing) demand where the agents composing the sectoral system are organisations and individuals.

4. Key Actors in the Solar Energy Sector and Installation Capacity

Drawing on the system of innovation literature, it leads us to signify different actors, agencies and polices among other features of environment surrounding in Indian solar energy sector. The key actors in the solar energy sector are depicted in Table 1.

Table 1: Main actors in Indian Solar Energy Sector

Key Actors	Particulars
1. Business Enterprises (Solar firms)	Domestic manufactures (Cells, modules, balance of systems): Tata BP solar, Moser Baer, Solar Semiconductor, Photon Energy Systems, Central Electronics Laboratory (CEL), Reliance Industries Limited, Bharat Heavy Electricals Limited (BHEL), Lanco Solar, IndoSolar Ltd., Websol Energy System Ltd. Titan Energy Ltd. etc. Foreign owned manufactures: SunEdison (US base), Trina Solar (China), etc. Project developers: Azure Power, Green Infra, Mahinder, Welspun, etc, Engineering, Procurement & Construction (EPC): Mahinder, Tatasolar etc.

2. Policy Support	Apex body and Regulatory Institutions: MNRE, Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission (SERC), Ministry of Power, Ministry of Finance, Ministry of Environment, Forest and Climate Change, SECI, IREDA, National Thermal Power Corporation Vidyut Vyapar Nigam (NVVN) Policy Instruments: Domestic Content Requirement (DCR), Generation Base Incentives (GBI), Accelerated Depreciation, Solar REC, state policies, Solar Viability Gap Funding (VGF), Direct Subsidies, Tax Incentives, etc.
3.Government Research Institutes (GRIs)	IITs, Central Universities, State University, 61-Educational Institutions (PG level) offering courses on Renewable Energy. National Physical Laboratory (NPL), Council of Scientific and Industrial Research (CSIR), National Institute of Solar Energy (NISE), Solar Energy Corporation of India (SECI), etc.
4.Financial Institutions	Domestic Sources: Scheduled commercial banks like SBI, Bank of Baroda, IDBI Bank, Axis Bank. Nonbanking Financial services like L&T Infra Financial, IDFC, PFC Green Ventures, DFC, IREDA, etc. External sources: International Finance Corporation (IFC), Asian Development Bank (ADB), Overseas Promotion & Investment Corporation (OPIC), U.S EXIM Bank, EXIM Bank of China, etc.
5.Industry Associations	Solar Energy Society of India (SESI), National Solar Energy Federation of India (NSEFI), Solar Thermal Federation of India (STFI), Indian Solar Manufactures Association, Solar Power Developers Association, Solar Energy Trade Association in India etc.
6.NGOs and Other Organizations	Barefoot Engineers, Greenpeace, Centre for Science and Environment (CSE).

Source: Author's compilation; MNRE (2016), TERI (2015).

India is a key emerging country in terms of solar power. During 2013-2014, the overall production was over 240 MW for solar cells and 661 MW for PV modules (MNRE, 2015). The Indian solar PV sector is a mix of three major approaches including patent licensing, joint ventures and acquisitions, and in-house R&D (Mallett et al. 2009), which matches the current development level of the technology and production capacity in the Indian solar PV sector.

Among the states of India, Gujarat is the leading state in solar energy installation in the country with 857.90 MW followed by Rajasthan (552.90), Maharashtra (100 MW), Madhya Pradesh (37.32 MW), Andhra Pradesh (23.35 MW) and so on. Gujarat, Rajasthan, Maharashtra, Madhya Pradesh and Andhra Pradesh covers 50.87%, 32.74%, 5.9%, 2.1% and 1.3% of the total grid connected solar energy capacity respectively in the country (MNRE, 2015). Among the various renewable resources wind has the maximum cumulative installed capacity which is around 59%, followed by solar (19.5%), bio-power (12%), small hydro (9%) and waste to power (0.5%). The

Table 2 shows the cumulative deployment of renewable energy sources (both grid and off-grid connected) at end of November 2016. The cumulative installed solar energy capacity is about 9,256.88 MW at the end of November 2016. Out of this 8,874.87 MW and 382.01 MW are from grid-connected and off-grid solar respectively (CEA, 2016; MNRE, 2016). The country stands at fourth position globally in terms of renewable energy market potential just after China, the US and Germany.

Table 2: Indian cumulative deployment in solar and other renewable resources (in MW), as on 30.11.2016.

Renewable resources	Grid-connected	Off-grid connected	Cumulative Achievements
Wind	28,419.40	-	28,419.40
Solar	8,874.87	382.01	9,256.88
Bio-power[5]	4,932.33	838.79	5,771.12
Small hydro	4,324.85	18.81	4,343.66
Waste to power	114.08	161.12	275.20
Total Renewable Energy	46,665.53	1,400.73	48,066.26

*Source:*http://mnre.gov.in/mission-and-vision-2/achievements/(accessed on 11.01.2017)

Renewable energy as whole, has the potential to meet 15% of total contribution under National Action Plan on Climate Change (NAPCC) by 2020[6] which will eventually reduce the emission of greenhouse gases (MNRE, 2013). India has a huge potential for solar power generation since about 58% of the total land area (1.89 million km^2) receives annual average global insolation above 5 $kWh/m^2/day$ (Ramachandra, et. al., 2011). The country's solar radiation is higher than countries like Germany where annual solar radiation ranges from 800 to 900 kWh/m^2 Moreover, there is around 1,000,000 sq. km of open and non-agricultural land which receives adequate radiation in the country and this land is available in Rajasthan, Gujarat, Madhya Pradesh and some parts of the Deccan plateau (Sukhatme, 2011). About 1% of this land area (around 10,000 sq.km) is sufficient to meet electricity needs of the country till 2031 as estimated by some sources. The

[5]Bio-power includes biomass-gasification and bagasse cogeneration which achieve maximum energy from off-grid system as 651.91MW and 186.88MW respectively as on 30.11.2016.

