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Exploring the Jawaharlal Nehru National Solar Mission (JNNSM): Impact on innovation ecosystem in India

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To make India one of the leaders in solar energy generation and to promote ecologically sustainable growth that addresses the nation's energy security challenge is one of the promising goals of the *Jawaharlal Nehru National Solar Mission (JNNSM)* or *National Solar Mission*. This paper presents the country's current solar energy scenario and explores ways in which various actors, agencies and policies shape the mission from the different perspectives on innovation literature. Innovation ecosystem is one of the perspectives where the sense of environment or ecology of various institutions, actors and other factors surrounds the activity of research and innovation. In this ecosystem, there is no single actor that can perform independently. The research outcomes, especially the patents, research publications and R&D investment, have become an increasingly essential area after the announcement of the JNNSM. The study also highlights that the number of research papers published in relation to solar energy has increased and there is a significant presence of productive R&D institutions, universities and supportive policy initiatives in the country.

Keywords: solar energy, innovation ecosystem, sectoral system of innovation, Jawaharlal Nehru National Solar Mission, India

Introduction

Energy is an important sector for the 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, consumption in the energy sector has increased rapidly. There is a wide gap between the country's energy production and its energy demand (Krishna, Sagar, and Spratt 2015). About 300 million people in the country lack access to basic energy services, according to the World Bank Report (2014). On the other hand, the country has huge potential for the generation of solar energy. The government of India launched a mission, the *Jawaharlal Nehru National Solar Mission* (hereafter JNNSM or *the National Solar Mission*) in November 2009 (it officially took off in January 2010). It is a major initiative to promote ecologically sustainable growth while addressing India's energy security challenge. The goal is to make the nation one of the leaders in solar energy production in the world by 2022. The mission has three phases, phase-I (2010–2013), phase-II (2013–17) and phase-III (2017–2022), each with different target achievements. The mission also has other additional goals such as promoting R&D, providing public domain information, developing trained human resources for the solar industry and expanding the scope and coverage of earlier incentives for industries to set up solar photo voltaic (PV) manufacturing in India. This mission, for various reasons, has garnered a lot of attention and inspired fully-fledged research into itself, while, simultaneously, impacting the innovation ecosystem in the country.

Solar energy technologies and innovation promote ecologically sustainable growth while addressing the country's energy security challenge (MNRE 2013). JNNSM constitutes 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 released its 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 the leading one among eight national missions[3] under the NAPCC because it fights the issue of climate change and it tries to answer the question of meeting India's energy demand while expanding development opportunities of different solar technologies throughout the country. There are different actors who constitute and shape the solar energy sector, like business enterprises or private firms, R&D institutions, universities, financial institutions, government ministries, non-governmental organization, etc. In our study, innovation ecosystem refers to the perspective where a sense of the environment or ecology of various institutions, actors and various other factors surrounds the activity of research and innovation.

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 a focus on solar energy. Others are:

- to study the various policies enunciated by the government with special reference to the first phase of *the National Solar Mission* and its impact on institution building; and

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- 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 was gathered 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 was drawn from the innovation system perspectives of National Innovation Systems (Freeman 1987 and 1995; Nelson 1993; Lundvall 1997; Edquist 1997) and Sectoral Innovation Systems (Carlsson 1995; Breschi and Malerba 1997; Mowery and Nelson 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 the Ministry of New and Renewable Energy (MNRE), the Solar Energy Centre (SEC), the Solar Energy Cooperation of India (SECI), the Indian Renewable Energy Development Agencies (IREDA), etc., were retrieved from their annual reports and websites. Some informal interviews were also undertaken to discuss various policy issues with professionals at the energy ministry.

To understand the research publications and patents' analysis, we used bibliometric analysis and databases available on USPTO (United States Patent and Trademark Office) and IPO (Indian Patent Office). Bibliometric is a set of online database tools for analyzing publication data. According to Norton, it defines the measure of texts and information associated with a publication, and 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 the solar energy sector in different universities and R&D institutions in the country were calculated and analyzed accordingly. The information gathered from the libraries of the Indian Institute of Technology IIT, Delhi and the Energy Resources Institutes (TERI) and others have also been incorporated.

Theoretical framework and literature review

This study was undertaken to explore the ways in which various actors, agencies and policies influenced the JNNSM or solar energy sector under the theoretical framework of innovation literature. Since the development and deployment of different solar technologies are driven by different actors and agencies, a study on the JNNSM cannot be complete without bringing them into perspective. The concept of a system of innovation was developed in parallel at different places in Europe and the USA in 1980s. As Schumpeter (1939) defines innovation, it is the key driver to economic change and regional development of a nation because it is responsible for the setting up of new production functions that create new commodities as well new forms of organization. Schumpeter (1939) further mentions that invention, innovation and successful diffusion of new technologies are the major drivers of modern economies. The Schumpeterian concept of innovation also draws attention to the introduction of new products, process innovation that is new to an industry, the opening of new markets, the development of new sources of supply for raw materials or other inputs, and 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 is more often the new combination of existing elements. He further describes the category of innovation as extremely complex and heterogeneous. Similarly, Fagerberg, Mowery, and Nelson (2005) also stress that innovation is crucial for long-term economic growth and it tends to cluster in certain industries or sectors, which consequently grow more rapidly than others, implying structural changes in production and demand and, eventually, organizational and institutional change. Innovation is nowadays therefore perceived as the fundamental driving force behind both advanced and advancing economies.

