ACTORS, TRENDS IN KNOWLEDGE PRODUCTION AND INNOVATION IN INDIAN RENEWABLE ENERGY SECTOR: A CASE OF SOLAR AND WIND TECHNOLOGIES

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ABSTRACT

The main focus of this paper is to understand the nature, structure and dynamics of renewable energy sector with special focus on solar and wind energy by identifying various actors and institutions, and the trends in the production of scientific knowledge. We adopt Sectoral System of Innovation (SSI) framework for the study. The SSI approach has composed of various actors, agents, institutions, types and structure of interactions among firms and non-firms organizations. The main findings of the study are the number of research publications and granted patents has been increased gradually in both solar and wind technologies in the country. India ranks among the top ten country in terms of scientific knowledge production pertaining to the field of solar which stands at fifth position and wind energy at sixth position. In terms of R&D investment in both solar and wind energy the country is far behind others leading countries. Though, there is a significant presence of productive R&D organization, academia and supportive regulatory policy initiatives in both solar and wind energy sectors.

Key words: Innovation; knowledge production; renewable energy; solar; wind; India.

INTRODUCTION

The study is motivated by the need to accelerate the supply of renewable energy with special focus on both solar and wind energy with a vision of affordable and reliable clean energy because it addresses the issue of climate change and fostering sustainable development in India. The economy of the country is one of the fastest growing in the world. The consumption in energy sector has increased rapidly in the country due to the rapid growing population and growing economy. About 300 million people (nearly 24%) are not connected to the national electrical grid (World Bank Report, 2014). There is also a huge gap between the country's energy production and the energy consumption (Krishna, C., et. al. 2015). According to Ministry of New and Renewable Energy (MNRE), solar and wind energy promote the ecologically sustainable growth and also addresses the country's energy security challenge among the various forms of renewable energy. In our country solar and wind energy are the promising sectors which discourse the issues of climate change under National Action Plan on Climate Change (MNRE, 2015). In our study knowledge production refers to the research outcomes mainly research publications from the various R&D institutions, university, firms etc. 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 and linkages means the interaction or collaboration between various actors or institutions who shape the whole solar/wind energy sector in the country. According to MNRE, 2016 report the country is ranked among the top ten countries of the world in the renewable energy sector particularly in wind, biomass and solar PV sectors. The wind energy continues to dominate the renewable energy sector and followed by solar, biomass power in the country. In terms of electricity generation, the renewable energy power installed capacity is generating around 70 billion units per year corresponding to about 6.5% in the total electricity mix (MNRE, 2016).

OBJECTIVES AND RESEARCH METHODOLOGY

The main objectives of the study are to explore the production trends of scientific knowledge and to understand dynamics of innovation by identifying various actors and institutions which determine the process of innovation in both solar and wind energy. The study has been undertaken first by reviewing the available literature related to renewable energy and in particular to both solar and wind energy. It is based on both quantitative and qualitative data. In order to achieve the desired outcome several sources of primary and secondary data have been considered in the study. The interviews of research community in different universities and government research institutions such as National Institute of Solar Energy (NISE) and National Institute of Wind Energy (NIWE) will focus on the formal and informal links and interactions with the other researchers. Some informal interviews has been taken to discuss various policy issues and other problems faced by both solar and wind firms. For understanding the production trends in scientific knowledge, we use the analysis of research publications with help of Scopus online database. By analyzing the online database, the productivity of research publications related to these fields in different universities and R&D institutions in the country are calculated and analyzed consequently. We have taken some specific keywords (different keywords in both solar and wind energy field) in the online database. For instance, we use the keyword "(TITLE-ABS-KEY (multi junction cells) AND PUBYEAR >2006 AND PUBYEAR<2017 AND (LIMIT-TO (AFFIL COUNTRY, "India")) AND (LIMIT-TO (EXACT KEYWORD, "Multi Junction Solar Cells") OR LIMIT-TO (EXACT KEYWORD, "Multi-junction Solar Cells"))) to find out the number of publications in "multi junction cells" from India during 2007 to 2016. For obtaining the granted patent number in Indian Patent office (IPO) website, we use the patent search in double field search. We put keyword "solar energy" in search field, then opt "OR" boolean operator. Then we have chosen invertor country as "IN" (stands for India) in search bar. Similarly, we have also done the same procedure in case of wind energy. In case of granted patents in United States Patent and Trademark Office (USPTO) online database, first we select Cooperative Classification Codes (CPC) for all the technologies which fall under solar and wind (see details in Appendix section). In order to find out the patent number, we put specific keyword for particular technology. For example, we use Keyword "ICN/IN AND CPC/YO2E10/723" to find out the number of granted patents in a particular description "Control of wind turbines (YO2E10/723)".

CONCEPTUAL FRAMEWORK AND REVIEW OF LITERATURE

We adopt Sectoral System of Innovation (SSI) framework for the study. The Sectoral Systems of Innovation (SSI) approach is represented by Breschi and Malerba, 1997; Malerba, 2002; Malerba, 2004 which breaks with the geographical orientation and focuses on the level of the industrial sector. Malerba (1997; 2002) defines 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. The SSI approach has composed of various actors, agents, institutions, types and structure of interactions among firms and non-firms organizations in the sector. 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 organizations and individuals. So agents may be individuals such as consumers, entrepreneurs, scientists etc. Organizations may be firms like as users, producers and non-firm organizations such as universities, financial institutions, government agencies, trade unions, or technical associations, including sub units of larger organizations (for instance R&D or production departments) and groups of organizations like industry associations. Malerba further explains agents are characterized by specific learning process, competencies, beliefs, objectives, organizational structures and behaviors (Malerba 2002, p.250).