[6]Annual Report 2012-13, Ministry of New and Renewable Energy (MNRE), Government of India 2013.

challenge of providing the energy access to the remote villages can be met only by solar PV, small hydro, wind or hybrid systems (Pillai and Banerjee, 2009).

While assessing the potential of solar energy, the real issue is not the availability of solar radiation as much as the availability of open land.[7] Mitavachan and Srinivasan (2012) argue that the solar power plants require less land in comparison to hydro power plants, nuclear and coal including when life-cycle land transformations are considered. Currently solar PV installations almost entirely consist of off-grid connectivity and small capacity appliances which are mostly used in public lighting such as street lighting, traffic lighting, and domestic power back up in municipal areas and small electrification systems and solar lanterns in the rural areas. In recent years, it is also being used for powering water pump for farming and small industrial areas (MNRE, 2014).

Solar technology can broadly divided into two categories such as solar PV technology and solar thermal technology (Bhargava, 2001 and Kharul, 2011). The several types of solar PV cells[8] which are globally available such as amorphous silicon, crystalline silicon, dye-sensitized cells and other newer technologies such as silicon-nano particle ink, carbon nanotube and quantum dots (Willey and Hester, 2009). Kharul (2011) also broadly categorized solar technology into four generations of technology. The first and second generation solar cells are commercially available globally, while the third and fourth generation solar cell technologies are in initial stage.

In case of solar thermal technology, this is quite diverse in terms of its operational characteristics and application that it includes fairly simple technologies such as solar space heating and solar cooking as well as complex and sophisticated ones like solar air conditioning and solar thermal power generation. As Asif and Muneer (2008) argue solar thermal technologies are the most diverse and effective renewable energy technologies in the world[9]. The most successful application of solar thermal technologies is in the form of solar water heating (SWH).

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[7]Sukhatme, P. (2011) Meeting India's needs of electricity through renewable energy sources. *Current Science* .101(5) pp.624-630.

[8]Solar PV cells are semiconductor devices that convert part of the incident solar radiation directly into electrical energy. The most common PV cells are made from single crystal silicon but there are many variations in cell material, design and methods of manufacture.

[9]Asif and Muneer (2008). Solar thermal technologies. Encyclopedia of energy engineering and technology. *Taylor and Francis,* New York, pp.1321-1330.

4.1 Status of Indian manufacturing solar sector

Indian solar manufacturing sector consists of both crystalline silicon and thin films in PV technologies and thermal technologies. This sector is little over three decades old. Solar thermal technologies are still in the early stage of development compare to the PV technologies. Since 1970s BHEL and CEL have been engaged in making solar panels and other equipment, but later on few companies began small scale manufacturing of modules which are limited to off-grid applications. With a 40 MW manufacturing capacity, Moser Baer Solar set up the first commercial scale manufacturing plant in 2006 (CSE, 2012). Since then, the domestic manufacturing industries experience a nurturing growth owing to global demands and the ambitious national solar mission implications.

According to World Bank (2013) most of the raw materials and consumables for solar cells and modules manufacturing are imported. There is no poly-silicon and wafer manufacturing capability in the country. But there have been more than 19 solar cell makers and 50 module makers registered with the MNRE in the country[10] (CSE, 2012). The Chinese are the leaders in both cell and module production globally (Spratt et.al., 2014; TERI, 2013). By the beginning of the national solar mission's second phase, about 1,500 MW of cell manufacturing capability existed in the country and around 2,000 MW of domestic module manufacturing capability existed as compared to only 15MW of ingots and wafers manufacturing (MNRE, 2015). So far, the biggest solar manufactures in the country are Moser Baer Solar, Tata Power and HHV Solar. The main driver of solar energy investment is a perceived business opportunity and such opportunity often rise because government provides incentives.

5. India's Policy on Solar Energy Sector

The flow of information and network linkages of technology of solar energy among people, enterprises and institutions is the key that leads to an innovative process. It contains the interaction between the actors who are needed to turn an idea into a process, product or service on the market. There is no single actor that can perform independently. The diverse actors function as the linkages and networks among the innovation eco-system for the development and growth of solar energy sector in the country. The Government of India has established the Ministry of New and Renewable