In this study, we also drew on the system of innovation from Metcalf (1995) who perceives that institutions which jointly and individually contribute to the development and diffusion of new technology also provide the framework that governments use in forming and implementing policies to influence the innovation process. A system of innovation has also been defined as 'all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations' (Edquist and Johnson 1997, 14). During the 1990s, it became 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 (Edquist and Johnson 1997). The development of innovations is seen as being characterized by a processes of interactive learning, i.e. there is often an exchange of knowledge between organizations involved in the innovation processes (Lundvall 1997). Various kinds of knowledge and information are exchanged between organizations and such exchanges often take the form of collaboration that is not mediated by a market. From the different perspectives of innovation, it could thus be studied in a national, regional or sectoral context such as the National Innovation System (NIS), the Regional Innovation System (RIS) or the Sectoral System of Innovation (SSI). The SSI perspective has been developed and increased in importance over time by Carlsson (1995), Breschi and Malerba (1997), Cooke et al. (1997), Mowery and Nelson (1999) and so on.

The concept of sectoral systems of innovation (SSI) is very popular today. Based on this framework, there are many studies that look at the dynamism of sectoral systems in many sectors. For instance, Turpin and Krishna (2007) view the dynamics underlying three promising sectors in India, namely ICT software, biotechnology and pharmaceuticals, through the lens of the SSI perspective. Krishna (2007) regards the three main building blocks of the innovation framework, namely 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 of all sectors.

The SSI helps 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. The SSI is composed of various agents, institutions, types and structures of interactions among firms and non-firm organizations in a sector. Malerba (2000; 2002b) defines the SSI as

> … 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 (2004) 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 has a knowledge base, technologies, input and (potential or existing) demand where the agents composing the sectoral system are organisations and individuals (Malerba 2002a).

The idea of innovation ecosystem that we employ here refers to the way in which various actors, agencies and policies are shaping the JNSSM or India's solar energy sector. In this ecosystem, there is a combination of public and private research institutions, universities and other technical and financial institutions in India. The country is trying to create its own innovation ecosystem by consolidation of various private or public institutions, universities, technical and funding bodies. The country can become a global innovation leader, if there is an effective innovation ecosystem with 'coherent synergy'[5] in the field of science and technology and 'technology foresight' to make the right technology choices in the national perspective (Chidambaram 2007). Research, however, involves generation of new knowledge and innovation requires adding economic value (or societal benefit or strategic value or both) to that knowledge.

Key actors in the innovation ecosystem and installation capacity

System of innovation literature leads us to the concept of innovation ecosystem (Chidambaram 2007) which, in the context of this study, signifies different actors, agencies and polices among other features of the environment surrounding the solar energy sector in India. The JNSSM has initiated numerous steps to catalyze innovation ecosystem for the development and implementation of different technologies of solar energy in the country (MNRE, 2010a). Key actors in the ecosystem are depicted in Table 1.

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 country's PV sector endeavours to focus on three key approaches which include licencing of patents, acquisitions and joint ventures, and in-house research and development, in a bid to match the sector's ongoing development levels of technology, production and knowledge capacity (Mallett et al. 2009).

Gujarat is the leading state in solar energy installation in India with 857.90 MW, followed by Rajasthan (552.90 MW), Maharashtra (100 MW), Madhya Pradesh (37.32 MW), Andhra Pradesh (23.35 MW) and so on. Gujarat, Rajasthan, Maharashtra, Madhya Pradesh and Andhra Pradesh respectively cover 50.87%, 32.74%,

Table 1: Actors in the innovation ecosystem in the 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) and TERI (2013)

5.9%, 2.1% and 1.3% of the total grid's connected solar energy capacity (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%). Table 2 shows the cumulative deployment of renewable energy sources (both grid and off-grid connected) at the end of November 2016. The cumulative installed solar energy capacity was about 9256.88 MW at the end of November 2016. Out of this, 8874.87 MW and 382.01 MW are from grid-connected and off-grid solar respectively (CEA 2016; MNRE 2016). The country stands in fourth position globally in terms of renewable energy market potential, just behind China, the US and Germany.

Renewable energy as a whole has the potential to meet 15% of the total contribution under the National Action Plan on Climate Change (NAPCC) by 2020[6] which will eventually reduce the emission of greenhouse gases (MNRE 2013). India has huge potential for solar power generation since about 58% of the total land area (1.89 million km^2) receives and annual average global insolation above 5 kWh/m^2/day (Ramachandra, Jain, and Krishnadas 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 km^2 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 km^2) is sufficient to meet electricity needs of the country till 2031 as estimated by some sources. The challenge of providing 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 consist almost entirely 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 has also been used for powering water pumps for farming and small industrial areas (MNRE 2015).

Solar technology can broadly divided into two categories, such as solar PV technology and solar thermal technology (Bhargava 2001 and Kharul 2011). Several types of solar PV cells[8] are globally available, such as amorphous silicon, crystalline silicon, dye-sensitized cells as well as other newer technologies, such as silicon-nano particle ink, carbon nanotube and quantum dots (Willey and Hester, 2009). Kharul (2011) 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 their initial stage.

Solar thermal technology is quite diverse in terms of its operational characteristics and applications in 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 (Purohit and Purohit 2010). 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).