Malerba further defines a sector as a set of activities that are unified by some linked product groups for a given or emerging demand and that categorized by some common knowledge (Malerba, 2002 and 2004). He explains the three building blocks of sector specific analysis of innovation and production in the SSI such as knowledge, technological domain and boundaries; actors, relationship and networks; and institutions (Malerba, 2002). These three main building blocks of SSI are Knowledge, technological domain and boundaries; actors, relationship and networks and Institutions. Knowledge plays a central role in innovation. It has to be absorbed by firms through their differential abilities accumulated over time. According to Malerba (2002) knowledge domain refers to the specific scientific and technological fields at the base of innovative activities in a sector. The boundaries of sectoral system are affected by the knowledge base and technologies. The knowledge base and technologies is change over time in the notion of innovation system. Sectoral systems are composed of heterogeneous actors. Actors and networks are formed of individuals or organizations and their interactions (Malerba, 2002). It can be interacted through communication, exchange, cooperation, competition or command and it can be in a way of market or non-market relationships. The types and structures of relationships and networks differ from a sector to another sector, as a consequence of the features of the knowledge base, the relevant learning processes, the basic technologies, the characteristics of demand, the key links and the dynamic complementarities. Institutions also play a vital role in affecting the rate of technological change, the organization of innovative activity and performance in all sectoral systems. Some institutional are specific to a sector and others are national (Malerba, 2002). Innovation greatly differs across sectors in terms of characteristics, sources, actors involved, the boundaries of the process and the organization of innovative activity. Further, Malerba (2004) further defines that firms are the key actors in the generation, adoption and use of new technologies. Actors include different users and suppliers which behave different types of relationships with the innovating, producing or selling in the sector. It has brought into light that the sectoral system of innovation is multidimensional, integrated and dynamic view of sector.

This SSI approach studies a wide ranges of factors that affect innovation and production in a sector. It has also a dynamic perspectives and the factors and process often differ from sector to sector (Malerba, 2004). The vital role and relationship of various actors and institutions, importance of linkages between different institutions can be discussed only after the understanding of the SSI framework. Nowadays, the approach is very prevalent in many other sectors. Based on this, there are many studies look at the dynamic process of sectoral system in software, biotechnology, telecommunication, aerospace, pharmaceutical sectors (Akoijam and Krishna, 2017). For example, Mani, S. (2010) uses the SSI framework to explore the evolution of sectoral system of innovation in Indian aerospace industry. He analyses three building blocks such as lead actors, knowledge, technology domain and demand. There are there sets of issues that the author analyze in the study. The first one deals with overall assessment of past and future policies on space programmes, the second is focused on the evolution of the space sector from one being more science oriented to one that is more commercial oriented, and third one deals with one particular kind of space technology namely remote sensing in which the country has accomplished to have considerable technological capability. He further claims that the sector get transformed over the period of time due to the changes in its constituent building blocks.

From the literature of SSI it is cleared that the dynamics and transformation of sectoral system differ from sector to sector. After reviewing various related literatures from different sources we are drawing six key actors who shape the whole solar or wind energy sector like solar/wind firms, policy supports, government research institutes (GRIs), financial institutes, industry associations and other non-governmental organizations (see table 2).

CURRENT SCENARIO ON INDIAN RENEWABLE ENERGY SECTOR

The country has witnessed an exponential growth in renewable energy sector during the last few years. The country's significant and sustained economic growth is engaging massive demand on its energy resources. However, there is a persistent demand-supply imbalance that necessitates serious efforts by the government to augment energy supplies. At present, renewable energy accounts for about 17.51% of the country's total installed power generation capacity of about 326 GW (nearly 3,26,848 MW, CEA, 2017). Table 1 shows the total energy installed capacity and their percentages in each section in 2017.

Table 1: Total Energy Installed Capacity (in MW) and Percentages, 2017

Fuels	**Hydro**	**RES**	**Nuclear**	**Coal**	**Gas**	**Diesel**	**Total**
Installed capacity (MW)	44,478.42	57,260.23	6,780.00	1,92,162.88	25,329.38	837.63	3,26,848.53
Percentage	13.60	17.51	2.07	58.79	7.74	0.25	100

Source: Central Electricity Authority (CEA), 2017

According to Central Electricity Authority (CEA), 2017 report the total renewable installed capacity has reached 57,260 MW out of the total installed power generation capacity of 3,26,848 MW in the end of March 2017 (CEA, 2017). Of this, 66.79% is from total thermal fuel plants where coal (58.79%), gas (7.74%), and oil (0.25%), 13.60% hydropower and 2.14% nuclear power. The following table 3 gives all India energy installed capacity as section-wise as on March 2017.

Table 2: Key Actors in the Indian Solar and Wind Energy Sector

Main Actors	Solar Energy Sector	Wind Energy Sector
1. Business Enterprises (Solar/Wind 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.	Domestic wind turbine manufactures: Suzlon, Inox Wind, Global Wind Power, Wind World India, ReGen Powertech, RRB Energy, Garuda Vaayu Shakthi, etc. Foreign-owned turbine manufactures: Gamesa, GE India, Kenersys India, Vestas wind, etc. Power developers: Mytrah Energy, CLP India, Greenko, Green Infra, Renew Energy, Welspun Energy, Tata Power, etc. Other firms who involve in the supply of different components such as bearings, blades, generators, yaw-system, gear-box, etc.
2. Policy and Regulatory Support	Apex body and Regulatory Institutions: Ministry of New and Renewable Energy (MNRE), Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission (SERC), Ministry of Power (MoP), Ministry of Finance, Ministry of Environment, Forest and Climate Change, Indian Renewable Energy Development Agency (IREDA), National Thermal Power Corporation Vidyut Vyapar Nigam (NVVN) Policy Instruments: Domestic Content Requirement (DCR), Generation Base Incentives (GBI), Accelerated Depreciation (AD), Solar REC, State Policies, Solar Viability Gap Funding (VGF), Direct Subsidies, Tax Incentives, etc.	Apex body and Regulatory Institutions: Ministry of New and Renewable Energy (MNRE), Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commission (SERC), Ministry of Power (MoP), Ministry of Finance, Ministry of Environment, Forest and Climate Change, Indian Renewable Energy Development Agency (IREDA). Policy Instruments: Generation Base Incentives (GBI), Accelerated Depreciation (AD), Renewable Purchase Obligation (RPO), Renewable Energy Certificate (REC), State policies, Direct Subsidies, Tax Incentives, Land Acquisition Policies, Feed-in Tariffs etc.

