AN OVERVIEW OF WIND ENERGY INDUSTRY IN INDIA: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Through a systematic literature review, this paper highlights the evolution and growth of wind energy in India. The majority of the literature has been written post-2010, and minimal literature is available before that. One hundred and two papers identified can be grouped into themes of Sector Overview, Policy and Wind Economics, and Finance. The growth of wind energy has been driven by government schemes like accelerated depreciation, preferential feed-in tariffs, and generation-based incentives. Migration to auctions post-2016 brought down tariffs, but profitability, land acquisition, and poor transmission infrastructure remain a challenge for the industry. The authors highlight the requirement of further study on the effectiveness of the policies and challenges related to wind energy in India. The author's recommendations include the need to study, compare and assess the effectiveness of the various policies in the growth of Wind Energy, comparison of the effectiveness of the same policy in other Renewable Energy Sectors like Solar and their effectiveness in other countries. We also suggest studying the efficacy of the National Off-Shore Wind Energy Policy and the Strategy, Competitiveness, and Business Models being followed by various Companies in the Wind Energy Sector in India.

***Keywords*:** Wind Energy India, Wind Economics and Finance, Wind Energy Policy; Systematic literature review

Highlights:

1. The paper collates and gives structure to all the literature related to wind energy in India.
2. Historical background and evolution of the wind energy sector in India.

3. Impact of various government policies on the growth of wind energy in India.

INTRODUCTION

Renewable energy (RE) emerged as a viable alternative to move towards an environmentally sustainable way by reducing the consumption of conventional fuels like Coal and Petroleum (1). The issue of Renewable energy has received considerable critical attention in recent literature (2) .Recently, a substantial literature has grown up around the theme of the wind energy sector to contribute to our understanding of energy access, security, and sustainable development goals. Investigating wind power's emergence, evolution, growth, and challenges is a continuing concern within the renewable energy literature. Wind power is one of the most critical factors in India's commitment to installing the RE power 450 GW target by 2030 for sustainable development (3). The last one-decade (post -2010) has seen a growing trend toward scientific literature in the wind energy sector's evolution, growth, and challenges, but in a fragmented way.

Of particular concern is scanty work done in India to comprehensively review the wind energy sector's evolution, growth, and challenges. However, the analysis and synthesis of the wind energy sector's evolution, development, and challenges through systematic review remain a significant hiatus. Thus, the presence of knowledge gaps inspired us to carry out this research work. The existing body of research on the wind energy sector in India suggests papers related to management, policy, and economic aspects. One hundred and two articles, mostly post-2010, indicate a growing interest in the wind energy sector but present a fragmented view of it without any underlying literature structure. To date, there has been little agreement on what defines the wind energy sector's historical background, evolution, growth, and challenges.

To the best of the researcher's knowledge, a search of the literature revealed no study that attempted to carry out a systematic literature review on the wind energy sector in India. Surprisingly, the wind energy sector's evolution, growth, and challenges have not been formally examined holistically. Most of the work carried out on the wind energy sector in India fails to categorize and comprehensively organize the fragmented literature and does not shed significant light on the themes or overlapping knowledge boundaries in this arena. It is required in the present circumstances as growing interest in the wind energy sector and GOI's ambitious

commitment to achieving 500 GW of RE by 2030 and out of which 140 GW through wind energy puts India at a critical juncture.

This paper traces the development of the wind energy sector's evolution, growth, and challenges in India and the status of the research on it. This prospective study is designed to investigate the following research question.

RQ1. What is the historical background and evolution of the wind energy sector in India?

RQ2. What are the significant themes defining knowledge area and boundaries of wind energy sector research in India?

RQ3. What is the impact of various government policies on the growth of wind energy in India?

RQ 4. What are the challenges and barriers to the development of wind energy in India?

RQ5. What are the gaps and research paths ahead?

This investigation takes the form of a systematic literature review. It helps search, review, and organize all pertinent conceptual and empirical evidence to put forward a comprehensive picture (4). Here we give structure to the available literature, including research papers, grey literature, and news articles concerning management, policy, and economic aspects of the wind energy sector in India, by doing a systematic review of the literature. This study offers a fresh perspective on literature related to the wind energy sector in India. It categorizes the literature in three broad themes: sector overview, policy & its effectiveness, and wind economics & finance, systematically analyzing and synthesizing them. Perhaps it is one of the first investigations to organize the fragmented literature of India's management, policy, and economic aspects of wind energy.

The remaining part of the paper proceeds as follows: Section 2 describes the historical background and evolution of the wind energy sector in India. Section 3 elaborates the research methodology followed in this paper.