Status of the Indian solar manufacturing sector

The 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 compared with the PV technologies. Since the 1970s, BHEL and CEL have been engaged in making solar panels and other equipment, but were later joined by other companies that 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 (Bhushan and Hamberg 2012). Since then, the domestic manufacturing industries have experienced nurturing growth owing to global demands and the ambitious national solar mission implications.

According to the World Bank (2013), most of the raw materials and consumables for solar cell and module manufacturing in India are imported. There is no poly-silicon or wafer manufacturing capability in the country. But more than 19 solar cell makers and 50 module makers have registered with the MNRE in the country[10] (Bhushan, and Hamberg, 2012). The Chinese are the

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*	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)

*Bio-power includes biomass-gasification and bagasse cogeneration which achieve maximum energy from the off-grid system as 651.91 MW and 186.88 MW, respectively.

leaders in both cell and module production globally (TERI 2013; Spratt et al. 2014). By the beginning of the national solar mission's second phase, about 1500 MW of cell manufacturing capability and around 2000 MW of domestic module manufacturing capability existed in India as compared with only 15 MW 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 an opportunity often arises because government provides incentives.

Policies on renewable energy with respect to solar energy in India

The flow of information and network linkages of solar energy technology among people, enterprises and institutions are 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 in the innovation ecosystem for the development and growth of the solar energy sector in the country. The Government of India has established the Ministry of New and Renewable Energy (MNRE), the Indian Renewable Energy Development Agency (IREDA), State Nodal Agencies, the Central Electricity Regulatory Commission (CERC) and the State Electricity Regulatory Commission (SERC) for the respectable functioning of the ecosystem. These bodies are engaged with each one another coherently in order to maintain the development of the renewable energy sector in general and the solar energy sector in particular.

In the early 1980s, the government began to introduce policies to support the expansion of renewable energy in the country. In 1982, the Department of Non-Conventional Energy Sources (DNES) was established. The 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). Then, in 2006, the MNES was renamed the 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 that have specific solar state policies[11] and some are in the pipeline in order to boost solar generation capacities and drive down costs through local manufacturing and R&D activities to accelerate the transition to clean and secure energy in the state itself. Figure 1 depicts the evolution of India's renewable energy policies with respect to solar energy.

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 to supplement 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 (MNRE 2011). 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.

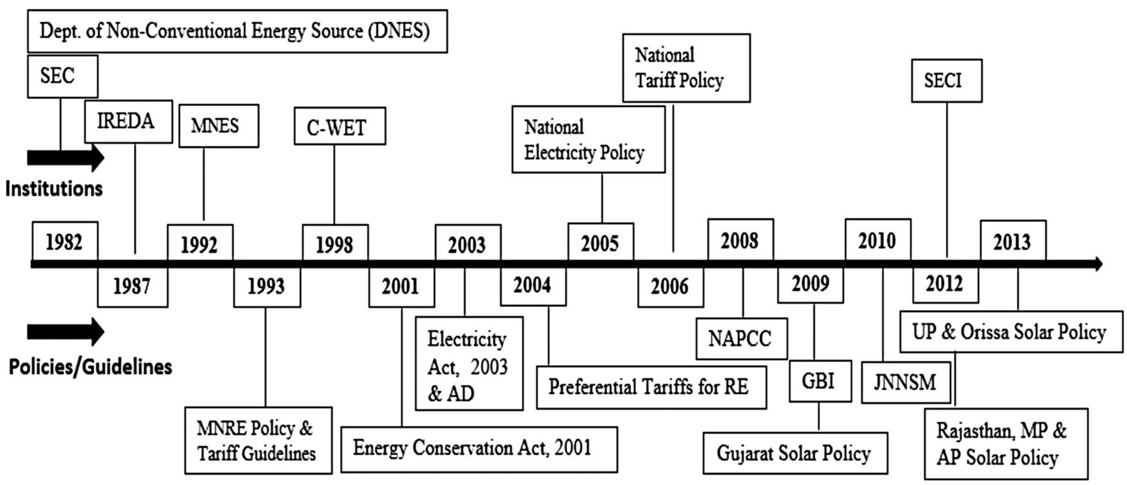

Figure 1: Timeline of various Indian energy policies and institutions set up to focus on the solar sector.
Source: Compiled by author; MNRE 2015

The vision of the MNRE is to develop new and renewable energy technologies, processes, materials, components, sub-systems, products and services on a 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 like supporting the Solar Energy Corporation of India (SECI). As a part of the Jawaharlal Nehru National Solar Mission (JNNSM), the Indian Institute of Technology (IIT) Delhi, IIT Mumbai, IIT Rajasthan, the Indian Institute of Science (IISc) Bangalore and the 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 the solar energy innovation ecosystem, the government is the main actor and 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 JNNSM. To achieve solar capacity and cost targets, the JNNSM 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.

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 (PPAs) with transmission or distribution utilities or with trading licensees (Schmid 2012). 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 a *Renewable Energy Certificate* (REC) to fulfil their RPO. Many states are now establishing RPOs, which have stimulated development of a tradable REC programme (Altenburg and Engelmeier 2012).