3.Government Research Institutes (GRIs)	Indian Institute of Technologies (IITs), Central Universities, State Universities, Engineering Colleges, Other institutions 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.	Indian Institute of technologies (IITs), Central Universities, State Universities, Engineering Colleges, Other institutions offering courses on Renewable Energy, National Physical Laboratory (NPL), Council of Scientific and Industrial Research (CSIR), National Institute of Wind Energy (WISE) etc.
4.Financial Institutions	Domestic Agencies: 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.	Domestic agencies: Indian Renewable Energy Development Agency (IREDA), Power Finance Corporation (PFC), Industrial Finance Corporation of India (IFCI), Rural Electrification Corporation (REC), State Bank of India (SBI), Industrial Credit and Investment Cooperation India (ICICI), etc. External sources: International Finance Corporation (IFC), Asian Development Bank (ADB), Danish International Development Agencies (DANIDA), Japan International Cooperation Agencies (JICA), U.S EXIM Bank, 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.	Indian Society for Wind Engineering (ISWE), Indian Wind Turbine Manufactures Association (IWTMA), Wind Independent Power Producers Association (WIPPA), Indian Wind Energy Association (InWEA), Indian wind Power Association (IWPA), etc.
6.NGOs and Other Organizations	Barefoot Engineers, Greenpeace, Centre for Science and Environment (CSE).	Greenpeace, Centre for Science and Environment (CSE).

Source: Author’s compilation; adapted from Akoijam and Krishna (2017); MNRE (2016) and WISE (2017)

Table 3: All India Energy Installed Capacity (MW) sector-wise as on March, 2017.

Sectors	Thermal				Nuclear	Hydro	RES	Grand Total
	Coal	Gas	Diesel	Total				
State	64,685.50	7,257.95	363.93	72,307.38	0.00	29,683.00	1,976.90	1,03,967.28
Private	73,142.38	10,580.60	473.70	84,196.68	0.00	3,144.00	55,283.33	1,42,624.01
Central	54,335.00	7,490.83	0.00	61,825.83	6,780.00	11,651.42	0.00	80,257.25
All India	1,92,162.88	25,329.38	837.63	2,18,329.88	6,780.00	44,478.42	57,260.23	3,26,848.53

Source: Compiled by author; adapted from Ministry of Power, CEA, 2017. (See http://www.cea.nic.in /monthly exesummary.html accessed on 20.05.2017).

According to the Ministry of New and Renewable Energy, renewable energy sources includes small hydropower plants which are lesser than or equal to 25 MW, biomass gasification, biomass energy, urban and industrial waste energy, solar energy, wind energy, etc. The following figure gives the percentage wise information about the total installed renewable energy in the country.

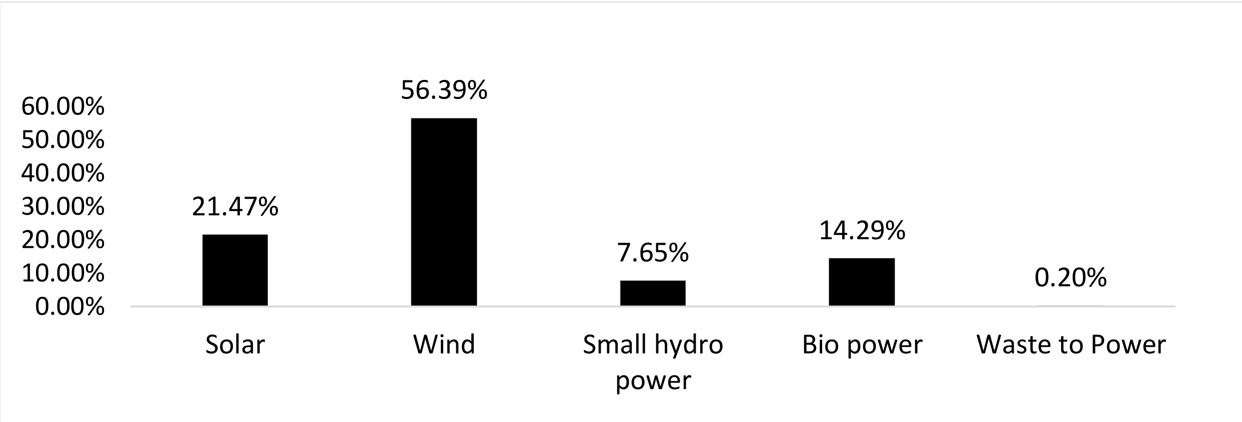

Figure 1: Percentage wise in the total installed renewable energy in India, 2017, Source: Central Electricity Authority (CEA), 2017

POSITION OF INDIAN SOLAR AND WIND ENERGY

Presently total solar energy installed capacity stands at 12.75 GW as at the end of March 2017 in the country (CEA, 2017). About 21.46% of the total renewable energy power is shared by the solar energy in 2017 in the country. 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, 2016).

In case of wind energy, the development and deployment of wind power began in the early of 1990's and has progressed steadily in the last few years. The short gestation periods for installing wind turbines, and the increasing reliability and performance of wind energy machines have made wind power a preferred choice for capacity addition in India. The country's total wind energy potential has been estimated at 45,000 MW (MNRE, 2016). The wind energy sector has been perceived for significant investments encouraged by the development potential, availability of wind farm equipment at competitive prices and encouraging government policies. This energy sector accounts for about 56.38 % of the total installed generation capacity from the renewable energy sources in the country (MNRE, 2017). India has a substantial wind power potential, estimated by India's National Institute of Wind Energy (NIWE) at around 302GW for onshore wind turbine installations with a hub height of 100 meters (MNRE, 2016). Currently the country stands in the fifth position and followed by China, the USA, Germany and Spain (REN 21, 2016 report). Overall, the wind energy sector shares about 9.87 % of the country's total energy installed capacity. The most promising sites of the wind power lie in the west and south, with around 90% of the potential in the states of Tamil Nadu, Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra and Gujarat.

PERSPECTIVES FROM RENEWABLE ENERGY POLICIES

The government of India begun to announce some policies to care the expansion of renewable energy in early 1980s. The renewable energy sector in the country is regulated by the Ministry of New and Renewable Energy (MNRE).The important functions of the MNRE are to develop, demonstrate and commercialize technologies for harnessing new and renewable energy sources in association with corporate, scientific and technical institutions. In addition to these functions, the ministry also supports research, design and development of new and renewable energy technologies, products and services in the country. Many renewable energy policies and programmes are undertaken by the ministry for the development and deployment of various sources of renewable energy. Another mission of the MNRE is to replace the use of different fossil fuels wherever possible and increase access to electricity or lighting in remote and rural areas. The following table 4 lists the milestones of Indian renewable energy policy.