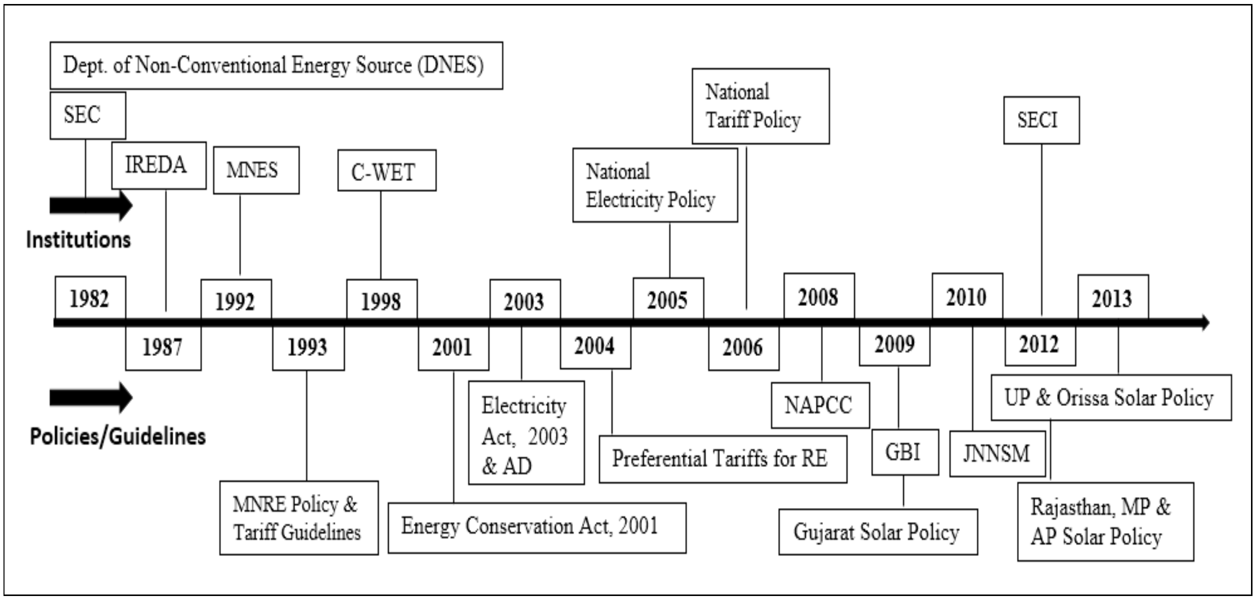
[10] Bhushan, C. and Hamberg, J. (2012). Facing the sun: Policy for sustainable grid-connected solar energy, Centre for Science and Environment, New Delhi.

Energy (MNRE), Indian Renewable Energy Development (IREDA), State Nodal Agencies, Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission (SERC) for respectable functioning of ecosystem which are engaged in coherence with each other in order to maintain the development of renewable energy sector in general and solar energy sector in particular.

Since early 1980s the government begun to introduce some policies to support the expansion of renewable energy in the country. In 1982 Department of Non-conventional Energy Sources (DNES) was established. Commission for Additional Sources of Energy (CASE) was created in the then Ministry of Energy. In 1992 the Indian government established the Ministry of Non-Conventional Energy Sources (MNES). Again in 2006 the MNES was renamed as Ministry of New and Renewable Energy (MNRE). Renewable energy promotion received a boost with the National Electricity Policy 2005, which provides measures for licensed utilities and producers of captive electricity to purchase certain amounts of renewable energy. In recent years, a number of specific federal and state-level incentive schemes have been created for specific purposes, ranging from rooftop PV installations to large-scale power plants. There are some states having specific solar state policies[11] and some are on the pipeline in order to boost solar generation capacities, drive down costs through local manufacturing, R&D activities to accelerate the transition to clean and secure energy in the state itself. The Figure 1 depicts the evolution of India's renewable energy policies with respect to solar energy

[11] For instance, Gujarat State Policy, 2009 is the first solar specific state policy introduced in the country predating the National Solar Mission. Some others like Rajasthan Solar Policy 2012, Andhra Pradesh Solar Policy 2012, Madhya Pradesh Solar Policy 2012, Tamil Nadu Solar Policy 2012, Uttar Pradesh Solar Policy 2013, Orissa Solar Policy 2013, etc. have come out with their own solar specific policies.

Fig. 1: Timeline of various Indian energy policies and institutions set up focus on solar sector



Source: Compile by author; MNRE, 2014

There are a number of government institutions whose competence extends into the renewable energy sector. *The Electricity Regulatory Commissions Act* instituted independent regulatory bodies both at the central and state-level which are known as the Central Electricity Regulatory Commission (CERC) and the State Electricity Regulatory Commissions (SERCs) respectively. The CERC is responsible for regulating tariffs of generating companies owned or controlled by the central government and for promoting competition in the electricity industry. While the SERCs deal with matters concerning generation, transmission, distribution and trading of electricity in their respective state.

The MNRE is the nodal ministry responsible for all matters relating to new and renewable energy such as solar, wind, biomass, small hydro, hydrogen, biofuels, geothermal etc. The broad aim of the ministry is to develop and deploy new and renewable energy for supplementing the energy requirements of the country. The MNRE's role is to facilitate research, design, and development of new and renewable energy that can be deployed in the rural, urban, industrial, and commercial sectors. The MNRE undertakes policymaking, planning, and promotion of renewable energy including financial incentives, creation of industrial capacity, technology research and development, intellectual property rights, human resource development, and international relations.

The Vision of the MNRE is to develop new and renewable energy technologies, processes, materials, components, sub-systems, products & services at par with international specifications, standards and performance parameters in order to make the country a net foreign exchange earner in the sector and deploy such indigenously developed and/or manufactured products and services in furtherance of the national goal of energy security.[12] Moreover the MNRE supervises national institutions such as *the Solar Energy Centre* (SEC, recently renamed *as National Institute of Solar Energy*), *the Centre for Wind Energy Technology* (C-WET), and *the Sardar Swaran Singh National Institute of Renewable Energy* (SSS-NIRE). Apart from administering the institutions the MNRE also affords financial assistance and support like Solar Energy Corporation (SECI) has established under the administration of the ministry with reference to the solar energy sector. As a part of the mission Indian Institute of Technology (IIT) Delhi, IIT Mumbai, IIT Rajasthan, Indian Institute of Science (IISc) Bangalore and Indian Institute of Management (IIM) Ahmedabad are conducting several research and development activities in the area solar energy under the rubric of centre of excellence.