Section 4 brings out the research analysis and findings. Section 5 gives research gaps and directions for future study. Limitations of the study are highlighted in Section 6, and finally, the conclusion is in Section 7.

WIND ENERGY SECTOR IN INDIA- BACKGROUND, AND EVOLUTION

The use of wind energy started in India for the first time in the 1950s for pumping water for domestic and irrigation use. A wind power sub-committee was established by Council for Scientific and Industrial Research (CSIR) in 1952 to study the economic possibilities of wind energy and investigate the available resources which could be practically utilized for the development of wind energy. In one of the earliest study on the economics of wind energy use for irrigation in India, Tewari (1978) concluded that windmills designed specifically to operate in the low wind velocities could be economically competitive for irrigation from open wells on small farms. However, the wind energy use for irrigation was not researched and developed further.

The Government established the Commission for Additional Sources of Energy (CASE) in 1981 to give impetus to RE, which gave momentum to the wind energy programme in the country. CASE was converted into the Department of Non-Conventional Energy Sources (DNES) in 1982, a full-fledged Ministry of Non-Conventional Energy Sources (MNES) was established in 1992. MNES was renamed the Ministry of New and Renewable Energy (MNRE) in 2006 (6)**.**In 1985, the Government started a wind resource assessment programme covering 25 states with over 600 stations to monitor and map the wind resources across the country (7). The first wind project in the form of a 40 KW machine connected to a grid in India was set up in 1985 in Veraval, Gujarat. It established the technical viability of operating wind turbines in the grid-connected mode in India. Later in 1988, Horizontal-Axis Wind Turbines (HAWTs) in the rating range of 18.5- 100 KW was successfully set up and operated at five locations in India, which further established the viability of grid connected wind farms in India(8)**.** The sector was liberalized for private sector participation in 1992, and it slowly grew with the support of several fiscal incentives and tax benefits like accelerated depreciation (AD), preferential feed-in tariffs (FiTs), custom and excise duty reliefs**.** Wind power saw steady growth in India for about three decades (1985-2015), and it dominated the RE capacity addition for almost three decades(9)**.** Wind-power installed capacity grew from 41 MW in March 1992 to 40. 35 GW as of 31 Mar 2022. Tamil Nadu, with total installations of 9866.36 MW leads in the country and is followed by Gujarat (9209.22 MW), Maharashtra (5012.83 MW),

Karnataka (5130.90 MW), Rajasthan (4326.82 MW), Andhra Pradesh(4077.37 MW), and Madhya Pradesh(2519.89) (10,11).

RESEARCH METHODOLOGY

The first step in a systematic literature review is identifying the databases and journals for searching the articles. Table 1 states the list along with the keywords. Articles were considered in the domain of management, policy and its effectiveness, and economic and financial aspects of the wind energy sector in India, and associated topics like science and technology aspects, environmental impacts, and the broader area of renewable energy are not covered in the study. Subsequently, after identifying and studying the articles, the citations and references were cross-checked, and additional articles and papers were added. Further, 61 journals, reports & magazines were explored, and 102 articles related to the wind energy sector in India were identified. Renewable and Sustainable Energy Reviews contains a maximum of 9 articles followed by Energy Policy with four articles. Some relevant studies and reports by various organizations have also been included for research.

Table 1: List of Key Words used and Databases Explored

Key Words Used	Databases
1. Wind Energy India	1. Scopus
2. Renewable Energy India	2. Taylor & Francis
3. Wind Economics India	3. Elsevier
4. Wind Sector India	4. Wiley
5. Renewable Energy Policy India	5. Jstor
6. Wind Energy Policy India	6. Springer
7. Wind Energy Policy Effectiveness	7. Google Scholar
8. Renewable Energy Policy Effectiveness	8. Researchgate
Key Words:8	**Databases:8**

RESEARCH ANALYSIS & FINDINGS

After a thorough reading, these 102 papers were grouped into three distinct categories based on the central theme of these papers. This categorization will help organize the overall available literature related to the wind energy sector in India and will be helpful for any future research on the subject. Of the three areas, sector overview has the most articles with 55, followed by the policy with 33, While wind economics and finance have the least with 14. The details are highlighted in table 2 below. Sector overview being the dominant theme and articles under the same have touched upon all aspects related to wind energy, i.e., historical development and evolution of wind energy in India, various policies and enabling measures, overall and state-wise installation status, and barriers to the development of wind energy in India. For assimilation, sector overview was further divided into the historical background and current status, Offshore wind energy in India, Wind Solar Hybrid Policy and barriers and challenges in the growth of wind energy in India. Policy categorization has been further subdivided into wind energy policies, policy effectiveness. Wind economics and finance have been further subdivided into wind farm economics and financing mechanisms. In order to further understand the evolution of literature related to wind energy in India, a year-wise analysis of literature has been carried out and described in table 3. Most of the literature has been written post-2010, and minimal literature is available before that.