Table 4: Milestones of Renewable Energy (RE) policy in India

Major Milestones (Year)	Government's Initiatives
Commission for Additional Sources of Energy (CASE, 1981)	Looked at overall responsibility of developing RE.
Department of Non-Conventional Sources (DNES, 1982)	Formed an independent department to development and application of RE.

Expansion of Ministry of Energy to include Departments of Petroleum and Non-conventional Energy Sources (1982)	Except the atomic energy, all other forms of energy were brought under one ministry.
Solar Energy Centre (SEC, 1982) Renamed as National Institution of Solar Energy (NISE)	Establishment of SEC for development of solar energy technologies and its related science and engineering.
Advisory Board on Energy (1983)	Establishment of an Integrated Energy Policy covering commercial and Non-conventional energy resources.
Indian Renewable Energy Development Agency (IREDA, 1987)	Establishment of IREDA to finance RE projects.
Ministry of Non-conventional Energy Sources (MNES, 1992)	The DNES was upgraded into full-fledged Ministry.
Renewable power purchase guideline, 1993	MNES has prepared the policy guidelines for the promotion of RE.
Small wind energy and hybrid system, 1994	Promotion of water pumping windmills and solar wind hybrid systems.
Common Minimum National Action Plan for Power (1996)	Setting up of state and union level regulatory commissions, and rationalization of tariff.
Centre for Wind Energy Technology (C-WET) 1998, Renamed as National Institute of Wind Energy (NIWE)	Establishment of autonomous R&D institution; C-WET by MNRE.
Energy Conservation Act, 2001	Establishment of a comprehensive law that adopts standards and procedures, and prescribes measures for energy conservation.
Electricity Act, 2003	It enacted with the provisions in the act with regards to promotion of RE.
National Electricity Policy, 2005	It recognized the role of renewable electricity in the areas where grid electricity is neither cost effective nor the feasible.
National Tariff Policy, 2006	Enacted with the provisions in the act directing SERC's to fix a minimum purchase of energy.
Renaming of MNES (2006)	Renamed as Ministry of New and Renewable Energy
Generation Based Incentive (GBI, 2009)	Introduction of GBI Scheme
Renewable Energy Certificate (REC, 2010)	Introduction of REC Scheme
Jawaharlal Nehru National Solar Mission (JNNSM, 2010)	Introduction of Jawaharlal Nehru National Solar Mission with ambitious goals and targets by 2022
Andhra Pradesh Solar Policy, Chhattisgarh Solar Policy, Madhya Pradesh Solar Policy, Punjab New and Renewable Source of Energy Policy, Tamil Nadu Solar Energy Policy (2012)	States such as Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Punjab and Tamil Nadu announced their own state policies to fuel of solar energy promoters and facilitators in 2012.

Source: Compiled by author; adapted from MNRE (2016) and Yenneti, K. (2016)

In India, electricity is a shared responsibility between the central government and the States. After the independence the States played a predominant role in the development of the power sector. The Electricity (Supply) Act (MoP, 1948) prescribed the creation of State Electricity Boards (SEBs) with the responsibility to plan and implement power development programmes in their respective states. Poor operational performance, continued power shortages and precarious financial situation of SEBs led to a number of policy and regulatory changes. Since 1991 amendments to the Indian Electricity Act 1910 and Electricity (Supply) Act 1948 marked the beginning of the liberalization process promoted by the central government. Reforms included private sector participation in electricity generation up to 100% foreign investor ownership as well as simplified administrative procedure for clearance of projects (Singh, 2006). There are a number of government institutions whose competence extends into the renewable energy sector. The Ministry of Power (MoP) deals with the planning of power supply, provision of political guidelines, investment decisions for government projects, training of experts, administration of laws for power generation from conventional sources, and power transmission and guidelines. The Electricity Regulatory Commissions Act (MoP, 1998) 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 Central Electricity Regulatory Commission, (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 State Electricity Regulatory Commissions deal with matters concerning generation, transmission, distribution and trading of electricity in their respective state. They monitor the quality of the services, tariffs, and fees.[1]

R & D ACTIVITIES AND INVESTMENT

Globally the investment in the renewable energy sector has increased steadily from USD 39.5 billion in 2004 to USD 285.9 billion in 2015[2]. Steep cost reductions in solar PV and wind power make renewables attractive for new markets, particularly in developing countries where new electricity generation capacities are needed to satisfy increasing energy demand. Renewable energy investments in the developing countries like China, Brazil and India has been raised steadily over the past decade and overtook the total investment of OECD countries for the first time in 2015. The steady growth was to a large extent due to the fact that renewables are now one of the lowest cost options for new power generation (REN21, 2017).

China is playing a dominant role which is increasing its investment by 17% to USD 102.9 billion, accounting for 36% of the global total (REN21, 2017). Overall, the developing countries like China, India and Brazil, committed a total of USD 156 billion (up 19% compared to 2014). The investment in

[1] Central Electricity Regulatory Commission (CERC), Government of India. (see link, http://cercind.gov.in//).

[2] See, BNEF (Bloomberg New Energy Finance) Report, 2016. Since the investment data includes wind power projects of more than 1 MW, geothermal power projects, biomass projects, small hydro power projects, solar power projects, biofuel projects with an annual production capacity of 1 million litres or more, ocean energy projects.

the renewable energy sector has also increased significantly in the countries like India, South Africa, Mexico and Chile. Other developing countries like Morocco, Uruguay, Philippines, Pakistan, etc. have been investing more money than in the renewable energy sector after 2015 onwards. The renewable energy investment in the USA, has been increased by 19% to USD 44.1 billion since 2011. The investment in the renewable energy has been weighted increasingly towards the wind and solar power among the various renewable energy sources (Bloomberg, 2016). Other technologies like small hydro energy, biomass energy, geothermal energy and waste to energy saw investment decline relative to 2014 (REN21, 2016). The renewable energy investment in the developed countries as a group declined by 8% in 2015, to USD 130 billion (Bloomberg New Energy Finance, 2015). The most significant decrease has seen in the European countries regardless of the region's record year of financing for offshore wind energy. 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. The following table indicates the R&D expenditure for ten years by a leading wind firm, Suzlon in the country.