In Indian solar energy sector the government is playing a vital role and being a main actor, it is responsible for the formulation of several renewable incentive policies that have increased the viability of increased deployment of solar energy technologies in the country ranging from electricity sector reform to rural electrification incentives. *Domestic Content Requirement (DCR)* is a new set of guidelines under *the National Solar Mission*. To achieve solar capacity and cost targets the mission auctions Power Purchase Agreements (PPAs) to solar developers and to ensure domestic solar manufacturing in the country the programme includes a DCR; developers must use solar cells and modules[13] manufactured in India. However, the guideline makes an exception for solar PV developers using thin film technologies, which may be imported. The majority of solar developers in the country currently use imported thin film modules in the country.

Another policy, *Feed in Tariff* is a mechanism designed to accelerate investment in renewable energy technologies in the country. They are minimum prices at which renewable energy projects can be purchased from the generating companies or private producers through contracts

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[12] Ministry of New and Renewable Energy, (MNRE) see http://www.mnre.gov.in/mission-and-vision2/mission-and-vision/vision/ accessed on 20th May 2013.

[13] Solar cells and modules are the building blocks of solar PV (Crystalline Silicon) which used to generate electricity.

(power purchase agreements) with transmission or distribution utilities or with trading licensees. Solar *renewable purchase obligation* (RPO) is the minimum amount of solar energy that obligated entities; distribution licensees, open access and captive consumers; have to deliver or consume as a percentage of their total available electricity. They can meet this obligation by purchasing the required quantity of solar power directly from producers. Alternatively, they can buy solar *renewable energy certificate* (REC) to fulfil RPO. Many states are now establishing RPOs, which have stimulated development of a tradable REC program.

Generation base incentives are provided to support small grid solar power projects connected to the distribution network under solar *generation based incentives* (GBI) scheme. Solar *rooftop PV and small solar power generation programme* (RPSSGP) is also an interesting scheme which was designed essentially for states to encourage them for grid connected projects focusing on distribution network and to strengthen the tail end of the grid system. These *Feed in Tariff*, Solar RPO and REC schemes, solar GBI scheme, solar RPSSPGP scheme become notable policies or schemes.

6. The National Solar Mission and the Status of Phase-I

The *National Solar Mission* is a major initiative of the government of India to promote ecologically sustainable growth while addressing the country's energy security challenge. It seeks to kick start solar generation capacities, drive down costs through local manufacturing, research and development to accelerate the transition to clean and secure energy. The following table highlights the chronology of events in the mission.

Table 3: Chronology of events in the *National Solar Mission*

Date	Event
2007	The MNRE initiates to frame an action plan or mission for solar energy internally.
2008-09	National Action Plan on Climate Change declared and the mission brought under the aegis of the Prime minister's office. The mission launched with an initial budget allocation of Rs. 3850 million made.
2009	NTPC Vidyut Vyapar Nigam Ltd. (NVVN) becomes nodal stakeholders in power purchase agreements through National Thermal Power Corporation (NTPC).
2010	Phase-I initiates with two different batches. Asian Development Bank declares US$ 400m commitment. Around 418 project bids submitted for a cumulative target of 1-2 GW for the first batch of phase-I. Project sizes are small (5MW cap)

	with DCR guidelines. Project developers prefer sourcing alternative equipment from foreign suppliers. Authorization of Rs.172.3 million to 37 solar cities.
2011	Solar Energy Industry Advisory Council is constituted to help attract investment, encourage R&D and make the Indian solar industry competitive. Allocated 350 MW in utility scale solar projects under the second batch of phase-I. 90% of the projects are in Rajasthan.
2012	NVVN replaced by the SECI under the supervision of the MNRE. Power purchase agreements directly signed with the SECI.
2013	Phase-I ends and Phase-II begins with a target on special focus on grid connected solar.

Source: Compile by author; Krishna, Sagar, and Spratt (2015).

It aims to dramatically increase installed PV through attractive feed-in tariffs and a clear application and administration process. Under this mission, there are three phases such as Phase-I (2010-2013), Phase-II (2013-17) and Phase-III (2017-2022). The mission aims installations of 20, 000 MW of grid-connected solar power generation, 2,000MW of off-grid solar applications, 20 million sq. meters of solar thermal collector area for industrial applications and 20 million solar lighting systems for rural areas by the year 2022.[14] The first phase, second phase and third phase have a target of 1100 MW, 3000 MW and 16000 MW of grid-connected solar respectively. In case of the off grid solar applications 200 MW, 800 MW and 1000 MW are the targets in the first, second and third phase respectively. And lastly the three phases target to achieve 7, 8 and 5 millions square meters of solar collectors (see table 4).

Table 4: Phase-wise and total targets in the *National Solar Mission*

Segment	Phase-I 2010-13	Phase-II 2013-17	Phase-III 2017-22	Total
Grid-connected Solar (MW)	1,100	3,000	16,000	20,000
Off-grid solar (MW)	200	800	1,000	2,000
Solar Thermal Collectors (million sq. meters)	7	8	5	20

Source: Ministry of New and Renewable Energy (MNRE)

[14] Ministry of New and Renewable Energy (MNRE), Strategic report, see http;//www.mnre. gov.in/accessed on 22th February 2013.

