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Actors, Trends in Scientific Publications and Innovative Policies in Renewable Energy: A Study of Solar and Wind Energy in India

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Abstract
India is a prominent emerging nation in the field of renewable energy generation, particularly regarding solar and wind power. The landscape of renewable energy in India, especially in solar and wind technologies, is influenced by a mix of scientific research, innovative policy-making, and evolving trends. Moving towards an economy powered by renewable energy is one of the most vital objectives for sustainability. This study is driven by the necessity to enhance the role of renewable energy technologies by tackling the challenge of sustainability, meeting energy needs while reducing environmental harm. The research employs an innovation system framework to explore the important roles, relationships among various actors and stakeholders, and the nature of knowledge development within the solar and wind energy technology innovation ecosystem. This research utilizes both qualitative and quantitative data. The findings reveal that India ranks fifth and sixth in terms of scientific publications related to solar and wind energy, respectively. Concurrently, there has been a notable increase in the outcomes of renewable energy research following the launch of several missions and the establishment of ambitious targets or policies in the sector.

Keywords: Renewable energy; Energy policy; Energy transition; Solar energy; Wind energy; Innovation systems; Sustainability

Introduction

Renewable energy innovation research has become a valuable strategy for tackling sustainability and promoting green industrialization. This study is driven by the necessity to boost the supply of renewable energy, particularly emphasizing solar and wind energy technologies in India. India ranks as one of the fastest-growing economies globally. The energy sector's consumption has surged due to the rapidly increasing population and economic growth (Altenburg and Engelmeier, 2012) [1]. There exists a significant disparity between the country's energy production and its energy consumption levels (Krishna, Sagar, and Spratt, 2015) [14]. As stated by the Ministry of New and Renewable Energy (MNRE), solar and wind energy contribute to ecologically sustainable development while also addressing the energy security issues faced by the nation among various renewable energy sources. Solar and wind energy in India are considered the most promising sectors that tackle climate change challenges outlined in the National Action Plan on Climate Change (MNRE, 2020).

In this study, scientific publications denote the findings primarily presented in journals and books from various research and development institutions, universities, and companies. Innovation is defined as the capacity to understand, modify, and implement a particular technology into distinct operational and managerial abilities that foster an innovative organizational culture, the traits of internal promotional efforts, and the communication capabilities of firms with others in both market and non-market contexts. According to the 2016 report from the Ministry of New and Renewable Energy (MNRE), the nation ranks among the top ten globally in the renewable energy sector, particularly excelling in wind, biomass, and solar photovoltaic (PV) sectors. Wind energy remains the leading source in the renewable energy landscape, followed closely by solar and biomass energy production in the country. With respect to electricity generation, the installed capacity of renewable energy produces approximately 70 billion units annually, accounting for about 6.5% of the overall electricity mix (MNRE, 2016).

This study aims to investigate the trends in scientific knowledge production concerning both solar and wind energy, as well as to comprehend the influence of public policies on renewable energy in facilitating research and development. After reviewing a

variety of relevant literature from diverse sources, we identify six key stakeholders who influence the solar energy sector, including solar/wind companies, policy supporters, government research institutes (GRIs), financial institutions, industry associations, and other non-governmental organizations (refer to table 1). To attain the intended results, we have gathered various primary and secondary data sources for this study. Interviews with research professionals from different universities and governmental research institutions, or industry associations such as the National Institute of Solar Energy (NISE), the National Institute of Wind Energy (NIWE), the Ministry of New and Renewable Energy (MNRE), the International Solar Alliances (ISA), the National Solar Energy Federation of India (NSEFI), and the Ministry of Environment, Forest and Climate Change, will focus on exploring formal and informal connections and interactions among researchers. We have also conducted some informal interviews to address various policy challenges and issues faced by solar companies. Information has been collected from a range of libraries, including the Indian Institute of Technology (IIT) Delhi, The Energy and Resources Institute (TERI), MNRE, and others, which have also been integrated into this study.

This study began by examining the existing literature on renewable energy, specifically focusing on solar energy. The research is grounded in both quantitative and qualitative data. To comprehend the patterns in scientific knowledge production, we utilize an analysis of research publications through the Scopus online database. By evaluating this database, we calculate and analyze the productivity of research publications related to these areas across various universities, and research and development institutions in the country. We have selected specific keywords related to solar and wind energy for this analysis within the online database. The structure of the paper is outlined as follows. The next section will cover a literature review and the conceptual framework. Following this, the research methodology utilized for the study will be described. The subsequent section presents the current state of the Indian solar and wind energy sectors, along with policy perspectives. The next part will explore investment trends and the evolution of scientific knowledge. Finally, a concluding remark will be made at the end.