Table 5: Expenditure on R&D by Suzlon

Year	**Investment (INR in Crores)**	**R&D Expenditure as a % of total turnover**	**Year**	**Investment (INR in Crores)**	**R&D Expenditure as a % of total turnover**
2007-08	14.81	0.21	2012-13	217.19	12.42
2008-09	50.07	0.69	2013-14	39.04	1.29
2009-10	114.90	3.29	2014-15	39.14	1.73
2010-11	76.4	1.75	2015-16	304.32	5.13
2011-12	102.3	1.49	2016-17	73.94	0.79

Source: Annual Reports Year wise; 2016-17, 2014-15, 2013-14, 2011-12, 2010-09, 2008-09.

PRODUCTION TRENDS OF SCIENTIFIC KNOWLEDGE RELATED TO SOLAR AND WIND

In order to understand the productivity of different R&D institutions and Universities in terms of the publications related to solar and wind energy in the country, we has analyzed Scopus online database. This online database 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[3]. For analysis the total number of publications related to solar energy we used the keywords such as ((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) . Similarly, in case of the wind energy, we used the query as ((TITLE-ABS-KEY(wind*) OR TITLE-ABS-KEY(Renewable*)) AND PUBYEAR > 2005 AND PUBYEAR < 2017 AND (LIMIT-TO (AFFILCOUNTRY,"India"))). The following figures show the number of publications related to both solar and wind energy.

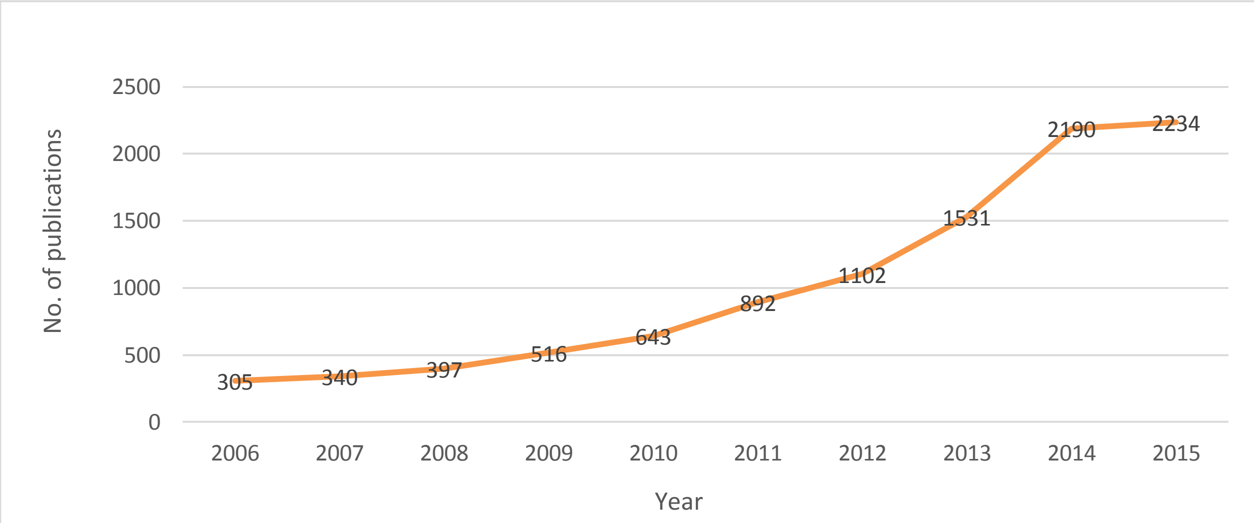

Figure 2: Number of publications related to solar energy in India, (2006-2015)
Source: Researcher's data based on the Scopus database

[3] See http://www.info.sciverse.com/scopus/.

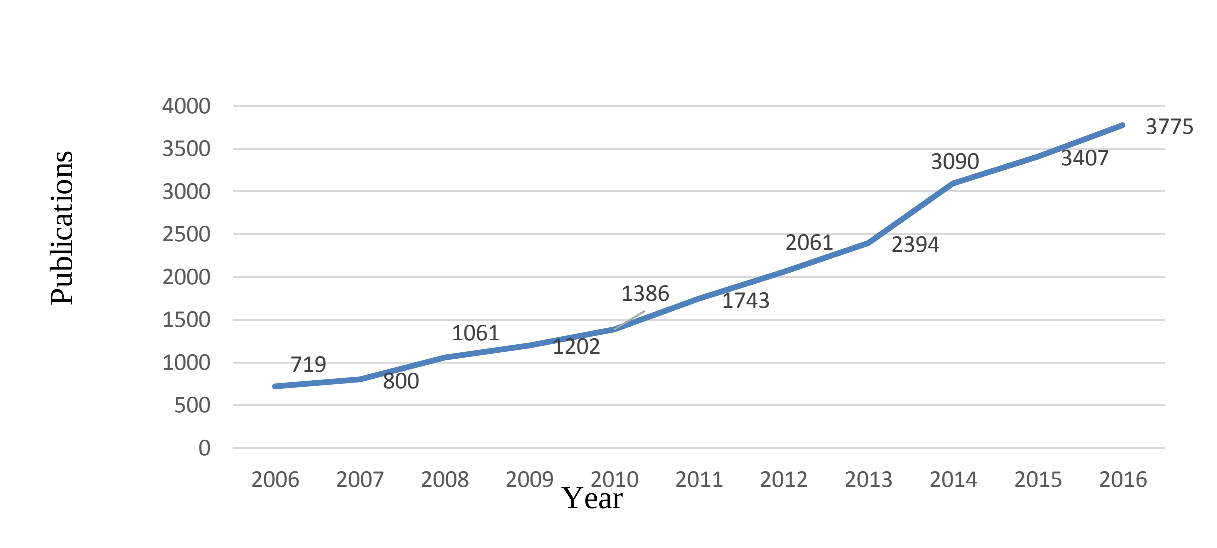

Figure 3: Number of publications related to wind energy in India (2006-2016)
Source: Researcher's data based on the Scopus Database

The number of scientific publication in various solar PV technologies (for instance; Amorphous, Concentrating PV, Dye-sensitized cells, Mono crystalline, Multi-junction cells, Poly crystalline, Thin film cells, etc.) and thermal technologies such as Parabolic Trough, Parabolic dish, Solar Power Tower, Linear Fresnel Reflector, etc. are indicated in the following table 6. The maximum number of scientific publications are found in thin film, poly crystalline and dye-sensitized solar cells.