Generation base incentives are provided to support small grid solar power projects connected to the distribution network under the solar *Generation Based Incentives* (GBI) scheme. The solar *Rooftop PV and Small Solar Power Generation Programme* (RPSSGP) is also an interesting scheme which was designed essentially to encourage states to implement grid connected projects focusing on the distribution network and to strengthen the tail end of the grid system. These *Feed in Tariff* and solar RPO, REC, GBI and RPSSPGP schemes have become notable policies or schemes during the implementation of the JNNSM.

Jawaharlal Nehru National Solar Mission and the status of Phase-I

The Jawaharlal Nehru National Solar Mission (JNNSM) is a major initiative of the government of India to promote ecologically sustainable growth while addressing the country's energy security challenge. The JNNSM seeks to kickstart solar generation capacities, drive down costs through local manufacturing, research and development to accelerate the transition to clean and secure energy (Deshmukh et al. 2011). Table 3 highlights the chronology of events in the JNNSM.

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: 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, 2000 MW of off-grid solar applications, 20 million

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

Date	Event
2007	The MNRE initiates the framing of 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.
2009	NTPC Vidyut Vyapar Nigam Ltd. (NVVN) become nodal stakeholders in power purchase agreements through the 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 (5 MW 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: Compiled by author; Krishna, Sagar, and Spratt (2015)

Table 4: Phase-wise and total targets in the JNNSM.

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) 2013

metres^2 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 respective targets of 1100 MW, 3000 MW and 16,000 MW of grid-connected solar. In case of the off grid solar applications, 200 MW, 800 MW and 1000 MW are the targets in the first, second and third phases, respectively. And lastly, the three phases target to achieve 7, 8 and 5 million metres^2 of solar collectors (see Table 4).

The mission has also other additional goals, such as promoting R&D, disseminating public domain information, developing trained human resource for the solar industry, and expanding 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 have been setting up solar projects during Phase-I. About 615 MW of different solar power projects, including both solar PV (145 MW) and thermal (470 MW) projects, were listed during according to NVVN. Out of them, the CSP projects are in Rajasthan (400 MW), Andhra Pradesh (50 MW) and Gujarat (20 MW), while 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) and Tamil Nadu (5 MW).[16]

The mission's phase-I is divided into batch-I and batch-II. In both batches, several schemes like NVVN scheme, migration scheme and RPSSGP scheme are introduced. Table 5 gives the status for both batch-I and batch-II under the JNNSM phase-I, including projects allotted under different schemes (see Table 5). About 1152.5 MW of grid connected solar projects have been allotted in batch-I and batch-II together. Out of the total 802.5 MW, 500 MW is allotted for solar thermal projects and 302.5 MW for solar PV projects in batch-I. On the other hand, 350 MW of solar PV projects are allotted with respect to batch-II. Among the schemes, the purpose behind launching the migration scheme in 2010 was to provide transition to affordable solar projects from the existing arrangement to the one envisioned under the mission. The scheme is further subjected to the consent of state governments, the disposition of the project developer and the distribution licensee[17] (MNRE 2012). The bundling of solar power was introduced in this phase. As per this bundling, the cost of solar power is about Rs.5/kWh for which 500 MW capacities of both solar PV and thermal projects have been selected (MNRE 2012).

In the case of the off-grid connected/decentralized solar power in the JNNSM phase-I, around 27,841 solar lanterns, 53,588 home lights, 21,957 solar street lights, 1055 water pumping system and stand-alone solar PV power plants of 9365.39 KW capacity were installed during 2012–13 (MNRE 2013).

R&D activities and knowledge production in solar energy technologies

Promotion of R&D and increasing the knowledge production in solar energy technologies is one of the main objectives of national policies on solar energy and its innovation ecosystem. The various research and development programmes are designed to improve the efficiency, reliability and cost competitive performance of different solar energy technologies in the country. The National Institute of Solar Energy (NISE) and the Solar Energy Corporation of India (SECI) are the two most important R&D institutions that are established under the Solar Energy Research Advisory Council to address the existing research infrastructure in the domain of the solar energy sector and help to set up a framework which would incubate an environment for accelerating research and development activities in the country related to 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

Table 5: Status of Batch-I and Batch-II of the JNNSM Phase-I.

	Projects allotted		Project commissioned	
I. For Batch-I (Schemes)	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 (MNRE) 2012 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 are important tasks. The institution is also responsible for conducting various training programmes, seminars, workshops and other solar energy technology courses with the objective of disseminating relevant knowledge. The MNRE has also introduced a fellowship, the national solar science fellowship programme. As part of the JNNSM, the SECI has taken up various projects or activities related to the solar sector across the country. One of the on-going schemes under the SECI is a 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 was launched in 2009 with a preliminary budget allocation of Rs.3.85 billion (IREDA 2012). India invests less money in its renewable energy sector than other countries globally. India has invested Rs 442.4 billion in the sector, which is only 2% of the global investment in the sector in recent year (MNRE 2015; BNF 2015). China has become the global leader in investment in the sector with around Rs.4532.4 billion invested, followed by the USA with about Rs.2450. These equal about 27% and 15% of global investment.