Review of Literature and Conceptual Framework

According to the National Innovation Council, innovation refers to "the novel application of established technologies, employing design to create new products and services, as well as new processes and structures to enhance performance across various domains, organizational creativity, and public sector efforts to improve service delivery." Simultaneously, the Department of Science and Technology (DST), Government of India, describes it as the driving force behind prosperity and national competitiveness in the 21st century. Denning (2004) [6] states that inventions involve creating something original, which could be an idea, artifact, device, or procedure. However, there is no assurance that an idea or invention, irrespective of its ingenuity, will evolve into an innovation. Innovation necessitates consideration of others and their values, while invention focuses solely on technology (Denning, 2004) [6]. Schumpeter (1939) [34] also asserts that "innovation is a crucial catalyst for economic transformation and regional development within a nation, establishing a new production function that pertains to both new commodities and new organizational forms." He further notes that invention, innovation, and the effective dissemination of new technologies are the primary engines of contemporary economies. The Schumpeterian notion of innovation encompasses "the launch of new products, process innovations that are novel to an industry, the creation of new markets, the development of new sources for raw materials or other inputs, and shifts in industrial structures" (Schumpeter, 1939) [34].

Innovations can be classified as either radical (discontinuous) or incremental (continuous). Radical innovations necessitate the establishment of new behavioural patterns stemming from entirely new products, typically resulting from firms' research and development initiatives. Conversely, incremental innovations are ongoing and tend to be less disruptive, involving only slight modifications of existing products or minor enhancements to current technologies (Herbig, 1994) [12]. Additionally, the notion of innovation can be explored through various perspectives of innovation systems as presented by different authors. Innovation systems are categorized into national innovation systems, regional innovation systems, local innovation systems, technological innovation systems, individual innovation systems, and sectoral innovation systems (Freeman, 1995) [10]. Furthermore, the concept of innovation systems has evolved to view the emergence of innovations as a multifaceted process defined by complex feedback mechanisms and interactive relationships involving science, technology, learning, institutions, production, public policy, and market demand during the 1990s (Edquist, 2001) [7]. The process of developing innovations is recognized as an interactive learning process, where knowledge is frequently exchanged among organizations engaged in innovation activities (Lundvall, 1992) [17]. Different types of knowledge and information are shared among organizations, and this sharing frequently occurs through collaboration that is not facilitated by a market. The entities involved can include various companies (suppliers, customers, competitors) as well as educational institutions, research organizations, investment banks, and government bodies, among others (Edquist, 2001) [7]. The Systems of Innovation is "an approach that emerged around the 1990s for examining innovations as an internal component of the economy, and it can be described as encompassing all significant factors that affect the development, dissemination, and utilization of innovations" (Edquist, 2001) [7]. It aims to acknowledge that a significant portion of the learning required for innovation development is inherently interactive. Therefore, various aspects of innovation can be examined more thoroughly within a national, regional, or sector-specific framework. We adopt the sectoral system of innovation framework for our study. The approach to sectoral systems of innovation is articulated by Malerba (2002 and 2004) [18, 19], who departs from a geographical perspective and instead emphasizes the focus on the industrial sector level. He describes Sectoral Systems of Innovation as "the set of diverse agents engaged in both market and non-market interactions aimed at the generation, adoption, and utilization of (both new and existing) technologies, as well as the creation, production, and usage of (both new and existing) products relevant to a particular sector." The approach of the sectoral system of innovation consists of a variety of actors, agents, institutions, and the nature and structure of interactions among both firms and non-firm organizations within the sector. According to