Table 6: Publication trends from India in various solar PV and thermal technologies (2007-2016)

Solar Technology	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Amorphous	57	81	117	120	139	92	118	108	152	165
Concentrating PV	0	0	0	0	0	0	0	0	1	0
Dye-sensitized cells	5	13	18	29	65	71	95	153	170	169
Linear Fresnel Reflector	0	0	0	0	0	4	3	5	4	7
Mono crystalline	4	7	9	6	6	10	8	8	13	15
Multi-junction cells	0	0	0	0	1	1	1	2	1	7
Parabolic Trough	0	0	1	0	1	3	4	5	4	6
Parabolic dish	0	0	0	2	1	4	6	2	1	0
Poly crystalline	1	8	80	148	154	168	170	185	198	206
Thin film cells	45	61	66	82	112	120	156	220	203	230
Solar Power Tower	0	0	0	0	0	0	1	0	1	0

Source: Author's Compilation based on Scopus database (accessed on 25.11.2017)

The country stands at fifth and sixth position in terms of scientific research publications related to solar and wind energy respectively. In case of the solar, it is about 5% contribution of the world publications. Whereas in case of wind energy, it is nearly 4.3% of the total contribution. The total number publications till 2016 in solar energy 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%).

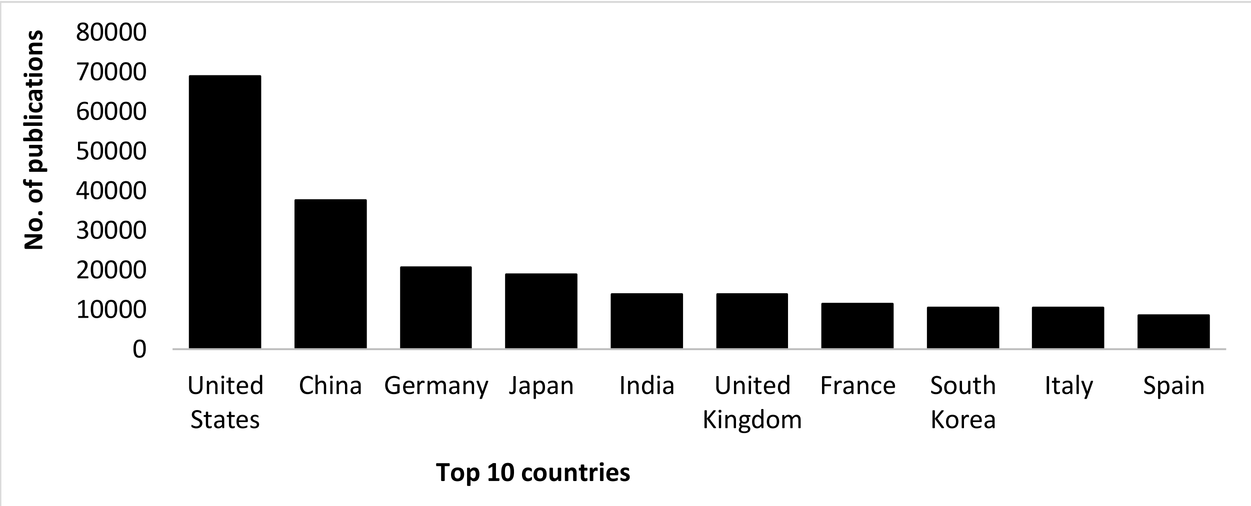

Figure 4: Publications related to solar energy by top 10 countries in the world, Source: Researcher's data based on the Scopus Database

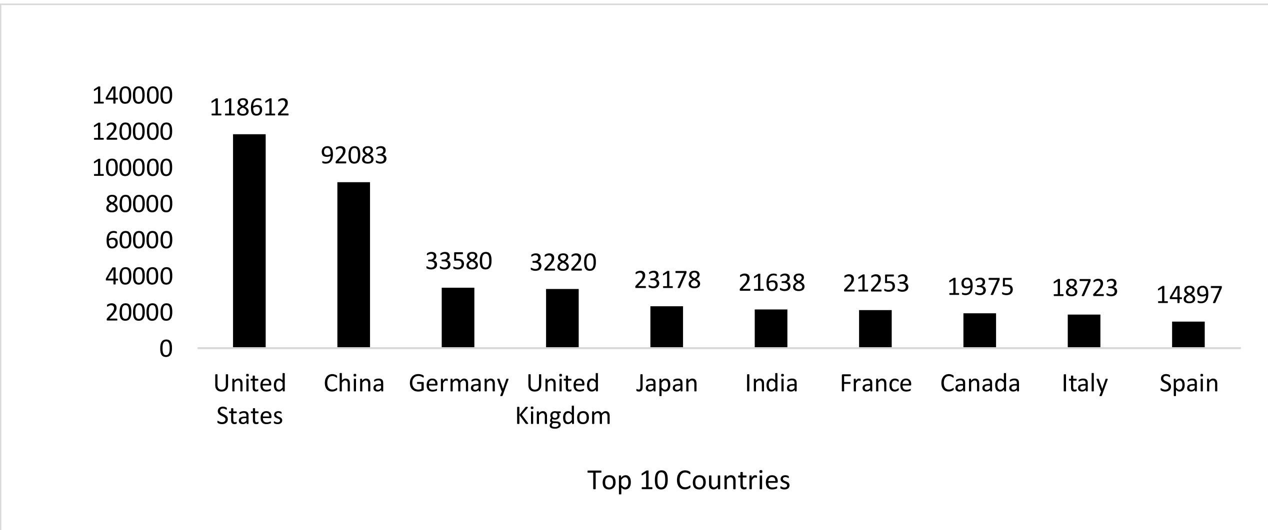

Fig. 5: Publications related to wind energy by top 10 countries in the world, Source: Researcher's data based on the Scopus Database

India has also a significant presence of productive R& D institutions and universities. The top 15 Institutions and universities paper published in the country in respective fields are given the following figures 5 and 6. In case of solar energy, IIT Delhi is on topmost with 1186 publications of the total publications (8.5%), followed by IIT Bombay 427 publications (3%), Indian Institute of Science 328 publications (2.4%) and others (refer figure 10). Similarly, the publication trends by top 15 affiliations related to wind energy is also represented in the figure 7. In both cases, it is observed that among the top 15 affiliations major dominant institutions are from Indian Institute of Technologies and most of them are the public research and development institutions in the country.