Table 2: Detailed Sub-distribution of articles related to Wind Energy Sector in India

Topic Area Study	Sub – Topic	Study
Sector Overview	Historical developments, background, current status, and growth potential Drivers of wind power	**55 (53.92%)**
	Barriers and challenges in the growth of wind energy in India	
Policy	Wind Energy Policies	**33 (32.35%)**
	Offshore Wind Energy Policy	
	Wind Solar Hybrid Policy	

	Policy effectiveness	
Wind Economics Finance & Competitiveness	Wind farm economics	**14 (13.72%)**
	Finance mechanisms	
	Wind Energy Sector Competiveness	

Table 3: Year Wise List of Article

Year	**Articles**
2022	02
2021	10
2020	05
2019	08
2018	05
2017	06
2016	13
2015	13
2014	09
2013	07
2012	04
2011	07
2010	02
2009	03
2007	01
2004	01
2000	01
1999	01
1998	01
1990	01
1988	01
1978	01
Total	**102**

Sector Overview

The Sector overview as research work has been covered most by the various researchers. All the works have generally followed standard structure, initially describing the historical background of wind energy development in the country, followed by briefly describing the leading wind markets in the world and India's position in the same. Some researchers have given state-wise potential and installation status. The various policy measures like AD, GBI, RPOs, FiT, etc., have been briefly defined, and the barriers in the development of wind energy in the country have been elaborated. The timeline of wind energy development in India as compiled from various papers related to sector overview is given in table 4.

Table 4: Timeline of the development of wind energy in India

Commission for Additional Sources of Energy (CASE) had been set up	1981	
	1982	CASE upgraded to the Department of Non-Conventional Energy Sources (DNES)
1st wind energy demonstration project of 1.15 MW at Tuticorin	1986	
Establishment of IREDA-Public Financing arm	1987	
	1989	Wind project financing by IREDA
100% AD	1990	
	1991	The Electricity Act amended for private sector participation, licensing agreements with International Wind Companies
Liberalization of Wind Sector for private players	1992	Establishment of a full-fledged Ministry of Non-Conventional Energy Sources (MNES)
	1993	Wind turbine exemption from Exercise Duty & Sales Tax, Reduced Import Duties on wind turbine components(rotor blades), issuance of state wind power procurement guidelines

Turbine approval and certification guidelines issued	1995	
	2002	AD reduced to 80%
Electricity Act 2003 passed, which required the establishment of preferential wind tariff	2003	
	2004	RPO regulations were first issued in Maharashtra
Entry of Indian Wind Projects into CDM markets to earn CERs	2005	The National Electricity Policy 2005 stipulates that the share of electricity from non-conventional sources would need to be increased progressively.
Ministry renamed as Ministry of New and Renewable Energy (MNRE)	2006	National Tariff Policy mandated SERCs to fix RPOs
First National Action Plan on Climate Change established (RPO share envisaged at 15% by 2020) ;	2008	Open access regulations; Indian Energy Exchange Limited instituted
	2009	GBI Introduced
CERC guidelines for REC	2010	Indian Electricity Grid Code 2010 (IEGC) incorporated special connection, operations, forecasting, scheduling, and commercial settlement for wind and solar generating plants.
REC trading initiated in IEX & PGCIL	2011	NCEF introduced, RRF introduced,
Withdrawal of AD & GBI	2012	
RRF made effective after being deferred on previous occasions	2013	GBI reinstated, Low-cost financing introduced;
AD Reinstated	2014	

	2015	GOI declares stated objective of attaining 175 GW of RE by 2022 with 60 GW of Wind Energy Mix
AD reduced to 40%	2016	Auctions or Competitive bidding sanctioned by MNRE on June 14, 2016. Solar Energy Cooperation of India (SECI)
First Tender for 1,000 MW ISTS wind power project issued by SECI also called SCEI Tranche I	2016	Wind Repowering Policy Introduced
GBI discontinued	2017	Various reverse auctions conducted by SECI SECI TI (Feb 2017), SECI TII (Oct 2017), GUVNL (Dec 2017)
RPO Monitoring Cell formed	2018	SECI TIII(Feb 2018),MSEDCL(Mar 2018) ,SECI TIV(Apr 2018),SECI TV (Sep 2018) ,NTPC(Aug 2018)
July 2019, the Ministry of Power (MoP) introduced some crucial amendments to the competitive bidding guidelines	2019	SECI TVI (Feb 2019) ,SECI TVII (May 2019) SECI TVIII (June 2019), SECI IX (Sep 2019)
No Wind Energy auctions were held	2020	The slowest growth in installed capacity of Wind Energy with just addition of 1.1 GW
SECI 750 MW T X was conducted in Jan 2021, and the lowest bid of Rs 2.77/MW was achieved.	2021	SECI 1200MW e reverse auction conducted in Sep 2021 and lowest bid received was at Rs 2.69 per unit