Malerba (2004) [18], the fundamental components of a sectoral system include products, agents, knowledge and learning processes, key technologies, inputs, and demand, all interconnected through links, interactions, and institutions. This system has a foundation of knowledge, technologies, inputs, and (either potential or existing) demand, with the agents constituting the sectoral system being both organizations and individuals. Individuals involved can range from consumers and entrepreneurs to scientists, whereas organizations may refer to firms that act as users or producers, as well as non-firm entities such as universities, financial institutions, governmental bodies, trade unions, or technical associations. This also comprises subdivisions of larger entities (for example, research and development or production departments) and coalitions of organizations like industry associations. Malerba elaborates that agents are defined by particular learning processes, capabilities, beliefs, goals, organizational frameworks, and behaviors (Malerba 2002) [18]. He also describes a sector as a collection of activities linked by certain product groups catering to a specific or emerging demand, characterized by shared knowledge (Malerba, 2002 and 2004) [18, 19]. He outlines three fundamental components for analyzing innovation and production within the sectoral system of innovation: knowledge, technological domains and boundaries; actors, their relationships, and networks; and institutions (Malerba, 2002) [18]. Knowledge is crucial for driving innovation. Firms must acquire it through their unique capabilities developed over time. The nature of knowledge varies between sectors based on their specific areas. To understand the dynamics of a sectoral system of innovation in the solar/wind energy sector it is required to map out various main actors in the solar/wind energy sector in India (table 1). We also know that from the sectoral system of innovation literature, innovative performance does not only depend on the firms, and research and development institutions performance but also it depends on how they interact, among them and other agents, as well as all the other forms by which they acquire, use and diffuse knowledge.

Table 1: Major 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, the 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, Tata Solar 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 involved 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 or State Universities, Engineering Colleges, 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, Indian wind Power Association (IWPA), etc.
6.NGOs and Other-Organizations	Barefoot Engineers, Greenpeace, Centre for Science and Environment (CSE), Council on Energy, Environment and Water (CEEW), etc.	Greenpeace, Council on Energy, Environment and Water (CEEW), Centre for Science and Environment (CSE), etc.

Source: Author's compilation; adapted from Singh, A. A and Krishna (2017) [36] and MNRE (2020)

Methodology

This study was initiated by examining the existing literature on renewable energy, with a focus on solar and wind energy. The research employs an innovation system framework to explore the important role and potential of various actors and stakeholders, as well as the characteristics of knowledge development within the chosen renewable energy technology (RET) innovation system. This research utilizes both qualitative and quantitative data. The empirical information has been collected through semi-structured surveys, focus group discussions, and ethnographic field observations. To achieve the intended results, various sources of primary and secondary data have been incorporated into the study. In terms of the quantitative method, bibliometrics is employed to examine publication trends in the field of solar and wind energy technologies. This approach allows us to gain insights into the collaboration patterns within the intellectual landscape, encompassing sources, authors, institutions, and countries. It aids in understanding the performance of the country and its standing in terms of intellectual contributions and publications. The concept of "Bibliometrics" was introduced in 1969, followed by the term "Scientometrics," which also serves as a synonym for bibliometrics. Bibliometric methods have become essential research tools for analyzing the development of knowledge. Our research also incorporates various annual reports from organizations

such as the National Institute of Solar Energy (NISE), Solar Energy Cooperation of India (SECI), National Institute of Wind Energy (NIWE), Ministry of New and Renewable Energy (MNRE), Energy and Resource Institutions (TERI), Centre for Science and Environment (CSE), and Council on Energy, Environment and Water (CEEW).

To examine trends in scientific knowledge production, we employ an analysis of research publications using the Scopus online database. Scopus ranks among the largest databases for abstracts and citations of peer-reviewed literature, featuring intelligent tools that track, analyze, and visualize research, encompassing over 20,500 titles from approximately 5,000 publishers. By conducting an analysis of this database, we evaluate the research publication productivity across various universities, and research and development institutions in the country. We have selected specific keywords for our analysis within the database, such as solar energy, solar power, solar photovoltaic, solar thermal, solar rooftop, wind turbine, wind energy, wind power etc. along with the specific years, affiliations and countries.

Current Scenario on Indian Renewable Energy

The nation has experienced remarkable expansion in the renewable energy sector over the past few years. The considerable and ongoing economic growth has created a substantial demand for energy resources. Nonetheless, there remains a persistent imbalance between demand and supply that requires the government to make significant efforts to enhance energy availability. Currently, renewable energy constitutes approximately 17.51% of the country's total installed energy generation capacity, which is around 326 GW (about 3,26,848 MW, CEA, 2017). Table 2 shows the total energy installed capacity and their percentages in each section in 2017. The total renewable installed capacity has reached 57,260 MW out of the total installed power generation capacity of 3,26,848 MW at the end of March 2017 (CEA, 2017). Out of this, around 67% comes from the overall thermal fuel plants, as detailed in table 3, which include coal at 59%, gas at 8%, and oil at 0.25%. Additionally, hydropower accounts for 13%, while nuclear power makes up 2%.