The mission has also other additional goals such as promoting R&D, public domain information, develop trained human resource for the solar industry, and expand the scope and coverage of earlier incentives for industries to set up solar PV manufacturing in India. Under this mission, NTPC Vidyut Vyapar Nigam (NVVN) Ltd.[15] has been designated as nodal agency for procuring the solar power by entering into a Power Purchase Agreement (PPA) with solar power generation project developers who has been setting up solar projects during the Phase-I. About 615 MW of different solar power projects including both solar PV (145 MW) and thermal (470 MW) projects are listed according to NVVN during 2013. Out of them, the CSP projects are in Rajasthan (400 MW), Andhra Pradesh (50 MW), Gujarat (20 MW) while those of Solar PV projects are in Rajasthan (100 MW), Andhra Pradesh (15 MW), Karnataka (10 MW), Maharashtra (5 MW), Uttar Pradesh (5 MW), Orissa (5 MW), Tamil Nadu (5MW)[16].

The mission's phase-I has divided into two batches i.e. batch I & II. In Batch I, capacity addition of 150 MW of grid connected solar PV plants and 500 MW of grid connected solar thermal plants was envisaged. Whereas in batch II, the remaining targeted capacity for Solar PV i.e.350 MW is awarded. Considering the fact that some of the grid connected solar power projects are at various stages of development prior to launch of the mission. A Migration Scheme is launched to provide these projects to migrate from the respective existing arrangement to the one envisaged under the mission subject to the consent of distribution licensee, state government and willingness of developer in 2010. Resulting solar projects worth 84 MW including 54 MW SPV and 30 MW solar thermal were migrated to the mission. Apart from these grid connected large scale plants, small rooftop plants of capacity less than 2MW each were also allotted under GBI scheme in RPSSGP. Table 5 below gives the status for both batch-I and batch-II under the mission's phase-I including projects allotted under different schemes.

In batch-I, a total of 802.5 MW capacity grid connected solar power projects have been allotted, which comprise of 500 MW capacity of solar thermal power projects and 302.5 MW of solar PV power projects. In batch-II, the total aggregate capacity of grid connected Solar Projects

[15] NTPC Vidyut Vyapar Nigam (NVVN) Ltd. is formed by National Thermal Power Cooperation (NTPC), as its wholly owned subsidiary to make the potential of power trading, capacity utilization of power generation, transmission assets and boost in the development of power market in the country.

[16] Selected projects for phase-I National Solar Mission, NTPC Vidyut Vyapar Nigam (NVVN) Limited, see http://nvvn.co.in/Selected%20Projects%20List.pdf accessed on 1st May 2013.

was 350 MW for the deployment of solar PV power projects. In order to facilitate grid connected solar power generation under the first phase, without any direct funding by the government, government has approved the NVVN as the nodal agency to purchase 1000 MW of solar power from the project developers, bundle it with the unallocated power available from the NTPC coal based stations and sell this "bundled"[17] power to the distribution utilities.

Table 5: Status of Batch-I and Batch-II of the *National Solar Mission's* Phase-I

I. For Batch-I (Schemes)	Projects Allotted		Project Commissioned	
	No.	MW	No.	MW
NVVN Scheme (Solar PV)	30	150	25	125
NVVN Scheme (CSP)	7	470	-	-
Migration Scheme (Solar PV)	13	54	11	48
Migration Scheme (CSP)	3	30	1	2.5
RPSSGP (Solar PV)	78	98.5	62	76.55
I. For Batch-II (Schemes)				
NVVN Scheme (Solar PV)	28	350	-	-
Total	159	1152.5	99	252.05

Source: Ministry of New and Renewable Energy, 2014.

In case of the off-grid connected/decentralized solar power in the phase-I, there are around 27841 solar lanterns, 53588 home lights, 21957 solar street lights, 1055 water pumping system and stand-alone Solar PV power plants of 9365.39 KW capacity has been installed during 2012-13 as at the end of December 2012 (MNRE, 2013).

7. R&D Activities and Knowledge Production in Solar Energy Technologies

Promotion of R&D and increasing the knowledge production is one of the main objectives of national policies on solar energy and its innovation ecosystem. The various research and

[17] The bundling concept is introduced to keep the cost of bundled power approximately Rs.5/kWh and it has decided to select projects of 500 MW capacities each based on solar thermal and solar photovoltaic technologies.

development programmes are designed to improve efficiency, reliable and cost competitive performance of different solar energy technologies in the country. The *National Institute of Solar Energy* (NISE) and *Solar Energy Corporation of India* (SECI) are the two main important R&D institutions that established under *Solar Energy Research Advisory Council* to address the existing research infrastructure in the domain of solar energy sector and help to set up a framework which would incubate an environment for accelerating research and development activities in the country in the association with the goals of the national solar mission.

The NISE which is the technical focal point of the MNRE assists other research organizations and industry in implementing innovative ideas and development of new products by offering its facility and expertise for developmental testing on various solar technologies. Under this R&D programme the evaluation of various emerging technologies and standardizing the technologies for applications suitable for various field conditions is an important task. The institution is also responsible for conducting various training programmes, seminars, workshops and other solar energy technology courses with the objective of disseminating the knowledge. The MNRE has also introduced a fellowship, *national solar science fellowship programme*. As part of the mission, the SECI has taken up various projects or activities related to solar sector across the country. One of the on-going schemes under the SECI is pilot scheme for large scale grid-connected rooftop solar power generation which is 30% subsidy on the project cost made available from the ministry through the corporation.