(Source: Author's compilation)

Policy

- ***Accelerated Depreciation***

Rajsekhar (10) has highlighted that 100% AD on wind-power equipment was the most attractive financial incentive in the 1990s as it provided significant tax benefits to the WPDs. However, the scheme was misutilized, as mostly wind-power plant investment decisions were

taken to avail tax breaks and at short notice, resulting in hasty wind-power plant installations leading to compromise in quality and performance and potential of sites, not the potential of sites getting fully exploited (12)**.** This resulted in the first AD changing to 80% in 2002 and its complete withdrawal on 01 April 2012. The AD scheme was reintroduced in 2014, but the depreciation rates have been reduced to 40% for projects commissioned after March 2017(13,14)**.**

- ***GBI***

As the AD provision was not available to foreign direct investors (FDI), therefore to increase the investor base, reward generation, and boost capacity addition, the central Government adopted generation-based incentives (GBI) scheme in 2009. The scheme provided an incentive of Rs. 0.50 per KWh of generation for a period of 4 to 10 years, with a cap of Rs. 100 lakhs per MW. Between 2009 to 2011, investors chose to opt for either GBI or AD based on their suitability, which led to a doubling of annual installation. AD and GBI were removed in 2012, resulting in a 50% drop in capacity additions. All this led to the reintroduction of the scheme in April 2013 (15)**.** Subsequently, GBI has been removed entirely from 2017.

- ***RPOs and REC***

To support solar, wind, and other renewable energy sources, renewable purchase obligations (RPOs), i.e., to meet a certain percentage of their electricity requirement from renewable energy sources, were made mandatory on certain entities like power distribution companies, captive power plants, and other large electricity consumers by Electricity Act of 2003. In 2010, the Indian Government launched a renewable energy certificate (REC). Obligated entities can purchase wind REC to meet the RPO instead of purchasing renewable power. One wind REC(non-solar) had been equated with 1 MWh of wind energy generated (16)**.** However, India's RPO policy has not been implemented in a significant way. No state government has enforced any penalties for not meeting the obligations; the maximum they have done is to issue notices to the discoms. As a result, an effective market did not start (15). In 2018, an RPO monitoring cell was formed to enforce the RPOs mechanism across the country(17).

- ***FiTs and other State Level Policies***

At the state level also several policies like preferential Feed-in Tariffs (FiT), wheeling charges, banking, third party sale, and open access transmission have been framed to attract wind energy investments in respective states. These policies and incentives vary from state to state. Under the preferential FiT mechanism, long-term contracts were given to WPDs, based on a pre-determined rate calculated based on the tentative cost of generation by respective state electricity regulatory commissions. FiTs had ranged from as high as Rs 5.92/MW to a minimum of Rs 3.52/MW. Many states like Rajasthan, Madhya Pradesh, and Maharashtra had relatively lower wind density and had higher tariffs than resource-rich states Tamil Nadu and Gujarat (16)**.**

In addition, several other incentives at the national and state level like reduction in customs duty and VAT of many products related to wind power generation, banking and wheeling, soft loans, and capital subsidy have led to the gradual development of wind energy in India. Wheeling charges are paid to the distribution company (discom) by the WPD for using its transmission infrastructure to transmit power from project locations to power purchasing entities. For wind energy in India, wheeling charges vary from state to state; for Madhya Pradesh and Maharashtra, these charges are 2 percent, and for Rajasthan, they are 7%. Banking is the amount of energy that can be banked and subsequently accessed later at any time during the financial year. The percentage of total wind energy fed to the grid allowed for banking also varies from state to state, e.g., Tamil Nadu allows 5 percent and Karnataka 2 percent of the energy to be banked. In addition, Maharashtra gives a capital subsidy of 11 percent for wind energy projects, and Rajasthan provides soft loans at low-interest rates equal to one-third of the capital cost of projects (16)**.**

- ***Reverse Auction Mechanism***

Wind capacity addition peaked in 2016-17, with about 5.5 GW of installations (9); however, in a significant policy change, India migrated to reverse auctions for wind energy in 2016. The first wind energy auction was conducted in Feb'2017 by SECI, in which a tariff of Rs 3.46/kWh was achieved. The following auction conducted was by the state of Gujarat in December'17 for 500 MW in which the lowest tariff till the date of INR 2.43/kWh was discovered. **Currently, twelve tranches of auctions have been conducted by SECI,** along with auctions by Gujarat,

Tamil Nadu, Maharashtra, and NTPC. The tariffs have settled in the range of INR 2.77 to 2.82/kWh, with the lowest touching at Rs 2.43/kWh.