Table 2: 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

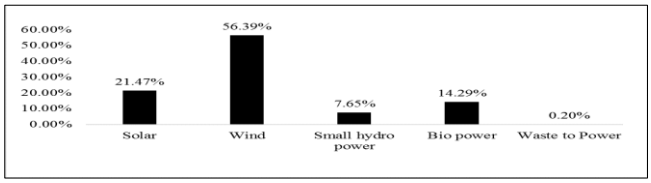
Source: Central Electricity Authority (CEA), 2017

Table 3 presents the installed energy capacity of India, as of March 2017. As defined by the Ministry of New and Renewable Energy (MNRE), renewable energy sources encompass small hydropower plants with capacities of 25 MW or less, bio-mass gasification, bio-mass power, energy derived from urban and industrial waste, solar power, wind power, and others.

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: Own Compilation, adapted from Central Electricity Authority (CEA), 2017.



Source: Central Electricity Authority (CEA), 2017.

Fig 1: Proportion of Total Installed Renewable Power in India, 2017.

Figure 1 gives the percentage wise information about the total installed renewable power in India. Presently total solar energy installed capacity stands at 12.75 GW as at the end of March 2017 in the country (CEA, 2017). In 2017, solar energy accounted for approximately 21.47% of the total renewable energy capacity in the country.

Policy Viewpoints and Trends in Scientific Knowledge Production

Since the early 1980s, the Indian government has started to introduce policies aimed at encouraging the development of renewable energy in the country and later, the Department of Non-Conventional Energy Sources was established (Singh, A. A. and Krishna, 2017) [36]. In 1992, the government set up the Ministry of Non-Conventional Energy Sources (MNES), which was renamed the Ministry of New and Renewable Energy (MNRE) in 2006 (Singh, A. A and Krishna, 2017) [36]. The National Electricity Policy of 2005 provided significant support for renewable energy initiatives, requiring licensed utilities and captive electricity producers to source specified amounts from renewable resources. In recent times, a variety of federal and state-specific incentive programs have been developed for a range of objectives, from rooftop

photovoltaic installations to large-scale power generation facilities. Certain states have introduced specific solar policies, while others are in development to enhance solar generation capabilities, reduce costs through local manufacturing, and engage in research and development activities to expedite the move towards clean and reliable energy in those regions.

The renewable energy sector in the country is overseen by the Ministry of New and Renewable Energy. Their primary duties encompass the creation, demonstration, and marketing of technologies that utilize new and renewable energy sources, working alongside corporate and scientific organizations. In addition to these duties, the ministry also promotes research, design, and development of technologies, products, and services related to new and renewable energy in the nation. Numerous policies and programs aimed at fostering the growth and implementation of various renewable energy sources are carried out by the ministry. Another goal of the MNRE is to substitute the utilization of different fossil fuels whenever feasible and improve electricity or lighting access in remote and rural areas. Numerous government agencies contribute their knowledge to the renewable energy sector. The Electricity Regulatory Commissions Act created autonomous regulatory bodies at both the national and state levels, referred to as the Central Electricity Regulatory Commission (CERC) and the State Electricity Regulatory Commissions (SERCs). The CERC oversees the regulation of tariffs for power generation companies that are either owned or overseen by the central government and promotes competition within the electricity industry. Meanwhile, the SERCs oversee the aspects of generation, transmission, distribution, and trading of electricity. Electricity management is a collaborative responsibility between the central government and the states in the country. Following independence, states took a leading role in developing the power sector. The Electricity (Supply) Act of 1948 facilitated the establishment of State Electricity Boards (SEBs) tasked with planning and executing different power projects. However, the ongoing issues of poor operational performance, persistent power shortages, and the financial instability of SEBs prompted frequent regulatory and policy shifts within the country (Schmid, 2011). Nonetheless, the Electricity (Supply) Act of 1948 marked the beginning of a liberalization process encouraged by the central government, including reforms that allowed private sector participation in electricity generation (Singh, 2006).