Knowledge production and comparisons with other countries

Solar energy has been harnessed mainly in two technologies. One is solar photovoltaic (PV) technology and the other solar thermal technology. The former technology is more advanced and developed than the latter (MNRE 2015). Among solar technologies, solar PV has emerged as the fastest growing renewable power technology worldwide (REN21 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, particularly 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, multi-junction cells, poly crystalline and thin film cells in the country for 10 years (2006–2015) are shown in Table 6. The country has published the highest number of research publications globally in thin film, poly crystalline, amorphous and dye sensitized solar cells. Seven research organizations, namely the Indian Association of Cultivation of Science (Kolkata), the Indian Institute of Technology (Delhi), the University of Poona (Pune), the National Physical Laboratory (Delhi), the Indian Institute of Technology (Madras), the Indian Institute of Science (Bangalore) and the Indian Institute of Technology (Kharagpur) were involved in research on various aspects of amorphous material 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).

In poly crystalline cells, in 2015 India ranked fourth globally with 981 publications. China had 2261 research publications in this particular technology leads the field globally the number of research papers published. In the case of dye sensitized, thin film cells and amorphous cells the country is ranked sixth and seventh, respectively. The rank-wise country in the publications of research in various solar technologies to 2016 is shown in Table 7.

In the case of number of patents granted in India related to solar energy, around 75 patents were granted by the Indian Patent Office (according to their website)[18] as at 2 July 2015. The online database on the patents was obtained by using the search engine 'Indian Patent Office' supported by the Office of the Controller General of Patents, Designs & Trade (CGPDT), the Ministry of Commerce and Industry and the government of India. But in the case of USPTO (United States Patent and Trademark Office) 53 patents[19] were granted in India in the different field of solar technologies. The highest number of patents were 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 and universities is very important. The linkage between academia, industries and government institutions boost the quality of research output and development activities that explore solar energy worldwide. The productivity of various

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**, 2016

**Based on the database, the number of publications related to a specific solar technology was 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') OR (LIMIT-TO (EXACTKEYWORD, '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)

Note: The figures within brackets indicate the number of publications by the respective country.
Source: Researcher's data based on the Scopus Database, 2016

universities and R&D institutions in India, compared with other countries globally, in terms of research publications related to the solar energy sector produced, was analyzed with the help of the data available in the Scopus database. To analyze the publications, we used the seven keywords[20] in the database. The total number publications in the solar energy sector as at 2016 was 287,853. Of this total, at 68,938 publications, the USA published the highest number of papers (24% of global publications), followed by China 37,562 (13%), Germany 20,601 (7%), Japan 18,844 (6.5%) and India 13,886 (5%). The country stands in fifth position. Figure 2 shows the number of publications by the top 10 countries in the world.

The country has also a significant presence of productive R&D institutions and universities. Figure 3 shows the year-wise growth of publications related to solar energy in India for a decade from 2006 to 2015. Out of the top 15 institutions and universities that published papers in India, the Indian Institute of Technology, Delhi, is topmost with 1186 publications (8.5% of the total publications), followed by the Indian Institute of Technology, Bombay, with 427 publications (3%), the Indian Institute of Science with 328 publications (2.4%) and others (see Figure 3). It is observed that among the top 15 affiliations there are four Indian Institutes of Technology and that all are the public research and development institutions and universities, except for the Tata Institute of Fundamental Research, Mumbai, which covers 1.5% of the total publications in the country (see Figure 4).

Conclusion

The innovation ecosystem in the solar energy sector is constituted of policies which regulate and provide stimulus to the industry as whole, which is endowed with R&D and technical support institutions, financial institutions, non-governmental organizations (NGOs) and business enterprises that are involved in manufacturing solar equipment. In an innovation system, there is no single actor that can perform independently, as all these above-mentioned actors are linked and connected in an ideal situation. In this ecosystem, 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 the Solar Energy Corporation of India (SECI) are the most important R&D institutions. They are part of the Solar Energy Research Advisory Council which addresses the existing research infrastructure in the solar sector and helps to set up a framework that nurtures an environment for accelerating research and development activities in the country. Before the beginning of the *National Solar Mission*, the activities of the NISE were confined to solar thermal energy areas. After 2010, the main focus was 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

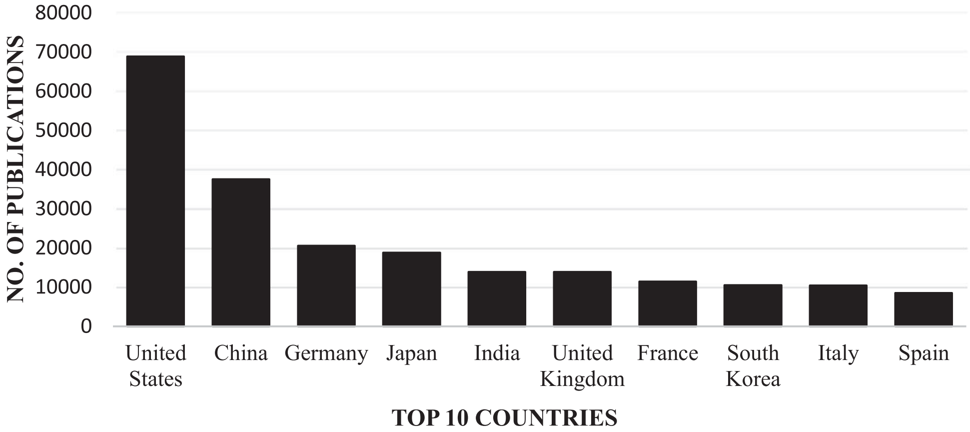

Figure 2: Publications by top 10 countries in the world.
Source: Researcher's data based on the Scopus Database, 2016