Besides these, the government of India also allocates funds or provides other subsidies for various R&D activities in the country. The solar mission has launched with a preliminary budget allocation of Rs. 3.85 billion made in 2009. Compare to other country in the world, India invests less money in the renewable energy sector. India invests Rs. 442.4 billion and covers only 2% of the global investment in the sector in recent year (MNRE, 2015 and Bloomberg New Energy Finance, 2015). China has become the leader in the global investment. Around Rs. 4532.4 billion and Rs. 2450 billion has been invested in China and USA respectively in the sector. It covers about 27% and 15% of the global investment.

7.1 Knowledge production and comparison with other countries

Solar energy has been harnessed mainly in two technologies. One is solar photovoltaic (PV) technology and another is solar thermal technology. The former technology is more advanced and developed than the latter (MNRE, 2014). Among solar technologies solar PV has emerged as the fastest growing renewable power technology worldwide (REN, 2015). It is one of the most promising ways to generate electricity in a decentralized manner at the point of use for providing electricity, especially for lighting and meeting small electricity needs especially in un-electrified households and unmanned locations.

The number of publications in various solar PV technologies such as amorphous cells, concentrating PV, dye-sensitized cells, mono crystalline, mutli-junction cells, poly crystalline and thin film cells in the country for ten years are shown in the following table 6. The country has published maximum number of research publication in thin film, poly crystalline, amorphous and dye sensitized solar cells. Seven research organizations namely Indian Association of Cultivation of Science (Kolkata), Indian Institute of Technology (Delhi), University of Poona (Pune), National Physical Laboratory (Delhi), Indian Institute of Technology (Madras), Indian Institute of Science (Bangalore) and Indian Institute of Technology (Kharagpur) were involved in research on various aspects of amorphous material research and process development (MNRE, 2015). Central Electronics Ltd. and Rajasthan Electronics & Instruments Ltd. were the industrial organizations involved in the design and development of PV systems based on this technology (MNRE, 2015).

Table 6: India’s number of publication in various solar technologies for 10 years (2006-2015)

Technology	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Amorphous	63	57	81	117	120	139	92	118	108	152
Concentrating PV	0	0	0	0	0	0	0	0	0	1
Dye-sensitized cells	1	5	13	18	29	65	71	95	153	170
Mono crystalline	3	4	7	9	6	6	10	8	8	13
Multi-junction cells	0	0	0	0	0	1	1	1	2	1

Poly crystalline	3	1	8	80	148	154	168	170	185	198
Thin film cells	63	45	61	66	82	112	120	156	220	203

Source: Researcher's data based on the Scopus Database[18], 2016

In poly crystalline cells, India ranks at fourth position with a number of 981 publications till 2015. China has 2261 research publications this particular technology and she is on the top which has published maximum number of the research papers in the world. In case of dye sensitized, thin film cells and amorphous cells the country stands at sixth and seventh rank respectively. The following table shows the rank wise country on the publications till 2016.

[18] Based on the database, the number of publications to a specific solar technology is analyzed. For instance, the keyword for dye-sensitized cells are (TITLE-ABS-KEY(dye sensitized solar cells) AND PUBYEAR > 2005 AND PUBYEAR < 2016 AND (LIMIT-TO (EXACTKEYWORD, "Dye-sensitized Solar Cells") ORLIMIT-TO (EXACT KEYWORD, "Dye-Sensitized Solar Cell") OR LIMIT-TO (EXACTKEYWORD, "Dye-sensitized Solar Cell") OR LIMIT-TO(EXACTKEYWORD,"Dye Sensitized Solar Cell")) AND (LIMIT-TO(DOCTYPE,"ar")) AND (LIMIT-TO(SRCTYPE,"j"))).

Table 7: Rank wise country on the number of publications in various solar technologies

Technology	Rank									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Amorphous	China (4371)	USA (3207)	Japan (2169)	South Korea (1660)	Germany (1584)	France (1160)	**India (1072)**	Taiwan (919)	UK (774)	Italy (650)
Concentrating PV	USA (20)	China (18)	UK (12)	Germany (5)	Spain (5)	Israel (4)	Italy (4)	Australia (3)	Austria (2)	Netherlands (2)
Dye-sensitized cells	China (3016)	South Korea (1354)	USA (891)	Taiwan (752)	Japan (709)	**India (620)**	Switzerland (331)	Australia (254)	Germany (253)	Italy (251)
Mono crystalline	China (737)	USA (590)	Germany (402)	France (286)	Japan (226)	Russia (213)	Poland (131)	UK (126)	Italy (123)	South Korea (102)
Multi-junction cells	USA (103)	Spain (40)	China (37)	Japan (36)	Germany (33)	UK (15)	South Korea (13)	Taiwan (13)	Canada (11)	Australia (10)
Poly crystalline	China (2261)	USA (2150)	Japan (1152)	**India (981)**	Germany (892)	France (696)	South Korea (603)	UK (477)	Russia (359)	Spain (275)
Thin film cells	USA (3828)	China (3402)	South Korea (1950)	Germany (1851)	Japan (1660)	**India (1128)**	Taiwan (921)	France (892)	UK (827)	Italy (557)

Source: Researcher's data based on the Scopus Database, 2016 and the figure within the bracket indicates the number of publications by the respective country.