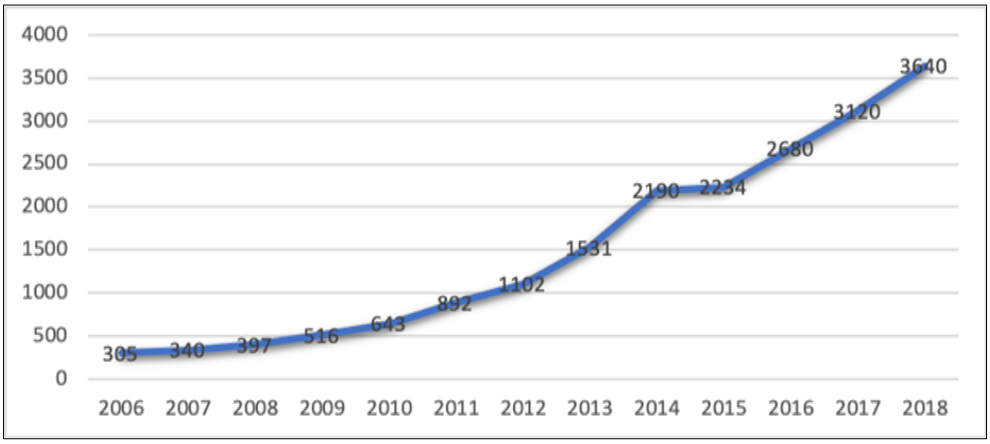
Table 4: Key developments in India's renewable energy policy

Major Milestones	Initiatives by Indian Government
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 (MNRE)
Generation Based Incentive (GBI, 2009)	Introduction of GBI Scheme
Renewable Energy Certificate (REC, 2010)	Introduction of REC Scheme
National Solar Mission (NSM, 2010)	Introduction of National Solar Mission (NSM) 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: Ministry of New Renewable Energy (MNRE, 2013; 2012; 2010; 2009)

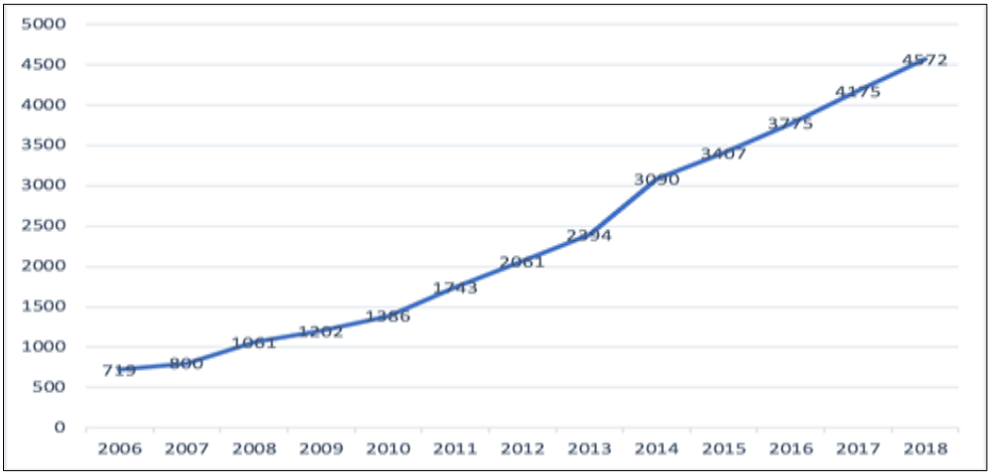
Table 4 presents the significant milestones of Indian renewable energy policy. Various government institutions have expertise that overlaps with the renewable energy sector. The Ministry of Power (MoP) focuses on the planning of power supply, political guidance, investment strategies for government projects, training of specialists, and administration of laws governing power generation from conventional sources, as well as power transmission and regulations. The Electricity Regulatory Commissions Act (MoP, 1998) established independent regulatory bodies at both central and state levels, which oversee service quality, tariffs, and fees. Efforts like the Energy Conservation Act of 2001, the Electricity Act of 2003, and initiatives for rural electrification have been key in improving energy conservation and distribution efficiency. These legislative initiatives align with the broader objectives of incorporating renewable energy. In India, the National Solar Mission (NSM) is crucial to the nation's approach to reaching net-zero carbon emissions by 2070. This initiative seeks to greatly expand solar power capacity, which is vital for decarbonizing the energy sector and fostering overall economic development. The Indian government is vigorously advocating for renewable energy to boost energy efficiency and lessen environmental effects. This effort includes significant investments in solar, hydroelectric, and wind energy, all of which are viewed as essential for decreasing pollution and greenhouse gas emissions while sustainably meeting rising energy needs (Mondal *et al*., 2024) [29].