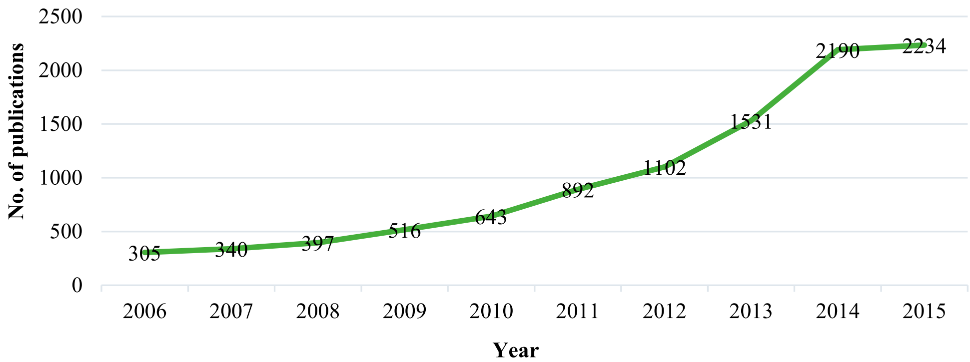

Figure 3. Number of publications in India for a decade (2006–2015).
Source: Researcher's data based on the Scopus Database, 2016

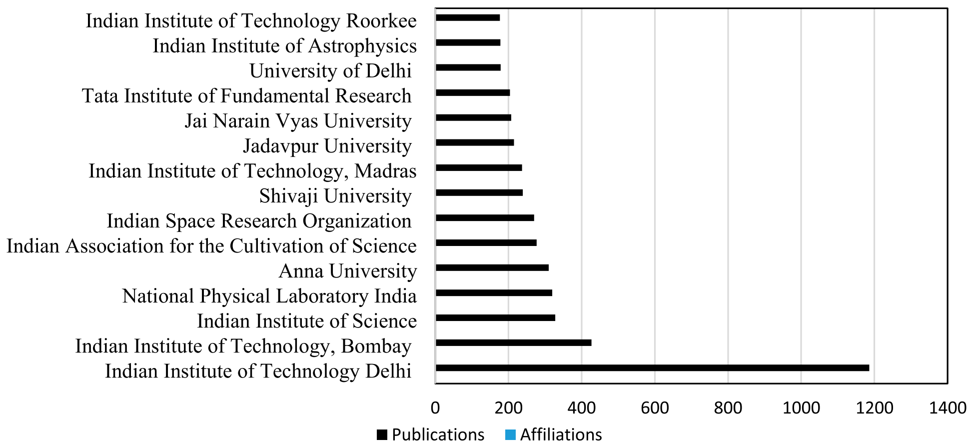

Figure 4: Publications by top 15 affiliations in India, 2016.
Source: Researcher's data based on the Scopus Database, 2016

for the development, promotion and widespread utilization of solar energy.

By far, the outcomes of phase-I have, to some extent, been ambiguous. The report given in the MNRE does not clearly show the mission's achievements in its first phase, as it is more of an overall cumulative report. Therefore, it is difficult to assess the individual outputs. In JNNSM 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 favourable 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 requirements. Following this, new developments pertaining to trade relations of the country with the rest of the world are inevitable.

India ranks at fifth position in terms of knowledge production pertaining to the field of solar energy. The country has published extensively, particularly in the area of polycrystalline, thin-film, dye-sensitized and amorphous solar technologies. However, the country still lags behind countries such as the USA, China, Germany and Japan. Regarding the status of India's solar manufacturing sector, the country's expertise is in crystalline silicon and thin films under PV technologies. The country is more advanced in PV technologies than thermal technologies. Notwithstanding this, in recent years India has only contributed 2% of the global investment in renewable energy, whereas China has invested 27% of the global total, making China the global leader in terms of investment in renewable energy. Although India has created institutional R&D set ups and other actors in the innovation ecosystem, the country 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 in terms of both its prices and investment for relevant authorities. Solar energy production in general must take into account the value of land. Resolving these minor issues are linked to the production of more efficient technology, whether thin films or crystalline modules or any other items.

Hence, the process of indigenizing solar films, including resolving infrastructural issues, seems imperative for the country. The import of films versus local manufacture deserves the utmost attention by decisionmakers. India has created all the necessary elements and actors relevant to a solar energy ecosystem, with a very high policy focus. However, further investment in research and strengthening innovation ecosystem will drastically improve India's comparative advantage.

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No potential conflict of interest was reported by the authors.