- ***National Offshore Wind Energy Policy***

India has a 7,600 km-long coastline and has an offshore wind energy potential of 140 GW by 2050. Among the states , Gujarat has a offshore wind energy potential of 36 GW and Tamil Nadu has nearly 35 GW . It was only in 2015 that Government-issued the "National Offshore Wind Energy Policy." As per the policy, MNRE is responsible for the development and overall monitoring of offshore wind energy development in India, and the National Institute of Wind Energy (NIWE), Chennai, will carry out resource assessment, surveys, and studies in EEZ, demarcate blocks and facilitate developers for setting up offshore wind energy farms. To harness the same, Indian government had initially planned for 5GW electricity through Off shore wind energy projects by 2022 and accordingly first offshore wind project in Gulf of Khambhat in Gujarat with a capacity was planned with a capacity of 1 GW . An expression of interest (EoI) for India's first offshore wind energy project of 1 GW capacity off the coast of Gujarat was issued by NIWE on 10.04.18. Thirty-five International and Indian developers had participated in the EoI (18,19)**.** A consortium led by COWI and supported by European Union was providing general assistance for capacity building of Indian stakeholders related to offshore wind energy up to the pre-financial-investment-decision stage(20). However the project is yet to take off.(21).(22).

- ***National Wind Solar Hybrid Policy***

Wind Solar Hybrid (WSH) systems have numerous advantages like better utilisation of transmission infrastructure and maintaining grid stability, lower generation variability due to hybridisation, better utilisation of land resources, reduced possibility of undesirable power peaks and complementary generation profiles. To harness the potential of WSH systems and to provide a framework for the promotion of large grid-connected wind-solar PV hybrid systems, MNRE adopted the National Wind-Solar Hybrid Policy in 2018. According to this policy, a project will be deemed a hybrid project, if the rated power capacity of either solar or wind should be at least 25% of the rated power capacity of the other resource. In addition, various state governments have also come up with their own WSH policies including Gujarat, Andhra Pradesh and Rajasthan. By 2023, India’s total wind-solar hybrid capacity is expected

to reach 11.7 gigawatt (GW) . SECI tenders for wind-solar hybrid projects without storage have attracted bids as low as 2.34 per kWh, which are comparable to plain solar and wind tariffs(23–27)

Policy Effectiveness

Very few scholars have attempted to assess the effectiveness of the various national and state-level wind energy promotion policies in the Indian context. Three significant studies of the two crucial central policies, AD and GBI, are available.

The case study of AD by Sud (12)revealed that the scheme had no provision for monitoring the performance and penalizing defaulters. Also, this tax depreciation benefit could not be availed by sizeable independent power producers and foreign investors. It suggested the need to link incentives to performance and the importance of monitoring, the need for policy to be helpful for all types of investors, and the importance of further investments in the grid infrastructure to enable support to new capacity additions.

CRISIL (28) study ordered by MNRE had concluded that the GBI scheme overcame the drawbacks of the AD scheme and led to change in investments in wind energy to outcome or generation linked objective. The percentage of GBI-based projects in the overall wind projects increased from 3% in 2010-11 to 30% in 2015-16.As per the study, the weak financial health of discoms which restricts them from procuring wind power is the biggest challenge facing the wind sector. The study recommends that measures be taken to improve the financial health of discoms, including incentivizing them to comply with RPO targets and introducing procurement-based incentives to encourage them to procure wind power and make timely payments to WPDs.

Shrimali (29) analyzed the relative differential effect of AD and GBI policies for wind using OLS regression on the generation efficiency of wind power plants. Using a sample of 40 Wind Power Plants, their results showed that the average plant load factor (PLF) of the wind power plants set up under the GBI scheme was at least three percentage points higher than that set up under the AD Scheme. The study has recommended the use of GBI instead of AD. The study recommended AD to be used only after modifying it so that monitoring of projects is done and WPDs ensure performance and operational efficiency of the plants.

The other papers assessing the effectiveness of various other government policies related to wind energy have been summarized in table-5.