To evaluate the productivity of various research and development institutions, and universities regarding publications on solar and wind energy in the country, we examined the Scopus online database. The country ranks fifth and sixth for scientific research publications related to solar and wind energy, respectively. For solar energy, it accounts for approximately 5% of global publications. In terms of wind energy, this figure is close to 4.3% of the overall contribution. The total number of publications on solar energy by 2016 was 287853. Among these, the USA has contributed approximately 68,938 publications. The USA leads with around 24% of total global publications, followed by China with 37,562 (13%), Germany with 20,601 (7%), Japan with 18,844 (6.5%), and India with 13,886 (5%). India also exhibits a noteworthy presence of productive research and development institutions and universities within the innovation ecosystem for both the solar and wind energy sectors. Figures 2 and 3 illustrate the number of publications related to solar and wind energy, respectively. In relation to the paper on the top fifteen institutions and universities in India, the figures 4 and 5 illustrate the contributions in the fields of solar and wind energy. IIT Delhi ranks the highest with a total of 1186 publications, accounting for 8.5% of the overall publications, followed by IIT Bombay with 427 publications (3%), Indian Institute of Science (IISc) with 328 publications (2.4%), and other institutions.



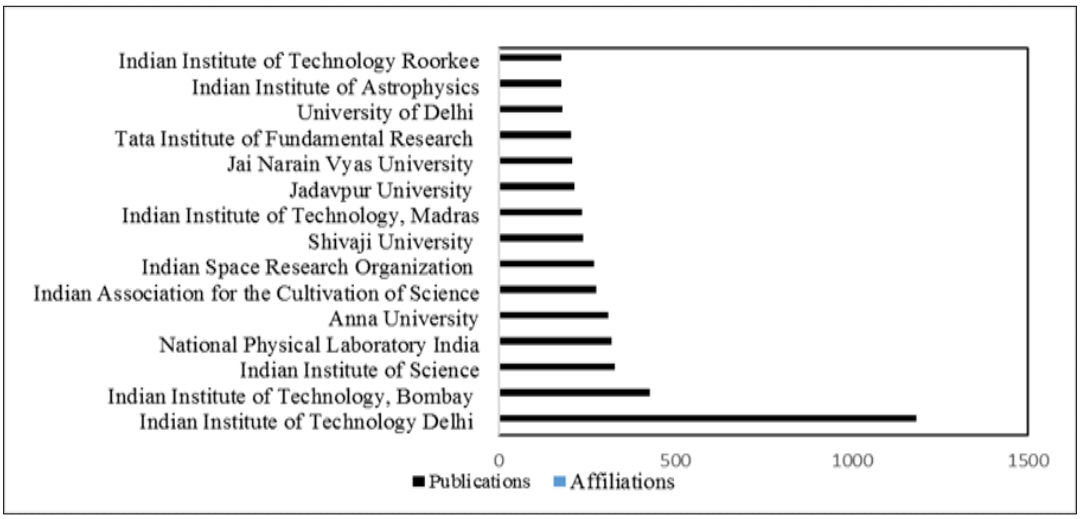
Source: Author's Compilation, data derived from Scopus

Fig 2: No. publications with solar energy in India (2006-2018)



Source: Author's Compilation, data derived from Scopus

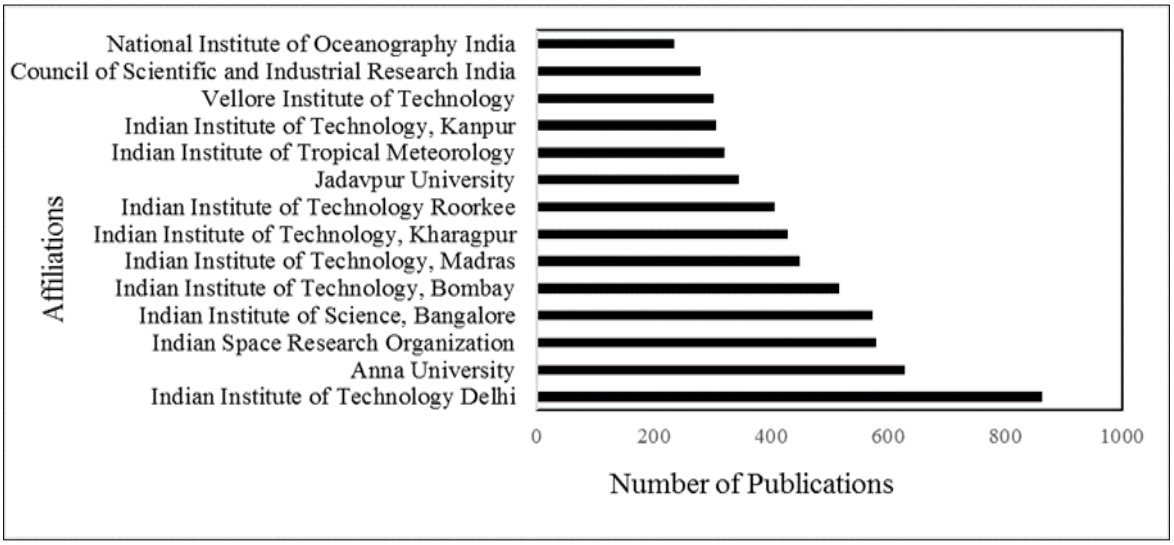
Figure 3: No. publications with wind energy in India (2006-2018)