In case of number of patents granted related to solar energy there are around 75 patents have been granted in the Indian Patent office website[19] as on second July 2015 in the country. The online database on the patents is obtained by using the search engine "Indian Patent Office" supported by the Office of the Controller General of Patents, Designs & Trade (CGPDT), Ministry of Commerce and Industry, Government of India. But in case of USPTO (United States Patent and Trademark Office) there are 53 patents[20] granted from the country in the different field of solar technologies. The maximum number of patents are granted in the area of organic solar pv cells (18), followed by grid-connected applications (7), dye sensitized solar cells (7), concentrated pv (5), pv energy (3), solar thermal (3) and so on.

In the innovation ecosystem, universities are the one of the main actors because the interaction between industries/government institutions with university is so much important. The linkage between the academia, industries and government institutions boost the more quality output of the research and development activities to explore the solar energy study throughout the globe. With the help of analyzing the data available in the scopus database, the productivity of research publications related to solar energy sector in different universities and R&D institutions in the country are produced. For analyzing the publications, we have taken the seven keywords[21] in the database. The total number publications till 2016 in solar energy sector was 287853. Out of this, USA has published about 68,938 publications. USA has published highest papers about 24% of total world publications and then followed by China 37,562 (13%), Germany 20,601 (7%), Japan 18,844 (6.5%) and followed by India 13,886 (5%). The country stands at fifth position. The following figure shows the number of publications by top ten countries in the world.

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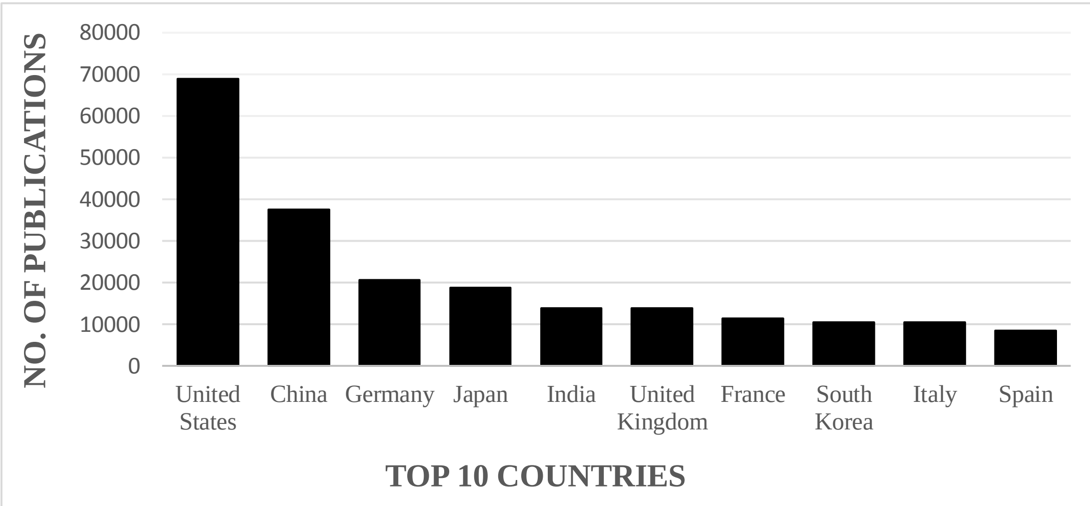
[19] See http://www.ipindia.nic.in/. The patent search was made in double field search. The first field used was as search on title with keyword "solar" and "solar energy" in the second field.

[20] For example, the number of patents granted in solar thermal, tower concentrators, dish collectors, Fresnel lenses, trough concentrators, stirling solar thermal engines, thermal updraft, mounting or tracking, photovoltaic energy, PV systems concentrators, material technologies, CulSe2 material PV cells, dye sensitized solar cells, solar cells from group II-VI materials, solar cells from group III-V materials, micro-crystalline silicon PV cells, poly-crystalline PV cells, mono-crystalline PV cells, amorphous silicon PV cells, organic PV cells, power conversion electric or electronic aspects, for grid-connected applications were obtained by using the CPC codes such as ICN/IN AND YO2E 10/40, ICN/IN AND YO2E 10/41, ICN/IN AND YO2E 10/42, …….ICN/IN AND YO2E 10/63, etc.

[21] Your query : ((TITLE-ABS-KEY(solar energ*) OR TITLE-ABS-KEY(solar photovoltaic*) OR TITLE-ABS-KEY(solar cell*) OR TITLE-ABS-KEY(solar thermal*) OR TITLE-ABS-KEY(solar power*) OR TITLE-ABS-KEY(solar panel*) OR TITLE-ABS-KEY(photovoltaic*)) AND PUBYEAR > 1979 AND PUBYEAR < 2017)