Table 5

Summary of literature assessing the effectiveness of state policies in the development of wind energy in India

Author	Year	Results/Recommendations
Thapar, Sharma and Verma(Thapar et al., 2018)	2018	Authors have used panel data techniques on a data of 6 Indian states from 2003 to 2016 using 16 exploratory variables with installed capacity as indicator of investment .Existing Wind Capacity and its share in total generation capacity; the states' economy came out as significant variables. Policy variables (FiT & RPO) and geographic variables (the percent of wind potential harnessed in a state; road network length) came as insignificant variables.
Jain, Panse, and Mishra (Jain et al., 2018)	2018	This paper studies impact of local factors on decision making in wind energy investment based on select districts of Maharashtra considering installed capacity as indicator of investment using multi criteria modelling framework and case study methodology. Authors conclude that policymaking alone is not sufficient to increase the utilization of wind potential, and with bureaucratic efficiency and efficient government intervention at the ground level, districts with higher potential and lagging capacity could attract investment.
Panse and Kathuria (R Panse, 2018)	2018	Authors used case study methodology to identify factors that result in a skewed diffusion of wind power technology (WPT) in Maharashtra (2006-2013). They conclude that geographical, technological, societal, and bureaucratic factors influence the firm's investment decision in wind power technologies.
Panse and Kathuria (Panse and Kathuria, 2016)	2016	Authors have used panel data regression technique with installed capacity as dependent variable and state policies like wheeling charges, banking facility, FiT, RPOs as independent/control variables on a data of 7 Indian States for period 19 years (1993- 2012). The study concludes that the favorable policy facilitates the deployment of wind energy.

Kathuria, Ray, and Bhangaonkar (Kathuria et al., 2015)	2015	The paper studies the role of state level policies of feed-in-tariff, open access transmission, third party sale, banking, and wheeling charges in attracting FDI (foreign direct investment) in wind energy in 08 Indian states from 2004 to 2011 using panel data techniques. The results indicate that state-specific policies for wind energy are significant in attracting FDI in a state.
Schmid (Schmid, 2011)	2011	Schmid studied 9 Indian states from 2001 to 2009 on the impact of RPOs and tariff policy on the growth of RE. Study concludes that RPOs introduction has had a positive and significant impact on the development of RE and there is no significant positive correlation between the development of RE and the introduction of preferential feed-in tariffs.
Rao and Kishore (Rao and Kishore, 2009)	2009	Authors correlated installed capacity and a composite policy index of state specific policies and applied theory of diffusion of innovation. The study concludes that there is a correlation between the ranking of diffusion parameters and the composite policy index.
Benecke and Elisabeth (Benecke and Elisabeth, 2011)	2011	Author studied pro-activeness of govt., industry culture and power shortage in growth of wind energy and concluded that states like Kerala, which enjoy energy security, have less incentive to promote RE technologies and vice versa. The characteristics and dynamics of emerging local governance arrangements are a key factor explaining mechanisms and effects of renewable energy governance in the selected states.
Jagadeesh (Jagadeesh, 2000b)	2000	The study recommended that all Incentives continue for some more years until the wind projects sustain independently. There is also a requirement to create a Wind Fund, establish cooperative wind farms, set up wind estates, link generation to incentives for optimum production, promote reliable water pumping windmills, and wind battery chargers for small-scale applications for the rapid growth of wind energy.
Rajsekhar, Van Hulle and Jansen	1999	Authors used case study methodology to study wind-power policies, wind installations, technical factors and concluded that initial development of wind energy in India is due to capital incentives

(Rajsekhar, B., Van Hulle, F., Jansen, 1999)		

Wind Economics and Finance

The literature related to wind energy economics and finance mechanisms is limited and can be divided into two sub-themes: wind farm economics and financing mechanisms. Most of the financing mechanisms are related to government incentives and schemes; therefore, there is considerable overlap in this literature with the policy mechanisms.

One of the earliest research work in the wind farm economics was done in 1988 by Hossain et al.(30) , in which they have stated minimum expenditure on developing the site, better operational efficiency and reduced downtime of machines, and use of the most cost-effective rating of wind electric converters as the main factors at that time for a cost-effective wind energy generation. Sinha and Kandpal(31) empirically established a cost estimate scaling function for HAWTs and used it to estimate the cost of electricity from the wind farms in India and compared the cost of electricity generation reported from various wind farms. For windmills being used for irrigation water pumping, Purohit and Kandpal (32) developed a framework for their techno-economic evaluation.