Source: Author's Compilation, data derived from Scopus

Fig 4: Publications related to solar energy by top fifteen affiliations in India.

Additionally, the publication trends of the leading fifteen affiliations in wind energy are depicted in figure 5. In both instances, it is noted that the major institutions among the top fifteen affiliations primarily belong to the Indian Institutes of Technology (IITs), with most being public research and development establishments in India.



Source: Author's Compilation, data derived from Scopus

Fig 5: Publications in wind energy by top fifteen affiliations in India.

Conclusion and Way forward

The landscape of Indian renewable energy, particularly in solar and wind technologies, is shaped by a confluence of scientific publications, innovative policies, and emerging trends. There is a significance in the scientific publications in both solar and wind energy research. In the country, the Ministry of New and Renewable Energy (MNRE) is the only dedicated ministry who is proactively creating an enabling environment for the renewable energy sector to grow by rapidly bringing in innovative policy initiatives. It is well dignified to facilitate and advance the growth of renewable energy and strive to become one of the world leaders in both such technologies in the coming years. Moreover, the National Institute of Solar Energy (NISE) and the National Institute of Wind Energy (NIWE) are the important research and development institutions which address the existing research infrastructure in solar and wind energy sector respectively. Solar/wind firms, policy and regulatory support, government research institutes, financial institutes, industry associations and NGOs are the key actors who involved in the sector. Government research institutions play a crucial role, as the collaboration among industries, government entities, and universities is essential. The connection between academia, industries, and government bodies enhances the quality of research and development endeavours worldwide. Additionally, policy and regulatory support serves as another critical factor, aiding in the creation of various renewable incentive policies that have improved the feasibility of expanding both solar and wind energy deployment and development in the nation. The number of research publications has been increased significantly after the initiation of various renewable energy missions and setting of ambitious targets or policies on renewable energy in the country. There is also a significant presence of productive academia, research and development institutions; and supportive policy initiatives in the country. The country

stands at fifth and sixth position in terms of scientific research publications related to solar and wind energy respectively. In the case of the solar, it is about 5% contribution of the world publications. Whereas in the case of wind energy, it is nearly 4.3% of the total contribution. For our future research, we will emphasize in what ways the renewable energy sector is transformed over the last decade and how it has a bearing on actor's co-evolution and growth in the sector's sectoral system of innovation.