Fig.2: Publications by top 10 countries in the world



Source: Researcher's data based on the Scopus Database, 2016

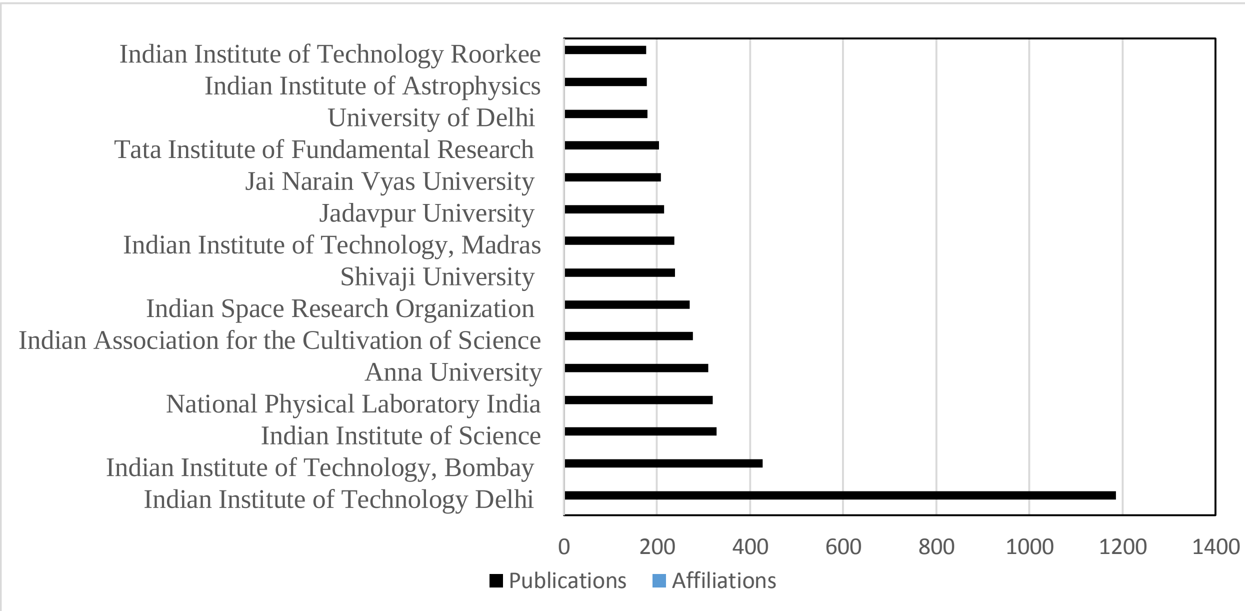
The figure 3 shows the year wise growth of publications related to solar energy in India for a decade from 2006 to 2015. The country has a significant presence of productive R& D institutions and universities.

Fig 3. Number of publications in India for a decade (2006-2015)

Source: Researcher's data based on the Scopus Database, 2016

The following fig. 4 illustrates the top 15 Institutions and universities paper published in the country. Indian Institute of Technology Delhi is on topmost with 1186 publications of the total publications (8.5%), followed by Indian Institute of Technology Bombay 427 publications (3%), Indian Institute of Science 328 publications (2.4%) and others.

Fig.4: Publications by top 15 Affiliations in India, 2016



Source: Researcher's data based on the Scopus Database, 2016

It is observed that among the top 15 affiliations there are four Indian Institute of Technologies and all are the public research and development institutions and universities except the Tata Institute of Fundamental Research, Mumbai which covers 1.5% of the total publications in the country.

8. Conclusion

Indian solar energy innovation system is constituted by policies which regulate, provide stimulus to the industry as whole, endowed with R&D and technical support institutions, financial institutions, business enterprises which are involved in manufacturing solar equipment and non-governmental organizations (NGOs). There is no single actor that can perform independently as all these above mentioned actors are linked and connected in an ideal situation. The policy support is the main actor which is responsible for the formulation of several renewable incentive policies that have increased the viability of increased deployment and development of solar energy technologies in the country. In alignment with the goals of the *National Solar Mission*, the National Institute of Solar Energy (NISE) and Solar Energy Corporation of India (SECI) are the important R&D institutions. They are part of Solar Energy Research Advisory Council which address the existing research infrastructure in the solar sector and help to set up a framework that nurtures an environment for accelerating research and development activities in the country. Before beginning the mission the activities of the NISE were confined to solar thermal energy areas only. After 2010 the main focus lies on the development and promotion of solar PV technologies (mainly thin films and crystalline modules). Both the institutions provided an effective interface among the government, R&D institutions, industries and users of the technology for development, promotion and widespread utilization of solar energy.

By far, the phase-I's outcome has been ambiguous to some extent. The report given in MNRE does not clearly show the mission's achievement in its first phase as it is more of an overall cumulative report. Therefore it is difficult to assess the output one by one. In the *National Solar Mission's* phase II, the mission identifies the need for international support in the form of technology transfer and financial assistance so as to meet its higher goals. Large scale expansion of grid connected solar power is its main target. It is imperative for the central government to create a favorable environment for developing both solar PV and thermal technology to enhance its power sector. For Phase-II, it would be mandatory to use cells and modules manufactured in India. So, some changes could be essential in domestic content requirement. Following this, it is inevitable for a new development pertaining to trade relations of the country with the rest of the world.

India ranks at fifth position in terms of knowledge production pertaining to the field of solar energy. The country has maximum publications particularly in the area of poly-crystalline, thin-film, dye-sensitized and amorphous solar technologies. However, the country is still lagging behind countries such as USA, China, Germany and Japan. Regarding the status of Indian manufacturing solar sector, the country's expertise is on crystalline silicon and thin films under PV technologies. The country is more advanced in PV technologies as compared to thermal technologies. Notwithstanding, the country covers only 2% of the global investment in renewable energy in the recent year. In case of China, the country invested 27% of the global investment in renewable energy. China has become the global leader in terms of investment in renewable energy. Though India has created institutional R&D set up and other actors in the innovation ecosystem, the country it is still far behind China in terms of investments in solar R&D.

Apart from low level of investments, there are some infrastructure related problems. For instance, installation of thin films has already created some controversy. The acquisition of land and its investment is yet to be resolved. Subsequently, land acquisition has been an issue of both in terms of its prices and investment for relevant authorities. Solar energy production in general has to take into account the value of land. Resolving these minor issues are linked up with production of more efficient technology; be it thin films or crystalline module or any other items.

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