NRDC and CEEW (33) studied the various financing mechanisms and policies in vogue in India's Wind market. It has described fundamental financial mechanisms like non-recourse financing, private equity funding, green bonds, IPOs, mezzanine finance, debt repayment by pooling wind farm assets, and policies for wind energy like AD, GBI, RPOs, clean development mechanisms, and carbon credits, etc. in India. The study concludes that lender confidence is low because of poor enforcement of RPOs and uncertainty about the future of RECs. The cost of all RE projects has significantly increased because of the relatively high cost and low availability of debt in India. Shrimali et al. (34) has studied the financing challenges to India's entire renewable energy sector, including wind. The report's main conclusions are that the entire RE sector is facing a significant challenge due to the high cost of debt due to high-interest rates, which has had a significant impact on the levelized cost of

electricity. In addition, the project risks have also significantly increased due to the poor financial health of state discoms Kar and Sharma (35) have given an overview of the various renewable energy financing models in India like equity financing, debt financing, government financing /subsidy. They have further stated that high risk and moderate returns, underdeveloped bond market, lack of awareness about technology and potential of financial institutions, lack of consistency in policy, and poor financial conditions of state discoms as significant impediments to financing renewable energy.

Irfan *et al.*,(2019) in their paper Competitive assessment of Indian wind power industry: A five forces model developed a value chain model of the wind power industry, assessed the competitiveness of the Indian wind power industry, and comprehensively analyzed the factors that have a significant influence on the industry by using the "Five Forces Model" and analysing Five main stakeholders of the Indian wind industry, i.e., buyers, suppliers, competitors, substitutes, and potential competitors. They have recommended more institutional coordination, feed-in tariffs, reformations in the grid structure, encouragement of differentiated business models, enhancing research and development activities, developing professional base and the full range of government support.

Challenges and Barriers to the development of Wind Energy in India

Amin (37) , Rajshekhar et al. (10) and Singh and Parida(38) have highlighted various wind energy growth-related challenges of the 1990s**.** During that period, the performance of wind power plants was low, with an annual capacity utilization factor below 20%. Wind mapping was inadequate, lack of skills for operation and maintenance of wind farms, poor infrastructure for evacuation and distribution of power, installation of low second-hand turbines which could not operate in Indian conditions, complicated and time-consuming process of obtaining clearances and finance. In addition, there was a lack of technicians and experts for the operation and maintenance of wind farms.

The Indian wind energy sector progressed a long way from the challenges faced in the 1990s, but many areas still need attention. The issues of grid integration, modernization of transmission networks, forecasting and scheduling, lower capacity utilization, high cost of evacuation, and dual jurisdiction of the state and central Government in policy need to be

addressed on priority. Also higher level of regulatory intervention is needed in terms of timely tariff revision and RPO fixation (13,35)**.**

The WPDs face a significant challenge on the finance side as interest rates have increased and there is limited availability of debt financing. There is also a requirement to develop wind turbines to cater to the lower wind speed in large parts of the country (39)**.** Internationally successful RE finance mechanisms such as green bonds, clean energy development banks, and tax credits must be implemented in the country (33)**.** The sudden transition to auction mechanism in 2016-17 has further shaken the sector. Nine tranches of auctions have been conducted by Solar Energy Corporation of India (SECI) and 06 by various states. However, most projects allocated through auctions are behind schedule, and many tenders have gone undersubscribed**.** Land availability is a significant challenge for WPDs and is primarily due to arbitrary policies followed by state governments like change in land allotment policy by Gujarat, land ceiling limits issue, and land blocking for state government projects, and change in land use. In addition, the poor financial state of state discoms and transmission and infrastructure availability for grid integration have delayed nearly all the auctioned projects. PPA renegotiations as being carried out by the Andhra Pradesh government are also hurting the investor sentiment. All this is making lenders lose interest in the sector and are being extremely conservative, which has significantly impacted the anticipated returns of WPD and has led to delay in project implementation priority(40) (41)**.** Further, CRISIL(42)**,** after studying the ongoing auctions, has brought out that Competitive bidding will reduce OEM margins, contracts for under-construction wind projects are likely to be renegotiated. Also, OEMs and WPDs would have to settle for lower returns, and the market will consolidate towards Independent Power Producers (IPPs). Recent research by Crisil says wind installations may reach only 45 GW by March 2022. (9). Though offshore wind power projects are being pursued, they are considered financially unviable by many. The industry demands a better policy for tariff and repowering of current projects, financial incentives, and improved coordination with state governments for the Offshore Wind Energy Projects(43).