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References

1. Altenburg T, Engelmeier T. Rent management and policy learning in green technology development: The case of solar energy in India. Discussion Paper 12/2012. Bonn: German Development Institute; c2012. Available from: www.die-gdi.de/uploads/media/DP_12.2012.pdf (accessed on 15 May 2015).
2. Bloomberg New Energy Finance. Global Trends in Renewable Energy Investment c2015. Available from: http://fs-unep-centre.org/publications/global-trends-renewableenergy-investment-2015
3. Central Electricity Authority. Load generation balance report, 2016-2017. Ministry of Power, New Delhi; 2016.
4. Central Electricity Authority. Ministry of Power, New Delhi; 2017.
5. Council on Energy, Environment and Water. Assessing Green Industrial Policy: The India Experience. New Delhi; 2014.
6. Denning PJ. The social life of innovation. Communications of the ACM. 2004;47(4):15-19.
7. Edquist C. The systems of innovation approach and innovation policy: an account of the states of the art. 2001; pp.1-24.
8. Edquist C, Johnson B. Institutions and organizations in systems of innovation. In: Edquist C, editor. Systems of Innovation: Technologies, Institutions and Organizations. London: Pinter Publishers; 1997.
9. Fagerberg J, Mowery D, Nelson R, editors. The Oxford Handbook of Innovation. Oxford: Oxford University Press; 2005.
10. Freeman C. The 'National System of Innovation' in historical perspective. Cambridge Journal of Economics. 1995;19(1):5-24.
11. Gulati A, Manchanda S, Kacker R. Harvesting Solar Power in India. Working Paper 329. Indian Council for Research on International Economic Relations; 2016.
12. Herbig PA. The Innovation Matrix: Culture and Structure Prerequisites to Innovation. Westport: Praeger Pub Text; 1994.
13. International Renewable Energy Agency. Renewable Energy and Jobs - Annual Review 2016. 2016.
14. Krishna C, Sagar AD, Spratt S. 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; 2015.
15. Krishna VV. Dynamics in the Sectoral System of Innovation: Indian Experience in Software, Biotechnology and Pharmaceuticals. In: Turpin T, Krishna VV, editors. Science, Technology Policy and the Diffusion of Knowledge: Understanding the Dynamics of Innovation Systems in the Asia-Pacific. Cheltenham: Edward Elgar; 2007. p. 193-233.
16. Lema R, Lema A. Technology transfer? The rise of China and India in green technology sectors. Innovation and Development. 2012;2(1):23-44.
17. Lundvall BA. National Innovation System: Towards a Theory of Innovation and Interactive Learning. London: Pinter; 1992.
18. Malerba F. Sectoral systems of innovation and production. Research Policy. 2002;31:247-264.
19. Malerba F, editor. Sectoral Systems of Innovation: Concepts, Issues and Analyses of Six Major Sectors in Europe. Cambridge: Cambridge University Press; 2004.
20. Malerba F, Mani S, editors. Sectoral Systems of Innovation and Production in Developing Countries: Actors, Structures and Evolution. Cheltenham: Edward Elgar; 2009.
21. Mallett A, Ockwell DG, Pal P, Kumar A, Abbi YP, Haum R, MacKerron G, Watson J, Sethi G. UK-India collaborative study on the transfer of low carbon technology: phase II final report. Sussex University and Institute of Development Studies; 2009.
22. Mani S. The flight from defence to civilian space: Evolution of the sectoral system of innovation of India's aerospace. Working Paper 428; 2010.
23. Ministry of New and Renewable Energy. 25 years of Renewable Energy in India. New Delhi: Ministry of New and Renewable Energy; 2009.
24. Ministry of New and Renewable Energy. Jawaharlal Nehru National Solar Mission, towards building solar India. New Delhi: Ministry of New and Renewable Energy; 2010.
25. Ministry of New and Renewable Energy. Jawaharlal Nehru National Solar Mission Phase II-policy document. Available from: http://mnre.gov.in/file-manager/UserFiles/draft-jnnsmpd-2.pdf; 2012.
26. Ministry of New and Renewable Energy. Annual Report 2015-14. New Delhi: Ministry of New and Renewable Energy; 2015.
27. Ministry of New and Renewable Energy. Annual Report 2016-15. New Delhi: Ministry of New and Renewable Energy; 2016.
28. Ministry of New and Renewable Energy. Annual Report 2020-21. New Delhi: Ministry of New and Renewable Energy; 2020.
29. Mondal S, *et al*. India's shift toward sustainable energy: A comprehensive approach to renewable energy integration and environmental sustainability. Journal of Renewable and Sustainable Energy. 2024;16(4).
30. Puri A. Bounds on the smoothing of renewable sources. In: Power & Energy Society General Meeting, 2015 IEEE. New York: IEEE; 2015. p. 1-5.
31. Renewable Energy Policy Network for the 21st Century. Renewable Global Status Report 2015. International Energy Agency; 2015.
32. Renewable Energy Policy Network for the 21st Century. Renewables Global Futures Report: Great Debates towards 100% Renewable Energy. ISBN 978-3-9818107-4-5; 2017.
33. Schmid G. The development of renewable energy power in India: Which policies have been effective? Energy

Policy. 2012;45:317-326.
34. Schumpeter JA. Business Cycles; A Historical, and Statistical Analysis of the Capitalist Process. New York: MacGraw-Hill; 1939.
35. Singh A. Power sector reform in India: Current issues and prospects. Energy Policy. 2006;34(16):2480-2490.
36. Singh AA, Krishna VV. Exploring Jawaharlal Nehru National Solar Mission (JNNSM): Impact on Innovation Ecosystem in India. African Journal of Science, Technology, Innovation and Development. 2017;9(5):574-589.
37. Suzlon Energy Limited. Suzlon Annual Report 2018-19. Suzlon Energy; 2018-19.