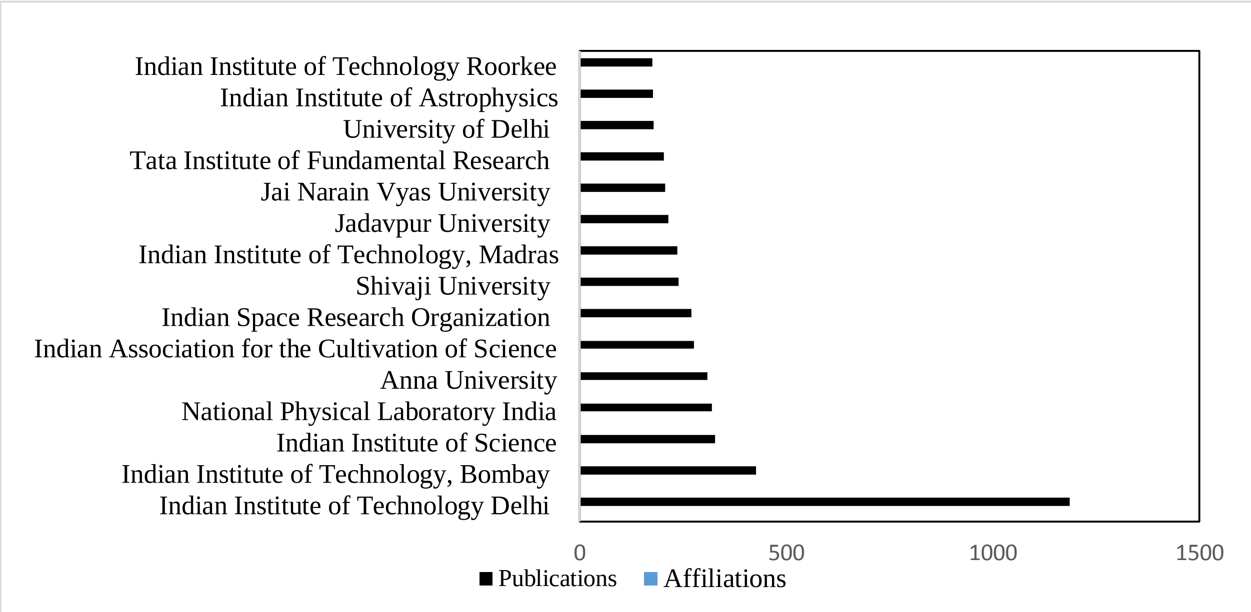

Figure 6: Publications related to solar energy by top 15 Affiliations in India, Source: Researcher’s data based on the Scopus database.

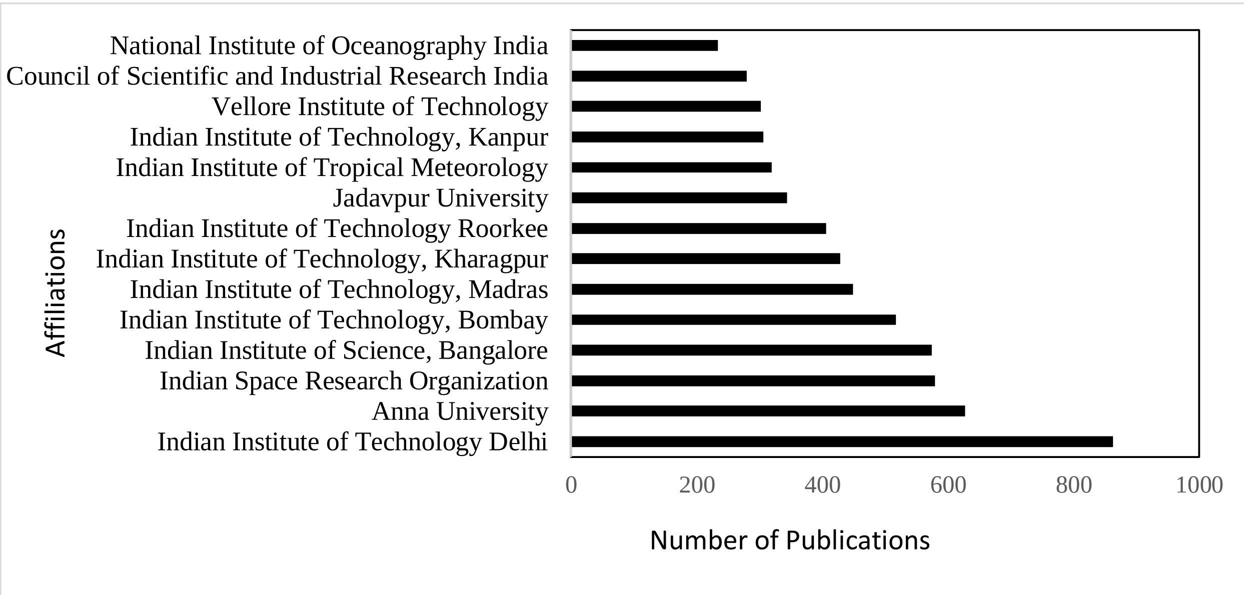

Figure 7: Publications in wind energy by top 15 affiliations in India, 2016
Source: Researcher’s data based on the Scopus database

The analysis of granted patents related to various solar and wind technologies is considered in our study. About 19 patents related to various solar PV technologies has been registered until 2009 in the country (Goel, M., Maurya, V. and Desai, P. 2013). From Indian Patent office (IPO) online database, it is also found that around 40 patents from solar energy and 67 patents from wind energy have been granted from the country till 2017. The number of granted patent is retrieved by using 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. There are 101 granted patents[4] from India till 2017 in various solar PV and thermal technologies in United States Patent and Trademark Office (USPTO). But in case of wind energy technologies, around 171 patents are granted. The maximum number of patents are granted in the area of blades or rotors (47), control of wind turbines (46) and solar PV cells (23). The main assignee of the patents in solar PV cells are Indian Institute of Technology (IIT), Council of Scientific and Industrial Research (CSIR), Yeda Research and Development Co., Ltd. and Applied Materials, Inc. The number of granted patents in various solar and wind technologies from the country in USPTO are shown in the following tables.