Notes

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 (MNRE, 2010b).
4. Scopus is one of the largest online abstract and citation database of peer reviewed literature with smart tools that extract, analyze and visualize research which that covers more than 205,000 titles from nearly 5000 publishers. See http://www.info.sciverse.com/scopus/.
5. According to Chidambaram, coherent synergy means coherence among the varieties of synergetic efforts; it may be Human Resource Development, R&D with prioritization, academia-industry interaction, international collaboration, made by the concerned parties in the field of science and technology for economic development in the country.
6. Annual report 2012–13, Ministry of New and Renewable Energy (MNRE), Government of India 2013.
7. Sukhatme (2011).
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 (Sharma 2011).
9. Asif and Muneer (2008). Solar thermal technologies. Encyclopaedia of energy engineering and technology. *Taylor and Francis,* New York, pp.1321−1330.
10. Bhushan and Hamberg (2012).
11. For instance, Gujarat State Policy, 2009 is the first solar specific state policy introduced in the country predating the JNNSM. 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.
12. Ministry of New and Renewable Energy, (MNRE); see the link: http://www.mnre.gov.in/mission-and-vision2/mission-and-vision/vision/ accessed 20 May 2013.
13. Solar cells and modules are the building blocks of solar PV (crystalline silicon) which are used to generate electricity.
14. Ministry of New and Renewable Energy (MNRE), Strategic Report; see http://www.mnre.gov.in/ accessed 22 February 2013.
15. NTPC Vidyut Vyapar Nigam (NVVN) Ltd. was formed by the National Thermal Power Cooperation (NTPC), as its wholly owned subsidiary to realize the potential of power trading, capacity utilization of power generation and transmission assets, and boost the development of the power market in the country.
16. Selected projects for phase-I JNNSM, NTPC Vidyut Vyapar Nigam (NVVN) Limited; see http://nvvn.co.in/Selected%20Projects%20List.pdf accessed 1 May 2013.
17. Jawaharlal Nehru National Solar Mission Phase II-Policy Document, 2012, Ministry of New & Renewable Energy. See the link: http://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf
18. See http://www.ipindia.nic.in/. The patent search was made in a double field search. The first field used was as search for titles with keyword "solar", and "solar energy" in the second field.
19. 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.

20. Your query: ((TITLE-ABS-KEY(solar energy*) 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)

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References

Altenburg, T., and T. Engelmeier. 2012. “Rent Management and Policy Learning in Green Technology Development: The Case of Solar Energy in India.” Discussion Paper 12/2012, Bonn: German Development Institute, Accessed May 15, 2015 www.die-gdi.de/uploads/media/DP_12.2012.pdf.

Asif, M., and T. Muneer. 2008. “Solar Thermal Technologies.” *Encyclopedia of Energy Engineering and Technology* Taylor and Francis, New York. 7: 1321–1330.

Bhargava, B. 2001. “Overview of Photovoltaic Technologies in India.” *Solar Energy Materials and Solar Cells* 67: 639–646.

Bhushan, C., and J. Hamberg. 2012. “Facing the Sun: Policy for Sustainable Grid-Connected Solar Energy.” New Delhi: Centre for Science and Environment.

BNEF (Bloomberg New Energy Finance). 2015. “Global Trends in Renewable Energy Investment 2015.” Available at http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2015

Breschi, S., and F. Malerba.1997. “Sectoral systems of innovation: Technological regimes, Schumpeterian dynamics and spatial boundaries.” In *Systems of Innovation: Technologies, Institutions and Organizations*, edited by C. Edquist, 130–156. London: Pinter Publishers.

Carlsson, B. 1995. *Technological Systems and Economic Performance: The Case of Factory Automation*. Dordrecht: Kluwer.

Chidambaram, R. 2007. “Directed Basic Research.” *Current Science* 92 (9): 1229–1233.

Cooke, P., M. Uranga, and G. Etxebarria. 1997. “Regional Innovation Systems: Institutional and Organisational Dimensions.” *Research Policy* 26 (4): 475–491.

Deshmukh, R., G. Gambhir, and G. Sant. 2011. “India’s Solar Mission: Procurements and Auctions.” *Economic and Political Weekly* 46 (28): 22–25.

Edquist, C., ed. 1997. *Systems of Innovation: Technologies, Institutions and Organizations*. London: Pinter Publishers.

Edquist, C. 2001. “The systems of innovation approach and innovation policy: An account of the states of the art.” DRUID Conference, theme on ‘National systems of innovation, institutions and public policies’ Aalborg, June 12–15, 2001, 1–24.

Edquist, C., and B. Johnson. 1997. “Institutions and Organizations in Systems of Innovation.” In *Systems of Innovation: Technologies, Institutions and Organizations*, edited by C. Edquist, 41–60. London: Pinter Publishers.

Fagerberg, J., D. Mowery, and R. Nelson. 2005. *The Oxford Handbook of Innovation*. Oxford: Oxford University Press.

Freeman, C. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter Publishers.

Freeman, C. 1995. “The ‘National System of Innovation’ in Historical Perspective.” *Cambridge Journal of Economics* 19: 5–24.

IREDA (Indian Renewable Energy Development Agency). 2012. “Annual Report 2011-12, Delhi”.

Kharul, R. 2011. “Grid-connected Photovoltaic.” In *A Solar Future for India*, edited by G. M. Pillai, 118–140. Pune: World Institute of Sustainable Energy (WISE). ISBN 81-902925-2-8.

Krishna, V. V. 2007. “Dynamics in the Sectoral System of Innovation: Indian Experience in Software, Biotechnology and Pharmaceuticals.” In *Science, Technology Policy and the Diffusion of Knowledge: Understanding the Dynamics of Innovation Systems in the Asia-Pacific*, edited by T. Turpin and V. V. Krishna, 193–233. Cheltenham: Edward Elgar.

Krishna, C., A. D. Sagar, and S. Spratt. 2015. “The Political Economy of Low Carbon Investments: Insights from the Wind and Solar Power Sectors in India.” IDS University of Sussex. Working paper no. 104.

Lundvall, B. A. 1997. “*National Systems and National Styles of Innovation*.” Paper presented at the fourth international ASEAT conference, “differences in “styles” of technological innovation”, Manchester, UK, Sept. 1997.