Offshore Wind Energy in India is a very expensive technology ,with per megawatt cost of offshore wind turbine being two to three times the cost of onshore wind turbines . Dhingra, Sengar and Sajith (2022) in their study on the barriers to the growth and development of Off shore wind energy in India have identified 46 barriers under 07 broad categories Technical,

Financial, Social, Institutional, Geographical, Supply chain, and Regulatory & Political barriers and further used a multi-criteria decision-making approach (Fuzzy AHP) to categorize and prioritize these barriers. As per the study ,the top four barriers are an initial capital requirement (financial), lack of social acceptance & visual, noise impacts (social), and immature offshore engineering market (financial) and further barriers in the individual relative ranking are; Lack of servicing and maintenance facilities in technical barriers, Initial Capital in financial barriers, lack of social acceptance in social barriers, and Lack of skilled HR in institutional barriers ,Natural disasters in geographic barriers, non-alignment between tooling and facilities at the yards, and serial production of large monopiles & jacket foundations in Supply chain barriers and entry barriers in Regulatory & Political barriers are at top-ranked individual barriers. To increase offshore wind deployment in resource-rich Indian coast would require an effective policy mix which has financial incentives to drive down initial capital, a clear framework for planning and delivering grid infrastructure as well as directing resources to build a skilled OWE workforce.(21,22,44)

RESEARCH GAPS AND DIRECTIONS FOR FUTURE STUDY

Most of the studies have focused on sector overview, covering broadly the historical developments, policies /incentives introduced by the Government, and challenges and barriers in the growth of wind energy in India. The sector has witnessed the introduction of different incentives, their sudden withdrawals, and subsequent reintroduction. Still, only limited studies have been carried out assessing the effectiveness of the same and the reason for these abrupt changes. The limited available studies have tested state-specific policies using panel data techniques, and a case study approach has been used for assessing the effectiveness of central government policies of AD and GBI.

Wind energy development is influenced by policies and other economic, social, and infrastructural factors like energy demand, RPO mandates, consumer tariff, grid penetration of wind power, and road network, which is required to be studied (45). There are also few studies on the exact impact of the auctions held until now and on the challenges that have arisen for the WPDs due to the same. Also, compared to the earlier implemented FiT Policy, the impact

on earlier negotiated PPAs and under-construction wind projects and the effect on the profitability of OEMs and WPDs is also required to be studied.

The offshore wind potential is higher than over land, and most of the western parts of India are congenial for low wind farming . However, Offshore wind energy is a neglected area. Efficacy of the National Off-Shore Wind Energy Policy, its current status, and challenges and drivers for the growth of offshore wind energy are recommended areas to be worked upon. In addition, strategy, competitiveness, and business models being followed by various companies in the wind energy sector is also a niche area to work on. Also, there is a need to study and compare the policies, drivers of growth, and challenges between wind and solar in India and the wind sector in other countries. In addition, there is a planned capacity addition of 10 GW in the form of hybrid projects that combine turbines with solar panels as well; however, no research on the subject is available(47).

LIMITATIONS

Though all effort has been made to make this an all-encompassing and comprehensive review paper, there are still several limitations. First, wind energy comes under the broad area of renewable energy. Therefore there is a possibility that some quality research work related to wind energy published as part of the renewable energy study may have been left out. In addition, most of the work contribution is related to sector overview following a standard structure, which is more of presentation of facts and background with no research question or objective, clearly brings out the lack of overall work done in this sector and a skewed representation. There is very little research concerning auction or competitive bidding mechanisms, which has started since 2017 in the Indian wind energy sector, and thus findings and challenges related to auction mechanisms do not give the complete picture.

CONCLUSION

Wind energy is ideal for India to provide a clean, reliable, and steady electricity supply to meet its rising energy demand. Tax exemptions like AD, preferential FiTs, and GBI had driven the

sector's growth. However, the sector has suffered due to various policies being introduced, withdrawn without corresponding research. The migration to competitive bidding in 2017, along with the withdrawal of all other incentives, has further aggravated the problems of WPDs. At present most of the auctioned projects are running behind schedule, and there has been very little capacity addition due to which the government's initial target of achieving 60 GW by 2022 appears difficult at present. There is an urgent requirement for Government to address the challenges which the wind power developers are facing. From less than 1 GW in 2000 to 40 GW in 2022, wind power has come a long way in India. By ensuring more coordination between centre and state governments for issues related to land availability, approvals, transmission and evacuation infrastructure bottlenecks, enforcement of RPOs, and timely payment of dues to WPDs and by ensuring uniformity as well as long term applicability of policies across all states, India can surely achieve its goal of achieving 140 GW by 2030 and overall estimated potential of 302 GW in future.

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