Table 7: Number of US Patent granted from India in various solar energy field

Description	**No. of US Patent granted**	**Description**	**No. of US Patent granted**
Solar thermal	5	Dye sensitized solar cells	10
Tower concentrators	2	Solar cells from grp. II-VI materials	0
Dish collectors	0	Solar cells from grp. III-V materials	2
Fresnel lenses	0	Microcrystalline silicon PV cells	0
Heat exchange system	1	Polycrystalline silicon PV cells	0
Trough concentrators	1	Mono-crystalline silicon PV cells	1
Stirling solar thermal engines	2	Amorphous silicon PV cells	2
Thermal updraft	1	Organic PV cells	23
Mountings or tracking	4	Power conversion electric/electronic	1
Photovoltaic (PV) energy	5	For grid-connected applications	14

[4] The number of granted patents in particular description such as solar thermal, tower concentrators, dish collectors, Fresnel lenses, heat exchange system, etc. are obtained by using CPC ooperative Patent Classification codes (See the details in Appendix section)

PV systems with concentrators	10	Concerning power management	6
Material technologies	0	Maximum power point tracking	9
CuInSe2 material PV cells	2	Thermal PV hybrids	0

Source: Compiled by author based on USPTO database, see http://patft.uspto.gov/netahtml/PTO/search-adv.htm (Accessed on 1st December, 2017)

Table 8: Number of US Patent granted from India in various wind energy field

Description	**No. of Patent granted**	**Description**	**No. Patent granted**
Wind turbines with rotation axis in wind direction	11	Offshore towers	0
Blades or Rotors	47	Onshore towers	6
Components or Gearbox	7	Wind turbines with rotation axis perpendicular to the wind direction	5
Control of turbines	46	Power conversion electric/electronic	2
Generator or Configuration	18	For grid-connected applications	12
Nacelles	14	Concerning power management inside the plant	3

Source: Compiled by author based on USPTO database, see http://patft.uspto.gov/netahtml/PTO/search-adv.htm (Accessed on 1st December, 2017).

CONCLUDING REMARKS

Ministry of New and Renewable Energy is the only dedicated ministry in the country who proactively creating an enabling environment for renewable energy sector to grow by rapidly bringing in innovative policy initiatives. India is well dignified to facilitate and advance the growth of renewable energy and strive to become one of the world leaders in both solar and wind energy sectors in the coming years. The National Institute of Solar Energy (NISE) and National Institute of Wind Energy (WISE) are the important R&D institutions which address the existing research infrastructure in solar and wind energy sector respectively. These institutions help to set up a framework which would incubate an environment for accelerating different R&D activities in the country. Solar/wind firms, policy and regulatory support, government research institutes, financial institutes, industry associations and NGOs are the key actors who involved in these sectors. Government research institutes 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 throughout the globe. The policy and regulatory support is also another key actor who is responsible for the formulation of several renewable incentive policies that have increased the viability of increased deployment and development of both solar and wind energy in the country. The research outcomes in terms of scientific research publications and R&D investment in this area become a more essential. The number of research publications and granted patents has been increased. There is also a significant presence of productive academia, R&D institutions and supportive policy initiatives in the country. India stands at fifth and sixth position in terms of scientific research publications related to solar and wind energy respectively. In case of the solar, it is about 5% contribution of the world publications. Whereas in case of wind energy, it is nearly 4.3% of the total contribution. The highest number of granted patents are found in the area of blades or rotors, control of wind turbines and solar PV cells. For our future research we will emphasized how these actors play a vital role in various activities of knowledge and technological base, forming networks and establishing innovation capacities and production in both solar and wind energy sector.

ACKNOWLEDGEMENT

The paper is derived from my PhD thesis work under Centre for Studies in Science Policy (CSSP), School of Social Science (SSS), Jawaharlal Nehru University (JNU), New Delhi (India). Author thanks for their constructive comments and valuable suggestions from faculties of Centre for Studies in Science Policy and Vineet kumar from Indian Renewable Energy Federation (IREF) where the first draft of this paper was discussed.

APPENDIX A

Table 9: Classification into technology classes for solar and wind technologies

Technology	Description	Cooperative Patent Classification (CPC) Codes
Solar	Solar thermal energy, Tower concentrators, Dish collectors, Fresnel lenses, Heat Exchange System, Trough concentrators, Stirling solar thermal engines, Thermal updraft, Mountings or tracking, Photovoltaic (PV) energy, PV systems with concentrators, Material technologies, CuInSe2 material PV cells, Dye sensitized solar cells, Solar cells from grp. II-VI materials, Solar cells from grp. III-V materials, Microcrystalline silicon PV cells, Polycrystalline silicon PV cells, Mono-crystalline silicon PV cells, Amorphous silicon PV cells, Organic PV cells, Power conversion electric/electronic, For grid-connected applications, Concerning power management inside the plant, Maximum power point tracking systems and	Y02E10/40, Y02E10/41, Y02E10/42, Y02E10/43, Y02E10/44, Y02E10/45, Y02E10/46, Y02E10/465, Y02E10/47, Y02E10/50, Y02E10/52, Y02E10/54, Y02E10/541, Y02E10/542, Y02E10/543, Y02E10/544, Y02E10/545, Y02E10/546, Y02E10/547, Y02E10/548, Y02E10/549, Y02E10/56, Y02E10/563, Y02E10/566, Y02E10/58 and

	Thermal PV hybrids.	Y02E10/60 respectively.
Wind	Wind energy, Wind turbines with rotation axis in wind direction, Blades or rotors, Components or gearbox, Control of turbines, Generator or configuration, Nacelles, Offshore towers, Onshore towers, Wind turbines with rotation axis perpendicular to the wind direction, Power conversion electric/electronic, For grid-connected applications and Concerning power management inside the plant.	Y02E10/70, Y02E10/72, Y02E10/721, Y02E10/722, Y02E10/723, Y02E10/725, Y02E10/726, Y02E10/727, Y02E10/728, Y02E10/74, Y02E10/76, Y02E10/763 and Y02E10/766 respectively.

Source: USPTO website, (see the link, http://patft.uspto.gov/netahtml/PTO/help/helpflds.htm#CPC)

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