Malerba, F. 2000. “Sectoral System of Innovation and Production.” ESSY Working Paper No. 1.

Malerba, F. 2002a. “Sectoral System of Innovation and Technology Policy.” Workshop on Frontiers of Innovation Research and Policy, Organised by Instituto de Economia/UFRJ and the Institute of Innovation at the University of Manchester, Rio de Janeiro, September 25–27, 2002.

Malerba, F. 2002b. “Sectoral Systems of Innovation and Production.” *Research Policy* 31 (2): 247–264.

Malerba, F., ed. 2004. *Sectoral Systems of Innovation: Concepts, Issues and Analyses of six major Sectors in Europe*. Cambridge: Cambridge University Press.

Mallett, A., D. G. Ockwell, P. Pal, A. Kumar, Y. P. Abbi, R. Haum, G. MacKerron, J. Watson, and G. Sethi. 2009. “UK-India collaborative study on the transfer of low carbon technology:” Phase II final report. SPRU. Sussex University and Institute of Development Studies. Available at http:///www.sussex.ac.uk%2Fsussexenergygroup%2Fdocuments%2Fdecc-uk-india-carbon-technology-web.pdf

Metcalfe, S. 1995. “The economic foundations of technology policy: Equilibrium and evolutionary perspective.” In *Handbook of the Economics of Innovation and Technological Change*, edited by P. Stoneman, 409–512. London: Blackwell Publishers.

Mitavachan, H., and J. Srinivasan, 2012. “Is land really a constraint for the utilization of solar energy in India?” *Current Science* 103 (2): 163–168.

MNRE (Ministry of New and Renewable Energy). 2010a. “Annual Report 2009-10, New Delhi”.

MNRE (Ministry of New and Renewable Energy). 2010b. “Jawaharlal Nehru National Solar Mission, Towards Building Solar India, New Delhi”.

MNRE (Ministry of New and Renewable Energy). 2011. “Strategic Plan for New and Renewable Energy Sector for the Period 2011-2017.” p-9.

MNRE (Ministry of New and Renewable Energy). 2012. “Jawaharlal Nehru National Solar Mission Phase II-policy Document.” See the link: http://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf.

MNRE (Ministry of New and Renewable Energy). 2013. “Annual Report 2012-13, New Delhi”.

MNRE (Ministry of New and Renewable Energy). 2015. “Annual Report 2015-14, New Delhi”.

MNRE (Ministry of New and Renewable Energy). 2016. “Annual report 2016-15, New Delhi”.

MoP (Ministry of Power) CEA (Central Electricity Authority). 2016. “Load Generation Balance Report, 2016-2017.” New Delhi.

Mowery, D. C., and R. R. Nelson, eds. 1999. *Sources of Industrial Leadership: Studies of Seven Industries*. Cambridge University Press: Cambridge.

Nelson, R. R., ed. 1993. *National Innovation Systems: A Comparative Study*. Oxford: Oxford University Press.
Norton, M. J., ed. 2001. *Introductory Concepts in Information Science*. New Jersey: Information Today, Inc.
Pillai, I., and R. Banerjee. 2009. "Renewable Energy in India: Status and Potential." *Energy* 34: 970–980.
Purohit, I., and P. Purohit. 2010. "Techno-Economic Evaluation of Concentrating Solar Power Generation in India." *Energy Policy* 38: 3015–3029.
Ramachandra, T.V., Rishabh Jain, and Gautham Krishnadas. 2011. "Hotspots of Solar Potential in India." *Renewable and Sustainable Energy Reviews* 15: 3178–3186.
REN21. 2015. "Renewable 2015 Global Status Report." Annual Reporting on Renewable; 10 years of Excellence, Paris. ISBN, 978-3-9815934-6-4.
Schmid, G. 2012. "The Development of Renewable Energy Power in India: Which Policies Have Been Effective?" *Energy Policy* 45: 317–326.
Schumpeter, J. A. 1939. *Business Cycles: A Theoretical, Historical, Statistical Analysis of the Capitalist Process*. New York: McGraw-Hill.
Sharma, A. 2011. "A Comprehensive Study of Solar Power in India and World." *Renewable and Sustainable Energy Reviews* 15: 1767–1776.
Spratt, S., W. Dong, C. Krishna, A. Sagar, and Q, Ye. 2014. "What drives wind and solar energy investment in India and china?" IDS University of Sussex. Working paper No. 87.
Sukhatme, P. 2011. "Meeting India's Needs of Electricity Through Renewable Energy Sources." *Current Science* 0.101 (5): 624–630.
TERI (The Energy and Research Institute). 2013. "TERI Energy Data Dictionary and Yearbook (TEDDY) 2012-2013 Report, New Delhi".
Turpin, T. and V. V. Krishna, eds. 2007. *Science, Technology Policy and the Diffusion of Knowledge: Understanding the Dynamics of Innovation Systems in the Asia-Pacific*. Cheltenham: Edward Elgar Publishers.
Willey, T., and S. Hester. 2009. "Solar electric technologies and applications." *Cogeneration and Completitive Power Journal* 18 (2): 37–47.
World Bank. 2013. "Paving the way for a transformational future: Lessons from JNNSM phase-1." Energy sector management assistance programme (ESMAP). Washington DC: World Bank.